The effect of off-axis seating on the marginal adaptation of full coverage crowns

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DECLARATION

I, George Paul Babiolakis declare that this research report is my own work. It is being submitted for an MSc degree in Dentistry at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University, and all the sources I have used or quoted have been indicated and acknowledged by complete references.

Signed: ____________________ Date 18/01/19

DEDICATION

I dedicate this report to the love of my life, Penny Coundouris, thank you for your motivation, guidance, support, and continual encouragement to further my studies, and complete my master’s degree, without you this would not have been possible.

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My parents, Paul and Rebecca, my siblings Antony and Stefanie, and my family for their encouragement to continue furthering my studies, and for their unwavering support, motivation and guidance throughout my studies.

ABSTRACT

Aim

None of the studies on the marginal gap or internal fit of crowns have reported on the effect of non-axial seating discrepancies, and these are known to happen in the clinical environment, as finger pressure is used to cement a crown. Therefore this *in vitro* study sought to investigate the off-axis seating of CAD/CAM crowns and its effect on the marginal gap and internal fit.

Method and materials

A resin typodont molar tooth was prepared to produce a standardised crown preparation. This tooth was then scanned and replicated into chrome cobalt, and the surface area of the preparation was calculated; 30 crowns with a flat occlusal surface were then milled using CEREC MC X milling machine (Sirona Dental Systems, Germany). Ten 10 Zirconia (Dentsply Sirona, Germany), 10 Enamic (Vita, Austria), and 10 Brilliant Crios (Coltene, Switzerland) crowns were milled, and in each group, five crowns were milled with a luting space of 100µm, and five with a luting space of 200µm. Each crown was seated, and the marginal gap was measured in two and three dimensions using a reflex microscope at 6 points buccally and 6 points lingually. Seating occurred axially/occlusally, and off axially at 5 degrees buccally and 5 degrees lingually. The crown was thereafter removed, and the silicone impression material was removed and weighed to calculate the overall internal fit.

Results

The results showed that axial cementation obtained the smallest marginal gap, irrespective of material or luting space. 3D measurements were larger than 2D measurements. However, the difference was not significant. None of the marginal gaps measured were larger than 120µm,

but the maximum off-axis gap was 117µm. When cementing off axis, the opposite side to which pressure was applied yielded a larger marginal gap. Zirconia had the largest internal fit measurement, followed by Enamic and then Brilliant Crios. The internal space did not alter the marginal gap results when cemented off-axis, however, a 100µm internal space yielded the smallest marginal gap measurement when the crowns were seated occlusally, compared with the 200µm space.

Conclusions

The need to create a luting space in full coverage all ceramic crowns will influence the marginal cement gap if the crown is not seated axially, irrespective of the size of the internal space and the material of the crown. Therefore clinically, care must be taken to ensure that luting takes place in an axial direction only.

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CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Crowns have an excellent history of being used for a variety of dental problems, for example, heavily restored teeth, badly destroyed crowns, discoloured teeth, endodontically treated teeth, and sometimes to improve aesthetics without the need for orthodontics. Conventional methods of fabricating crowns include the use of gold; porcelain bonded to a metal substructure; and the use of all-ceramic crowns. These methods include extensive laboratory work, whereby the patient has to be sent home with temporary crowns while the laboratory fabricates the crowns from the clinical impressions (Mitchell and Orr, 2005).

The majority of crowns are made from porcelain bonded to a metal coping so that the crown unit can withstand the pressures of mastication. These crowns tend to be time-consuming with regards to fabrication in the laboratory and can be non-aesthetic because of the metallic substructure. Due to new technology and the demand for better aesthetics, the metal framework can now be replaced by ceramics (Masek, 1999).

1.2 CAD/CAM

CAD/CAM stands for Computer-Aided Design and Computer-Aided Manufacturing. CAD/CAM restorations are milled from ceramic blocks. The process involves scanning the tooth preparation to create a digital impression (Masek, 2001). This digital impression is then sent to the computer, which uses software to create a virtual restoration. Data is then sent to the milling machine which then creates the restoration. Stains and glazes are added if necessary to create a natural tooth appearance. The restoration is adjusted in the patient's mouth and cemented in place (Masek, 2001).

1.3 Marginal gap and internal fit

The marginal gap can be defined as the vertical and horizontal dimension from the finish line of the preparation to the margin of the restoration. The internal fit can be described as the area between the crown and the tooth that will be occupied by cement (Kokubo et al., 2011).

1.4 Cementation and the importance of the marginal gap

Faulty cementation techniques can cause failure of restorations regardless of how accurately the steps for production have been accomplished (Bolouri, 1992). Several methods have been introduced to improve seating, including venting, use of axial grooves, axial space for cement flow (Wilson, 1994), etching and die spacing. All of these methods have been found to improve the seating and marginal gaps of restorations (Wilson, 1994). Failure of restorations to seat completely can result in a sizeable marginal gap and occlusal prematurities resulting in sensitivity and may cause the prosthesis to loosen prematurely (Abelson, 1980).

CAD/CAM has increased in popularity over the last two decades as it saves time by allowing the dentist to produce the crown at chairside, removing the need for the patient to return, and the need to send an impression to the laboratory for manufacture. CAD/CAM also saves money by eliminating the need for a provisional crown to be placed (Miyazaki et al., 2009). In addition to this, CAD/CAM allows the dentist to create crowns without the need for a metal framework while also improving aesthetics with the use of the translucency of all-ceramic crowns (Lee et al., 2008). All ceramic milled crowns are subject to the constraints of the milling process and the size of the burs, and this influences the preparation form, as well as the internal space to be milled to allow for the luting agent. This may affect the accuracy of the seating of the crown as off-axis seating and may result in an uneven cement lute. This can cause a discrepancy in the marginal gap, which can lead to microleakage (Jacobs and

Windeler, 1991), plaque retention at the margin (Valderhaug and Heløe, 1977), pulpal involvement (Goldman, Laosonthorn and White, 1992), and changes in the microflora causing the development of periodontal disease (Lang, Kiel and Anderhalden, 1983), any and all of which could ultimately result in failure of the crown.

1.5. Techniques used to measure the marginal gap and internal fit

Many studies have measured the marginal gap and internal fit of full coverage restorations using different methods, with varying results. Nobel Procera Zirconia (Nobel Biocare, Switzerland) crowns yielded a marginal gap between 52µm and 74µm (May et al., 1998). In a study measuring the marginal gap of lithium disilicate ceramic crowns, using both CAD/CAM and a heat pressed method, the marginal gap was found to be 130.2µm for heat pressed crowns and 132.2µm for CAD/CAM manufactured crowns (Akın, Toksavul, and Toman, 2014). However, another study reported that the marginal gap of lithium disilicate crowns was found to be below 90µm (Anadioti et al., 2014). Nakamura et al. (2003) found that when manufacturing crowns with CEREC 3 CAD/CAM system (Sirona Dental Systems, Germany), the marginal gap ranged from 52µm to 74µm, and the internal fit 116µm to162µm. Although different marginal gaps have been measured researchers agree that marginal gaps below 120µm are clinically acceptable (McLean and von Fraunhofer, 1971; Belser, MacEntee and Richter, 1985; Weaver, Johnson, and Bales, 1991; Fonseca et al., 2003). With regards to the internal fit, it is clinically relevant to ensure that adequate space is created to allow an even thickness of dental cement.

The problem with this agreement as first founded by McLean and von Fraunhofer (1971), however, is that it was done by measuring a few points around the circumference and with a metal crown. It was later found that to determine an accurate marginal gap it is necessary to measure at least 18 locations around the circumference of the tooth (Gassino et al., 2004). Several methods have been used to evaluate the marginal gap including the use of an optical microscope (Yeo, Yang and Lee, 2003; Akbar et al., 2006; Lee et al., 2008; Beuer et al., 2008; Alghazzawi, et al, 2012; Jayaraman et al., 2015); using a profile projector (Nakamura et al., 2003); profilometry (Mitchell, Pintado and Douglas, 2001); embedding in epoxy resin and sectioning and measured with a three-dimensional microscope (Tsitrou, Northeast and van Noort, 2007; Han et al., 2011; Souza et al., 2011; Biscaro et al., 2012; Sachs et al., 2014); cementation and use of microCT (Seo, Yi and Roh, 2009; Rungruanganunt, Kelly and Adams, 2010; Alfaro et al., 2015); and the use of a silicone luting replica technique (Nakamura et al., 2003; Kokubo et al., 2011; Tsitrou, Northeast and van Noort, 2007; Lee et al., 2008; Rungruanganunt, Kelly and Adams, 2010; Moldovan et al., 2011; Scotti et al., 2011; Anunmana, Charoenchitt and Asvanund, 2014).

1.6. The Reflex Microscope

The Reflex Microscope (Reflex Measurement Ltd., Cambridge, UK) is a microscope and an optical plotter. It links directly to a computer and allows one to measure objects in two and three dimensions (2D and 3D) up to a 100mm maximum dimension (Speculand, Butcher and Stephens, 1988), with an accuracy of 4μm. The Reflex Microscope measures by use of a virtual red light point that can be placed on the object in the field of view, and correlates this with other points selected by the user. In this way, two and three dimensions can be measured regarding both linear and angular measurements.

1.6.1 Operation of the Reflex Microscope

The object being measured is viewed through an adapted stereo microscope. A small red light spot is present in the field of view. The object is moved around by a motorised stage unit to yield X and Y measurements. The Z axis is measured by using stereoscopic vision to bring the object point being measured into focus. The points being measured are stored on command by the press of a button on the joystick used to move the stage and focus the stereomicroscope.

1.7. Ceramic Materials to be used

1.7.1 Zirconia

Zirconia is a crystalline dioxide of zirconium oxide. It was approved for therapeutic use in 1969 in the field of orthopaedics and has since been used to replace titanium and alumina prostheses in hip replacements. Zirconia has become popular as a material in dentistry because of its high strength, it is less brittle than ceramics and performs well when subject to tensile stress (McLean, 2001).

Zirconia is arranged in three different patterns: monoclinic, tetragonal and cubic. In its purest form zirconia is monolithic. However, when it reaches a temperature higher than 1170°C, it converts into its tetragonal phase, and subsequently its cubic phase. Zirconia has a melting point of 2370°C. When cooled this change is reversed as the tetragonal phase of zirconia converts back into monolithic at a temperature between 100°C and 1070°C (Denry and Kelly, 2014). Zirconia comes in CAD/CAM blocks and is used clinically for full coverage crowns, fixed bridges, and implant abutments.

1.7.2 Enamic

Enamic (Vita Zahn Fabrik, Germany) a new material, was developed in 2013 for use with CAD/CAM. It is a polymer-infiltrated ceramic network (PICN): a pre-sintered glass-ceramic scaffold infiltrated with urethane dimethacrylate which is secondarily polymerised under high temperature and pressure (Eldafrawy et al., 2018). It has high flexible strength and an elasticity near to dentine. The reliability and strength of the material are both considered to be high (Dirxen, 2013).

1.7.3 Brilliant Crios

Brilliant Crios (Coltene, Switzerland), is also a new material and is a reinforced composite CAD/CAM block of cross-linked methacrylate, with an inorganic filler of silica and barium glass. It has been recommended by the manufacturer for use in both anterior and posterior teeth as single permanent restorations, in the form of inlays, onlays, crowns, and veneers (Coltene package insert).

1.8 The Luting space

The luting space is the space between the crown preparation and the restoration to allow for the luting cement. Conventionally this space was created on the die before the crown was made, using spacer varnish. With CAD/CAM this space is created using the software. This is done by selecting the milling parameters to produce a pre-defined cement space when the restoration is milled. Different manufacturers have recommended different luting spaces. However, there is no consistency. This has been confirmed by a systematic review (Contrepois et al., 2013).

The silicone replica technique can also be used to measure the overall total fit of the crown and provides a correlation with the marginal gap. None of the studies, mentioned, however, have reported on the effect of non-axial seating discrepancies, and these are known to happen in the clinical environment, as finger pressure is used to cement a crown. Therefore this *in vitro* study sought to investigate the off-axis seating of CAD/CAM crowns and its effect on the marginal gap and internal fit.

CHAPTER 2: AIM AND OBJECTIVES AND NULL HYPOTHESIS

2.1 Aim

To determine the effect of off-axis seating on the marginal gap and internal fit of CAD/CAM crowns.

2.2 Objectives

- Devise a method to seat a crown off-axis at different angles consistently.
- Measure the marginal gaps and internal fit of crowns seated off-axis using the silicone replica technique, and compare with those seated axially.
- Compare the marginal gap and internal fit of crowns manufactured with different materials, different luting spaces, and different seating angles.

2.3. Null Hypothesis

Cementation of CAD/CAM crowns with off-axis seating results in a marginal gap that does not exceed the recommended clinically acceptable gap.

CHAPTER 3: METHOD AND MATERIALS

3.1. Tooth preparation

A resin typodont molar tooth was prepared to produce a standardised crown preparation with a total convergence angle of 12 degrees, (as measured digitally from the scanned image using FEA – Finite Element Analysis Software) internally rounded shoulder margins of 1.5 mm circumferentially, and an occlusal reduction of 1.5 mm. All line angles were rounded as shown in Fig 1.

Figure 1: Images showing the prepared typodont molar tooth.

3.2. Tooth replication

This tooth was then scanned and replicated into chrome cobalt using a three-dimensional (3D) printer, as seen in figure 2, to reduce the risk of damage to the tooth when cementing, removing and re-seating the crowns.

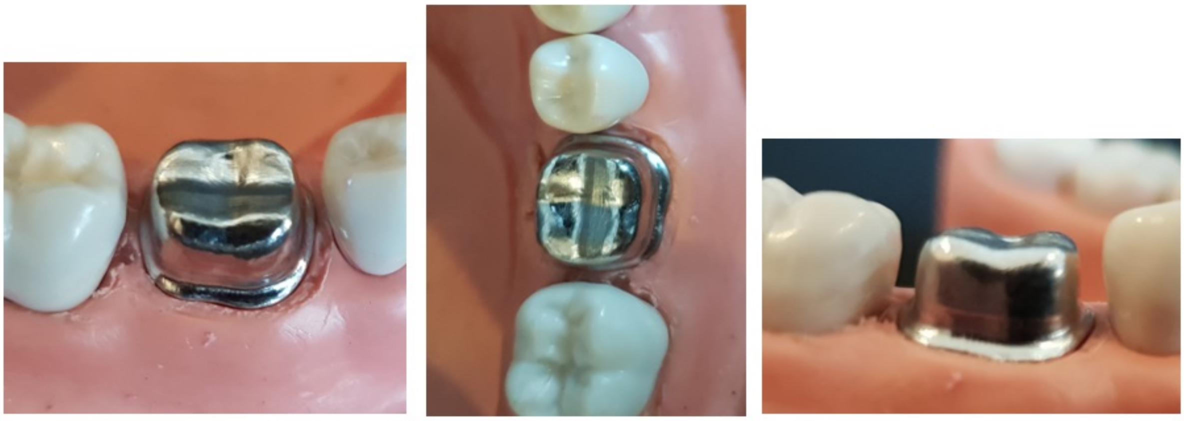


Figure 2: Images showing the replicated typodont tooth into metal

3.3. Scanning and Milling

The tooth was then scanned with the CEREC Omnicam intra-oral scanner (Sirona Dental Systems. Germany), and 30 crowns were milled with a flat occlusal surface (figure 3) using CEREC MC X milling machine (Sirona Dental Systems, Germany). The flat occlusal surface aided in seating the crown off-axis and axially. Also, the surface area of the preparation was calculated from the scan (figure 4) by importing the digital Standard Tessellation Language (STL) file into Finite Element Analysis (FEA) software (Solidworks, SolidWorks Corp, United States). 10 Zirconia (Dentsply Sirona, Germany), 10 Enamic (Vita, Austria), and 10 Brilliant Crios (Coltene, Switzerland) crowns were milled using CEREC MC X milling machine (Sirona Dental Systems, Germany). In each group, five crowns were milled with a luting space of 100µm and the other five crowns with a luting space of 200µm.

Figure 3: Images showing a milled crown with a flat occlusal surface

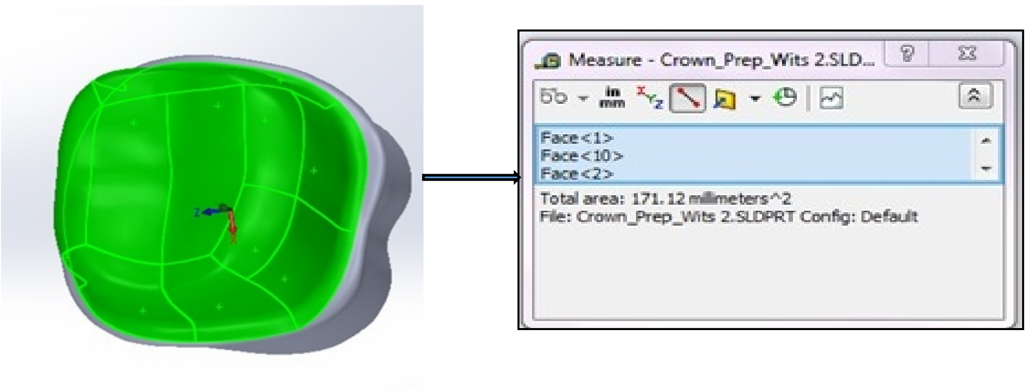


Figure 4: Diagram showing the calculation of the surface area of the prepared tooth using Finite Element Analysis (FEA) software

3.4 Off-axis cementation

The load placed buccally and lingually was achieved as follows: the metal tooth was put into a typodont model with adjacent teeth to provide contact points for the resulting crown. The typodont model was set on a custom-made tilting device (adapted from the model-holding device of a model surveyor) that allowed the model to be tilted 5 degrees to either side, and a standard 3kg weight was lowered parallel to the ground simulating buccal and lingual pressure (Figure 5).

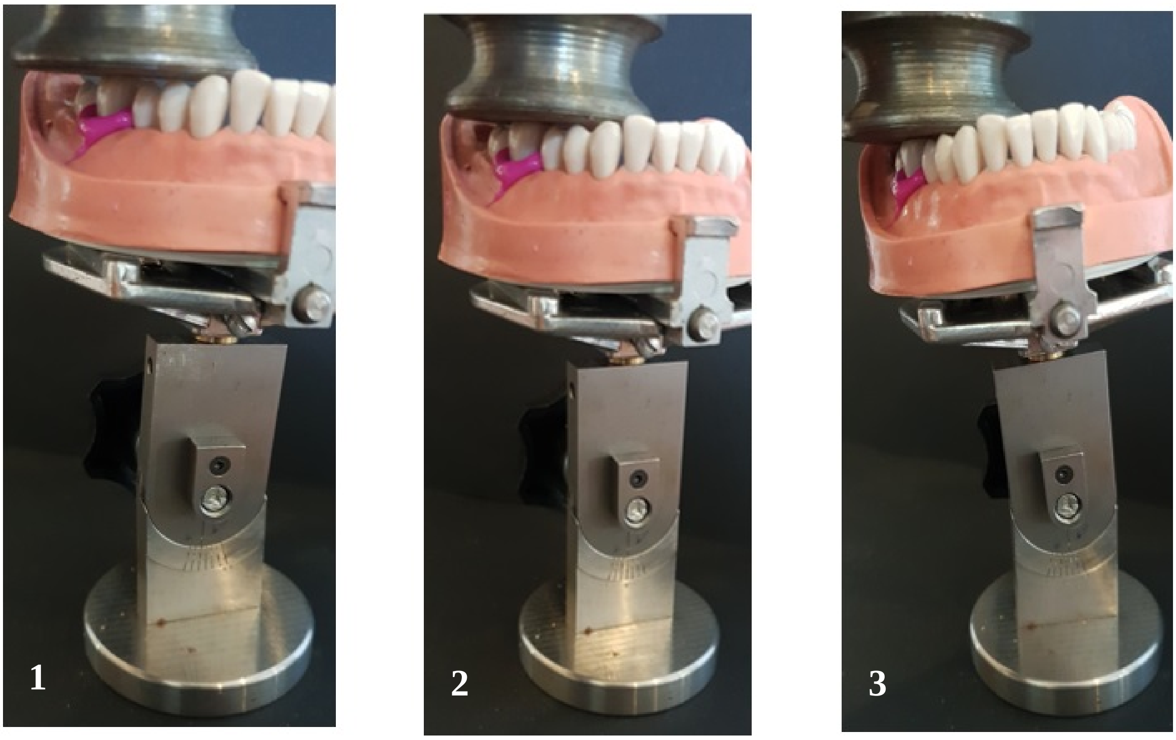


Figure 5: Images showing the crowns being cemented with the tilting device. 1 - Simulates buccal pressure, 2 - occlusal pressure and 3 - lingual pressure

Each crown was filled with light-body polyvinyl siloxane material (Express light-bodied, 3MESPE, Germany) to represent the luting agent and seated onto the tooth. A constant load was placed on the crown with a 3kg weight (with the model either straight, tilted 5 degrees buccally or 5 degrees lingually) for 10 minutes (Figure 6). Once the impression material set, the excess was removed using a number 11 scalpel blade. Thereafter the marginal gap was measured at 12 points. The measurements were done by marking the crown at 6 points buccally and 6 points lingually to be used as reference points for measurements. (Figure 7).

Figure 6: Image showing crown being cemented with silicone

Figure 6: Image showing Metal tooth with cemented crown and measurement markings below the crown.

3.5. Measurements

3.5.1 Marginal gap measurement

Each crown was seated, and the 3-D marginal gap was measured using a Reflex Microscope at 6 points buccally and 6 points lingually on three separate occasions (Figures 8 and 9).

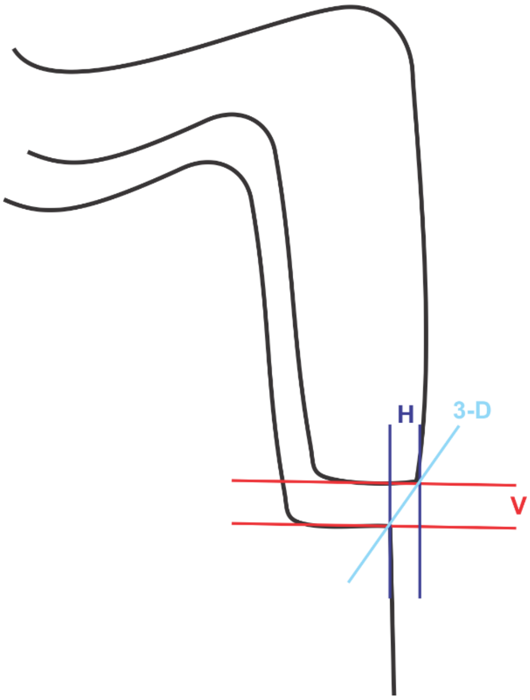


Figure 7: Two-dimensional measurement only records the vertical height (V) but does not consider any overlap (either positive or negative), hence the 3-dimensional measurement is a more realistic representation of the marginal gap.

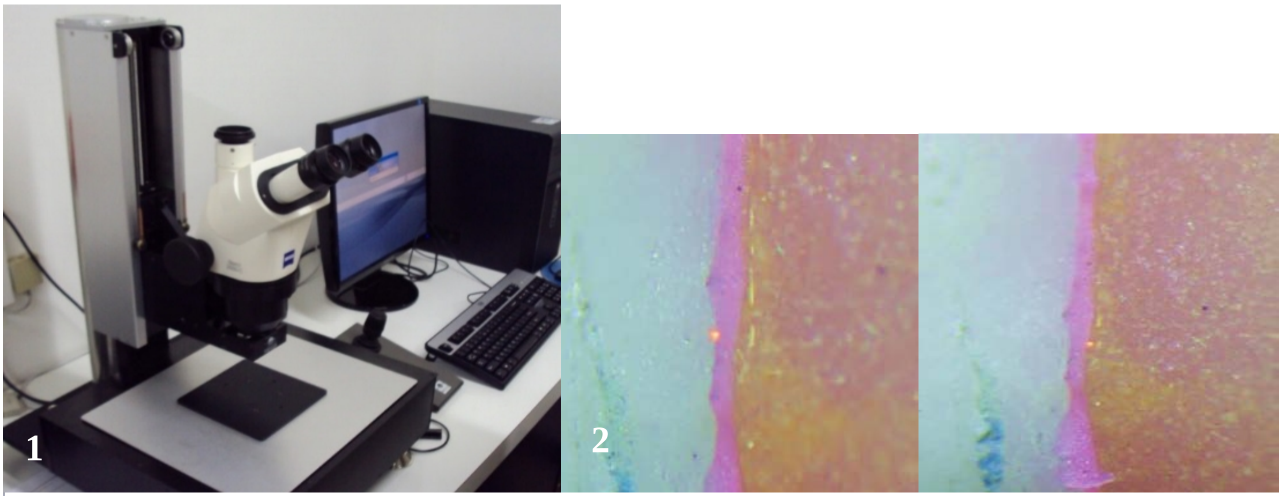


Figure 8: The reflex microscope (1) and the measurement of the marginal gap when a crown has been cemented with silicone (2). The red dots represent the virtual point of the microscope which measures the x, y, and z dimensions

3.5.3 Internal fit measurement

The crown was thereafter removed, and the silicone impression material was removed (Figure 10) and weighed to calculate the overall internal fit according to the formula (Nakamura et al., 2003).

Thickness (internal gap) = $^{weight}/_{(surface\ area\ \times\ density)}$

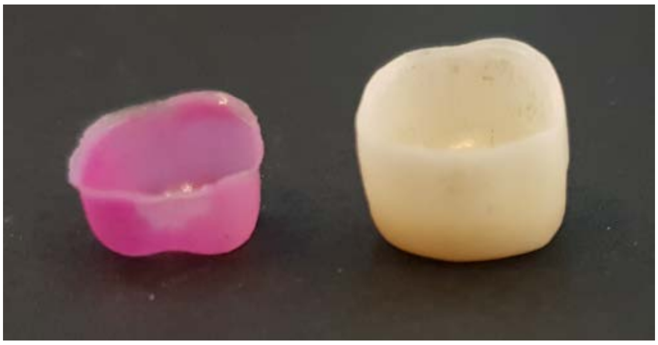


Figure 9: Image showing silicone removed from between the crown and the metal tooth for weighing to calculate the internal fit

3.6. Statistical Analysis and sample size

3.6.1. Sample size

Marginal gaps of greater than 120µm were considered the limit of clinical acceptability. Given an expected mean marginal gap of 0.110mm for any group, and aiming to detect a difference of more than 20% from this, given a within-group relative standard deviation of 22% (which corresponds to an effect size of d=0.83), 80% power and the 5% significance level, a total sample size of 24, i.e. 4 per group, would be required (Faul et al., 2007). It was decided, however, to use 5 per group as the expected mean gap may differ from the above.

3.6.2 Statistical analysis

Reliability was tested by the Intra-class Correlation Coefficient (ICC). Test-retest reliability for whether or not the marginal gap exceeded 0.120mm was determined by Cohen's kappa.

The average of the measurements from all three occasions was used for further analysis. Descriptive analysis of the data was carried out as follows: Study variables (all continuous) were summarised by the mean, standard deviation, median and interquartile range.

Post-hoc tests were carried out using the Tukey-Kramer adjustment for unequal group sizes (to allow for the deletion of outliers). From the post hoc tests, the material-luting space combinations which had the smallest values for the outcomes were determined.

All measurements were below the limit of 0.120 mm, so it was not necessary to measure comparisons between the experimental groups. Comparison of the marginal gap between matching 3D measurements was carried out using the paired samples t-test. Within each material, across both luting spaces, the difference between buccal and lingual readings for each pressure was compared using the paired samples t-test. The effect of luting space, for each pressure, on the 2D and 3D outcomes was determined by a repeated measures ANOVA with the outcome as the dependent variable, luting space as the independent variable, and experiment as the repeated measure. Post-hoc tests were carried out using the Tukey-Kramer adjustment for unequal group sizes (to allow for the deletion of outliers). The effect of material was determined similarly. Data analysis was carried out using Statistical Analysis Software (SAS) version 9.4 for Windows. The 5% significance level was used.

3.6.3 Ethical Considerations

This was a laboratory-based study. A waiver for ethical clearance was granted from the Human Research Ethics Committee (Reference: W-CJ-171114-1). See Appendix A.

The materials used in this study were self-funded and did not result in any bias.

CHAPTER 4: RESULTS

4.1. Measurement consistency

It has been observed in the past that researchers have some difficulty with locating the virtual point of light, especially on the z-axis, and so the entire experiment was repeated three times to assess measurement consistency.

The intraclass correlation coefficients (ICC) for the marginal gap measurements are shown in table 1 below. The ICC is used to determine the reliability of the results, in each instance, the experiment was repeated, and the marginal gap measured three times, and compared for reliability. An ICC above 0.75 is excellent and can be used for further analysis. This was done for the internal fit (IF), the 2D and 3D marginal gap buccally, the 2D and 3D marginal gap lingually, the 2D and 3D overall marginal gap which combined both the buccal and lingual marginal gap, and the 2D and 3D difference between the buccal and lingual marginal gap.

Table 1: Table showing the ICC for each outcome

Measure	ICC Measurement	Interpretation of ICC
Internal fit (IF)	0.99	Excellent
2D MG 3 buccal	0.86	Excellent
2D MG 3 lingual	0.81	Excellent
2D MG 3 overall	0.78	Excellent
2D MG 3 difference	0.91	Excellent
3D MG 3 buccal	0.82	Excellent
3D MG 3 lingual	0.94	Excellent
3D MG 3 overall	0.87	Excellent
3D MG 3 difference	0.93	Excellent

The ICC should be above 0.60 (good agreement), preferably above 0.75 (excellent agreement). As all the ICCs (as seen in table 1) met the latter criterion representing excellent agreement, the average of all three sets of measurements was used for further analysis.

4.2. Marginal gap measurements

4.2.1 Summary of Mean marginal gap measurements

Table 2 summarises the minimum, maximum, and mean marginal gap measurements in all scenarios. Blue shading indicates the largest buccal and lingual marginal gap measurements in each buccal, occlusal and lingual pressure groups, taking into account all scenarios. Orange shading highlights the smallest and green shading the largest value for each pressure group, irrespective of other factors.

Table 2: Summary of buccal and lingual marginal gap readings for all three materials and both luting spaces

<table>
<tr><th>Material</th><th>Mill</th><th>2D / 3D</th><th>Pressure</th><th>Reading</th><th>Min</th><th>Max</th><th>Mean</th></tr>
<tr><td rowspan="12">Zirconia</td><td rowspan="24">100µm</td><td rowspan="6">2D</td><td rowspan="2">Buccal Pressure</td><td>Buccal MG</td><td>35,7</td><td>44,3</td><td>40,1</td></tr>
<tr><td>Lingual MG</td><td>53</td><td>91,3</td><td>70,9</td></tr>
<tr><td rowspan="2">Occlusal Pressure</td><td>Buccal MG</td><td>37,3</td><td>57</td><td>44,4</td></tr>
<tr><td>Lingual MG</td><td>43,7</td><td>55,3</td><td>49,3</td></tr>
<tr><td rowspan="2">Lingual Pressure</td><td>Buccal MG</td><td>66,7</td><td>87,3</td><td>73,9</td></tr>
<tr><td>Lingual MG</td><td>35,3</td><td>44,3</td><td>40,9</td></tr>
<tr><td rowspan="6">3D</td><td rowspan="2">Buccal Pressure</td><td>Buccal MG</td><td>47,3</td><td>59</td><td>55,4</td></tr>
<tr><td>Lingual MG</td><td>70,3</td><td>101</td><td>88,3</td></tr>
<tr><td rowspan="2">Occlusal Pressure</td><td>Buccal MG</td><td>48,7</td><td>65,7</td><td>58</td></tr>
<tr><td>Lingual MG</td><td>45,7</td><td>59,7</td><td>53,1</td></tr>
<tr><td rowspan="2">Lingual Pressure</td><td>Buccal MG</td><td>78</td><td>101</td><td>86,8</td></tr>
<tr><td>Lingual MG</td><td>43</td><td>59</td><td>50,2</td></tr>
<tr><td rowspan="12">Enamic</td><td rowspan="6">2D</td><td rowspan="2">Buccal Pressure</td><td>Buccal MG</td><td>40,7</td><td>47,3</td><td>44,6</td></tr>
<tr><td>Lingual MG</td><td>51</td><td>63</td><td>58,6</td></tr>
<tr><td rowspan="2">Occlusal Pressure</td><td>Buccal MG</td><td>45,3</td><td>54,3</td><td>48,8</td></tr>
<tr><td>Lingual MG</td><td>51,7</td><td>60,3</td><td>56,3</td></tr>
<tr><td rowspan="2">Lingual Pressure</td><td>Buccal MG</td><td>63</td><td>65,7</td><td>64,3</td></tr>
<tr><td>Lingual MG</td><td>33,7</td><td>45,7</td><td>37,9</td></tr>
<tr><td rowspan="6">3D</td><td rowspan="2">Buccal Pressure</td><td>Buccal MG</td><td>53,7</td><td>62,3</td><td>57,1</td></tr>
<tr><td>Lingual MG</td><td>70,7</td><td>91,7</td><td>81,3</td></tr>
<tr><td rowspan="2">Occlusal Pressure</td><td>Buccal MG</td><td>55,3</td><td>61,7</td><td>57,5</td></tr>
<tr><td>Lingual MG</td><td>57,7</td><td>62,3</td><td>60,6</td></tr>
<tr><td rowspan="2">Lingual Pressure</td><td>Buccal MG</td><td>69,3</td><td>75</td><td>72,8</td></tr>
<tr><td>Lingual MG</td><td>40,3</td><td>58</td><td>50,1</td></tr>
</table>

Material	Mill	2D / 3D	Pressure	Reading	Min	Max	Mean
Brilliant Crios		2D	Buccal Pressure	Buccal MG	41,3	73	51,5
				Lingual MG	54,7	92,7	65,2
			Occlusal Pressure	Buccal MG	41	82,7	51,4
				Lingual MG	44,3	92,3	56,9
			Lingual Pressure	Buccal MG	58,7	102	70,7
				Lingual MG	34,7	39,3	36,2
		3D	Buccal Pressure	Buccal MG	50,7	81,7	61,9
				Lingual MG	68	109	85,1
			Occlusal Pressure	Buccal MG	46,7	86	56,3
				Lingual MG	45	95,3	59,7
			Lingual Pressure	Buccal MG	67,3	108	78,4
				Lingual MG	35	45,7	40,3
Zirconia	200µm	2D	Buccal Pressure	Buccal MG	57,3	62,7	60,5
				Lingual MG	58,7	89	69,9
			Occlusal Pressure	Buccal MG	30,7	56	46,8
				Lingual MG	66,3	87,7	82,1
			Lingual Pressure	Buccal MG	51,3	72,3	62,5
				Lingual MG	32	48	40,1
		3D	Buccal Pressure	Buccal MG	75	89	82,3
				Lingual MG	85,3	100	95,9
			Occlusal Pressure	Buccal MG	51	78	68,7
				Lingual MG	66,7	98,7	82,6
			Lingual Pressure	Buccal MG	69	81,7	76
				Lingual MG	47	59,3	51,6
Enamic		2D	Buccal Pressure	Buccal MG	43,3	50,3	47,4
				Lingual MG	66	77,3	71,8
			Occlusal Pressure	Buccal MG	40,3	54,3	47,1
				Lingual MG	49	68,3	60,7
			Lingual Pressure	Buccal MG	48,3	94,3	75
				Lingual MG	32,3	38	35,3
		3D	Buccal Pressure	Buccal MG	65	75,7	73,1
				Lingual MG	97,3	113	106,9
			Occlusal Pressure	Buccal MG	56,3	65	60,5
				Lingual MG	50	72,7	63,9
			Lingual Pressure	Buccal MG	71,3	103	88,5
				Lingual MG	40,7	48,7	44,1
Brilliant Crios		2D	Buccal Pressure	Buccal MG	47	54,3	50,9
				Lingual MG	69	75,7	72,7
			Occlusal Pressure	Buccal MG	44,3	53	48
				Lingual MG	52,3	69,3	63,1
			Lingual Pressure	Buccal MG	61,7	105	80,7
				Lingual MG	31	45	39,5

Material	Mill	2D / 3D	Pressure	Reading	Min	Max	Mean
		3D	Buccal Pressure	Buccal MG	60	69,3	65,6
				Lingual MG	103	112	108,5
			Occlusal Pressure	Buccal MG	50	65	59,5
				Lingual MG	62,7	84	74,9
			Lingual Pressure	Buccal MG	71,3	117	92,6
				Lingual MG	40	58	50,9

In all circumstances, the marginal gap did not exceed 120µm. The maximum value (that which came closest to 120µm) was obtained on the buccal marginal gap when lingual pressure was applied, and on the lingual marginal gap when buccal pressure was applied for all materials. With buccal pressure the marginal gaps ranged from 35.7µm - 112µm; with occlusal pressure, the range was 30.7µm - 98.7µm, and with lingual pressure, it was 31µm – 117µm.

4.2.2 Buccal and lingual measurement differences for all seating angles and both luting spaces

The difference between the buccal and lingual marginal gap measurements was calculated and then compared using a t-test to determine if there was a significant difference between the buccal and lingual marginal gap measurements for each pressure (buccal occlusal or lingual) within each material. These results are highlighted in table 3. Significant differences are shown in red. In each group, the 100 and 200 µm measurements were combined to yield a sample size of 10. This was done as the effect of pressure will be considered later. Smallest spaces are shaded in blue.

Table 3: Comparison of the buccal and lingual marginal gaps at all seating angles at both luting spaces, for all materials.

Material	Space	Pressure	n	Metric	Mean difference	95% CI for Mean		p-value
Crios	100 & 200 µm	buccal pressure	10	2D Buccal - Lingual	-17,8	-21,4	-14,1	<0.0001
Crios	100 & 200 µm	lingual pressure	10	2D Buccal - Lingual	37,5	25,3	49,7	<0.0001
Crios	100 & 200 µm	occlusal pressure	10	2D Buccal - Lingual	-10,3	-16,5	-4,1	0,0046
Enamic	100 & 200 µm	buccal pressure	10	2D Buccal - Lingual	-19,2	-24,3	-14,1	<0.0001
Enamic	100 & 200 µm	lingual pressure	10	2D Buccal - Lingual	33,0	22,8	43,3	<0.0001
Enamic	100 & 200 µm	occlusal pressure	10	2D Buccal - Lingual	-10,5	-16,5	-4,6	0,0030
Zirconia	100 & 200 µm	buccal pressure	10	2D Buccal - Lingual	-20,1	-33,6	-6,6	0,0082
Zirconia	100 & 200 µm	lingual pressure	10	2D Buccal - Lingual	27,7	20,6	34,8	<0.0001
Zirconia	100 & 200 µm	occlusal pressure	10	2D Buccal - Lingual	-20,1	-33,6	-6,6	0,0084
Crios	100 & 200 µm	buccal pressure	10	3D Buccal - Lingual	-33,1	-41,9	-24,2	<0.0001
Crios	100 & 200 µm	lingual pressure	10	3D Buccal - Lingual	39,9	25,7	54,0	0,0001
Crios	100 & 200 µm	occlusal pressure	10	3D Buccal - Lingual	-9,4	-16,8	-2,0	0,019
Enamic	100 & 200 µm	buccal pressure	10	3D Buccal - Lingual	-29,0	-35,9	-22,1	<0.0001
Enamic	100 & 200 µm	lingual pressure	10	3D Buccal - Lingual	33,6	23,7	43,5	<0.0001
Enamic	100 & 200 µm	occlusal pressure	10	3D Buccal - Lingual	-3,2	-7,6	1,2	0,13
Zirconia	100 & 200 µm	buccal pressure	10	3D Buccal - Lingual	-23,2	-33,0	-13,4	0,0005
Zirconia	100 & 200 µm	lingual pressure	10	3D Buccal - Lingual	30,5	22,0	39,0	<0.0001
Zirconia	100 & 200 µm	occlusal pressure	10	3D Buccal - Lingual	-4,5	-15,8	6,8	0,39

In all cases, the buccal and lingual measurements differed significantly for buccal and lingual pressures. However, they also differed significantly for all occlusal pressures, except for 3D measurements for Enamic and Zirconia. It must be noted that in all instances within each material the occlusal pressure marginal gap measurement yielded the smallest difference ranging from 3.2 µm – 20.1 µm.

4.2.3 Buccal and lingual measurement differences for material differences

The difference between the buccal and lingual marginal gaps was calculated, in this instance, to compare the materials against each other, with luting spaces combined, yielding a sample size of 10 for each material/pressure combination. The materials were compared under each material combination using a t-test to yield p-values as shown in table 4. The smallest values are shaded in blue.

Table 4: Table comparing the buccal and lingual marginal gaps for any material differences.

Material	Space	Pressure	n	Metric	Mean difference	95% CI for Mean		p-value
Crios	100 & 200 µm	buccal pressure	10	2D Buccal - Lingual	-17,9	-25,7	-10,1	C vs E: 0.96
Enamic			10		-19,3	-27,1	-11,5	C vs Z: 0.90
Zirconia			10		-20,2	-28,0	-12,4	E vs Z: 0.99
Crios	100 & 200 µm	lingual pressure	10	2D Buccal - Lingual	37,7	28,5	46,8	C vs E: 0.75
Enamic			10		33,1	23,9	42,3	C vs Z: 0.27
Zirconia			10		27,7	18,5	36,9	E vs Z: 0.67
Crios	100 & 200 µm	occlusal pressure	10	2D Buccal - Lingual	-10,4	-18,8	-2,0	C vs E: 0.99
Enamic			10		-10,7	-19,1	-2,3	C vs Z: 0.23
Zirconia			10		-20,1	-28,5	-11,7	E vs Z: 0.26
Crios	100 & 200 µm	buccal pressure	10	3D Buccal - Lingual	-33,1	-40,8	-25,3	C vs E: 0.74
Enamic			10		-29,1	-36,9	-21,4	C vs Z: 0.18
Zirconia			10		-23,4	-31,1	-15,7	E vs Z: 0.54
Crios	100 & 200 µm	lingual pressure	10	3D Buccal - Lingual	39,9	29,8	50,0	C vs E: 0.65
Enamic			10		33,6	23,5	43,7	C vs Z: 0.39
Zirconia			10		30,5	20,4	40,6	E vs Z: 0.90
Crios	100 & 200 µm	occlusal pressure	10	3D Buccal - Lingual	-9,4	-16,8	-2,0	C vs E: 0.49
Enamic			10		-3,5	-10,9	3,9	C vs Z: 0.61
Zirconia			10		-4,5	-12,0	2,9	E vs Z: 0.98

There were no significant differences between materials for any seating angle. The smallest differences (highlighted in blue) and were found for occlusal pressure in all cases. For 2D measurements, this ranged from 10.4 µm – 20.1 µm, and for 3D measurements, this ranged from 3.5 µm – 9.4 µm.

4.2.4 Measurement differences between the 100µm and 200µm spaces

The differences between the buccal and lingual marginal gaps were grouped into buccal, occlusal and lingual pressure combinations. Each space (100µm and 200µm) was compared under each pressure group. In this instance material was not considered, yielding a sample size of 15 in each group for comparison. The p-values (from a t-test) of significance are highlighted in red (Table 5). The smallest values are highlighted in blue.

Table 5: Table comparing the buccal and lingual marginal gaps for different milled internal gaps.

Material	Space	Pressure	n	Metric	Mean difference	95% CL for Mean		p-value
All materials	100 µm	buccal pressure	15	2D Buccal - Lingual	-19.6	-25.9	-13.3	0.82
	200 µm		15		-18.6	-24.9	-12.4	
All materials	100 µm	lingual pressure	15	2D Buccal - Lingual	31.4	23.7	39.0	0.58
	200 µm		15		34.3	26.7	41.9	
All materials	100 µm	occlusal pressure	15	2D Buccal - Lingual	-6.1	-11.9	-0.3	0.0007
	200 µm		15		-21.4	-27.2	-15.6	
All materials	100 µm	buccal pressure	15	3D Buccal - Lingual	-26.9	-33.4	-20.4	0.48
	200 µm		15		-30.2	-36.7	-23.6	
All materials	100 µm	lingual pressure	15	3D Buccal - Lingual	32.4	24.2	40.7	0.44
	200 µm		15		36.9	28.6	45.2	
All materials	100 µm	occlusal pressure	15	3D Buccal - Lingual	-0.7	-6.2	4.7	0.012
	200 µm		15		-10.9	-16.3	-5.4	

For buccal and lingual pressures there was no significant difference between the 100µm and 200µm spaces. For occlusal pressure, the difference between the buccal and lingual marginal gaps differed significantly between the 100µm and 200µm spaces, and the difference was larger for the 200µm space than the 100µm space. The smallest values were found for occlusal pressure at a 100µm space; these values were 6.1 µm for the 2D measurements and 0.7 µm for the 3D measurements.

4.2.4 Summary and comparison of 2D vs 3D measurements

This summary and comparison were made by comparing all 2D and 3D, irrespective of material, pressure and luting space.

Buccal marginal gap measurement

The 3D measurements for the buccal marginal gap were an average of 13.5µm higher than the corresponding 2D measurements (95% confidence interval: 12.0-15.0µm; $p < 0.0001$).

Lingual marginal gap measurements:

The 3D measurements were an average of 13.4µm higher than the corresponding 2D measurements (95% confidence interval: 10.9-15.8µm; $p < 0.0001$).

Buccal and lingual measurements combined / overall marginal gap measurement:

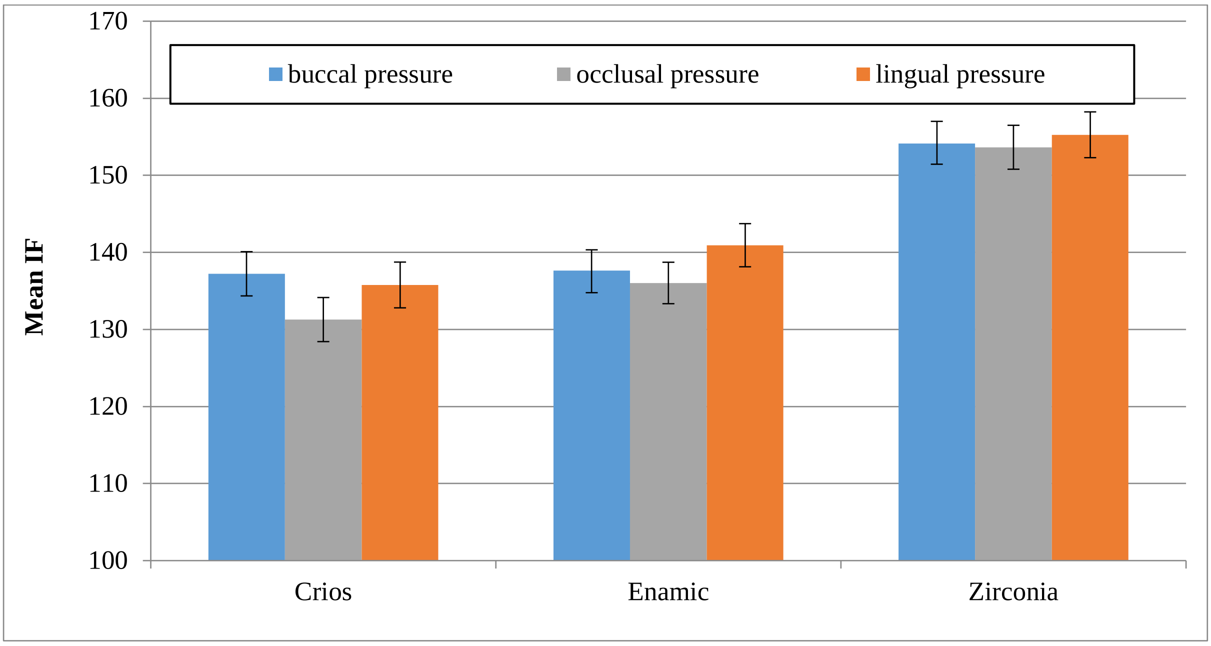
The 3D measurements were an average of 13.4µm higher than the corresponding 2D measurements (95% confidence interval: 11.7-15.1µm; $p < 0.0001$).

The 3D measurements were not significantly different from the corresponding 2D measurements ($p = 0.92$).

4.3. Internal fit measurements

4.3.1 Effect of seating buccally, lingually and occlusally for each material

The internal fit results, 100µm luting space and 200µm luting space for each material were combined, and in each group, the buccal-lingual and occlusal pressures were compared for each material by using the mean. ANOVA was used to compare the means. The accuracy of the milling would mean that the results should be close to 150µm as the spaces were combined. These results are shown in figure 11. Buccal pressure is indicated in blue, occlusal pressure is indicated in grey and, lingual pressure is indicated in orange. The error bars denote the 95% confidence interval for the means.



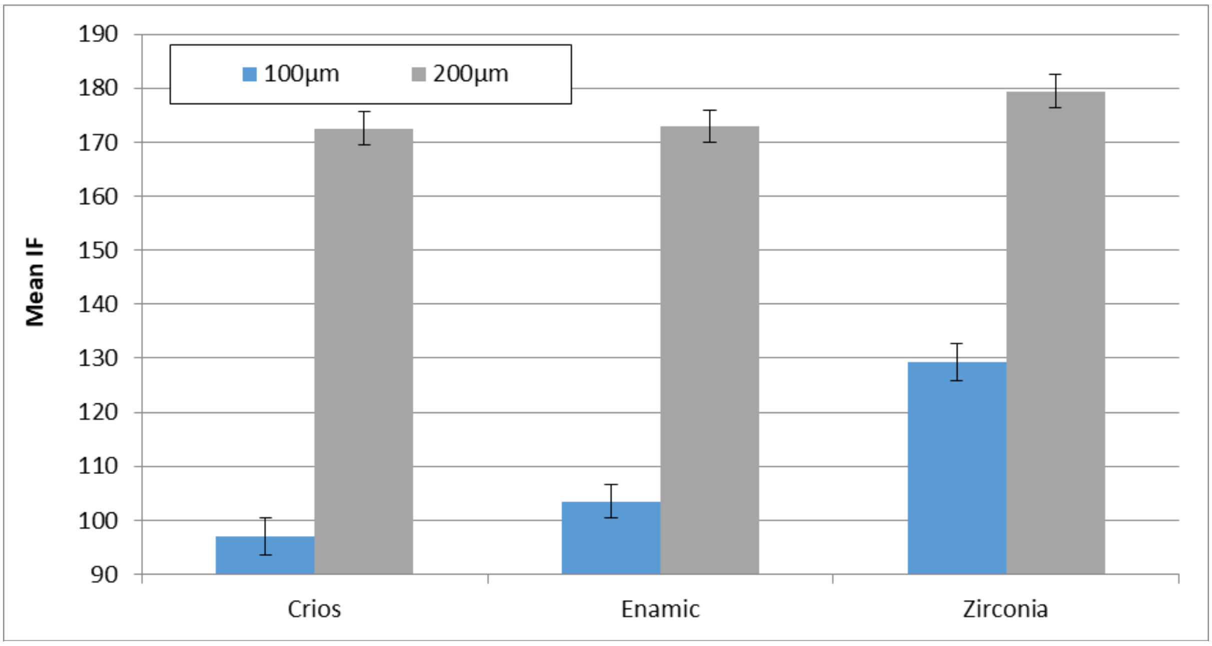
The error bars denote the 95% confidence interval for the means

Figure 10: Graph showing the estimated mean outcome from the effect of seating direction on the internal fit for each material

Signifiant differences were found for the occlusal pressure for all materials ($p<0.0001$); for the internal fit of the Zirconia crowns in all pressure scenarios ($p<0.0001$); and for Enamic which was significantly higher than Brilliant Crios for all pressures ($p<0.0001$).

4.3.2 Effect of luting space milled on the internal fit for each material

The CEREC software used to mill the crowns was set to mill either a 100µm luting space or a 200µm luting space. To test the accuracy and see which material yielded the better fit with these two different milled spaces, the pressures (buccal, occlusal and lingual) were combined, to make two groups for each material, 100µm space shown in blue and 200µm space shown in grey. ANOVA was used to compare the space-material combinations. The error bars denote the 95% confidence interval for the means. The results are summarised in figure 12.



The error bars denote the 95% confidence interval for the means

Figure 11: Graph showing the effect on internal fit for each material taking luting space milled into account

The mean internal fit was significantly higher for all 200µm crowns when compared with 100 µm crowns ($p < 0.0001$). Zirconia yielded the highest internal fit followed by Enamic, followed by Brilliant Crios.

CHAPTER 5: DISCUSSION

This is the first study to be carried out to measure and compare the effect of off-axis seating on the marginal adaptation of full coverage crowns. This study used the Reflex Microscope to measure in both 2D and 3D, with an accuracy of 4µm.

The longevity of CAD/CAM restorations is dependent on various factors such as the material used, the thickness of material, fit, bond/cement used, the clinician, and the patient. The importance of preparation, design, and milling can all affect the longevity, but the marginal gap and internal fit can act as excellent proxies for the clinical quality and success of a restoration.

5.1 Marginal gap

The marginal gap can be defined as the vertical and horizontal dimension from the finish line of the preparation to the margin of the restoration. The internal fit can be described as the area between the crown and the tooth that will be occupied by cement (Kokubo et al., 2011).

In the literature, many values have been said to be clinically acceptable from less than 120µm (McLean and von Fraunhofer, 1971) to between 50 and 100µm (McLean and von Fraunhofer, 1971; Hung et al., 1990) and between 50µm and 180µm (Coli and Karlsson, 2004). It is generally accepted that a sizeable marginal gap can lead to micro-leakage (Jacobs and Windeler, 1991), plaque retention at the margin (Valderhaug and Heløe, 1977), pulpal involvement (Goldman, Laosonthorn and White, 1992), and changes in the microflora causing the development of periodontal disease (Lang, Kiel and Anderhalden, 1983), any and all of which could ultimately result in failure of the crown.

Theoretically, the space required for the cement to lute is 20 - 40µm, as cement thickness, ranges from 25-50µm, and an acceptable practical guide was set between 50µm and 100µm (Martins et al., 2012). The problem is that the resin cement seal degrades over time, depending on factors such as contraction, polymerisation shrinkage, and mechanical stress, absorption of fluids and dimensional change of the material used. Due to all the factors, the amount of time for microleakage to occur cannot be determined. Also, the many variables, suggestions, theories, and contradictions, make it almost impossible to decide on the ideal marginal gap, luting space and material to use (Söderholm, 1991). Although difficult, it is clear that microleakage and fit of the restoration are related.

Many studies have been carried out measuring the marginal gap. However, none have considered the fact that in the clinical environment, crowns can be cemented off-axis, and that this might affect the marginal gap and internal fit. Therefore, this study sought to determine whether there is an effect on the marginal gap and internal fit when a crown is seated off axis.

All data measured was used for statistical analysis, there was an excellent ICC rating of agreement as seen in table 1. From this, table 2 was constructed to summarise the minimum, maximum, and mean marginal gap measurements in all scenarios. In all circumstances, the marginal gap did not exceed 120µm. The maximum value (that which came closest to 120µm) was obtained on the buccal marginal gap when lingual pressure was applied, and on the lingual marginal gap when buccal pressure was applied for all materials. The table also shows the minimum and maximum values for each pressure. With buccal pressure the marginal gaps ranged from 35.7µm - 112µm; with occlusal pressure, the range was 30.7µm - 98.7µm, and with lingual pressure, it was 31µm – 117µm. It is evident from this table that a tilt indeed affects the marginal gap, but it was interesting to note that none of the marginal gaps measured exceeded 120 µm. The null hypothesis was therefore rejected.

The buccal marginal gap measurement minus the lingual marginal gap measurement was calculated and then compared using a t-test to determine if there was a significant difference between the buccal and lingual marginal gap measurements for each pressure (buccal occlusal or lingual) within each material. Table 3 compared the buccal and lingual marginal gaps at all seating angles at both luting spaces for all materials. The results confirmed that there was a significant difference between the buccal and lingual marginal gap measurements in all cases when the crowns were seated off axis. This was true irrespective of material, except for the 3D measurements of Enamic and Zirconia where the difference was not significant. Table 3 also shows that the marginal gaps obtained (although significantly different in most cases) when cemented occlusally were the lowest and therefore had the best fit.

The difference between the buccal and lingual marginal gaps was calculated, in this instance, the materials were compared against each other, Table 4 compared the materials used without taking into account the luting spaces. There were no significant differences between materials for any seating angle. Once again, the smallest differences were found for occlusal pressure in all cases irrespective of material. This indicates from the data that occlusal seating yields the smallest marginal gap.

Table 5 showed the results obtained when seating at different angles but taking into account the luting space to determine if this affected the marginal gap. The results indicate that there were no significant differences between the 100µm and 200µm spaces when cementing off-axis. There was, however, a significant difference when cementing occlusally. For the 2D measurements the marginal gap measured with a 100 µm luting space was 15.3µm less than with a 200 µm luting space, and for the 3D the marginal gap measured with a 100 µm luting space was 10.2µm less than with a 200 µm luting space. Therefore, when cementing occlusally an internal milled luting space of 100µm yielded a smaller marginal gap when compared with an internal space of 200µm. Different manufacturers have recommended different luting spaces, but there appears to be no consistency in this. A systematic review found that the luting space can influence the marginal gap (Contrepois et al., 2013) but found no consistency in the studies reviewed. This study has shown that internal fit affects the marginal gap when crowns are seated axially, and should other studies have taken the seating angle into consideration they may have arrived at the same conclusion.

Overall, the 3D buccal measurements were on average 13.5µm higher than the corresponding 2D measurements, and 13.4µm higher for the lingual marginal gap measurements. Overall the 3D measurements were 13.4µm higher, but not significantly different from the corresponding 2D measurements ($p=0.92$). These measurements are to be expected, as the 3D gap is likely always to be higher than the 2D measurement, but they are nevertheless all extremely low, which is a testament to the accuracy of the milling of these crowns.

5.2. Internal fit

The effect of off-axis seating on the internal gap can be seen in Figure 11. Within each material, occlusal seating yielded the smallest internal fit when compared with off-axis seating. Zirconia, however, produced the highest internal fit for all scenarios (buccal, occlusal and lingual pressure) and was significantly different from the other materials. Enamic had the second highest internal fit followed by Brilliant Crios. Enamic (all pressures) was significantly higher when compared with Brilliant Crios occlusal pressure.

The CEREC software used to mill the crowns was set to mill either a 100µm luting space or a 200µm luting space. To test the accuracy and see which material yielded the better fit with these two different milled spaces, the pressures (buccal, occlusal and lingual) were combined, to make two groups for each material, 100µm space and 200µm space as seen in figure 12. The mean internal fit for all 200µm crowns was significantly higher than the 100µm crowns, which was expected. The graph also indicates that zirconia yielded the largest internal fit followed by Enamic, followed by Brilliant Crios. This also shows that the CAD/CAM process is highly accurate, generating an internal fit for each crown which closely resembles the luting space chosen on the machine.

Clinically the results obtained in this study have implications. It can be deduced from Table 2 that irrespective of material used when cementing a crown, a minor tilt of even 5 degrees can result in a larger marginal gap specifically on the opposite side to the pressure being applied. Although this study did not find these measurements to be above 120µm, these marginal gaps were still large, reaching 117µm. Previous studies that measured the marginal gap of crowns found that they ranged from 52µm to 74µm (May et al., 1998), 132.2µm (Akın, Toksavul, and Toman, 2014), below 90µm (Anadioti et al., 2014), 52µm to 74µm (Nakamura et al., 2003). In this study the marginal gaps ranged from 35.7µm - 112µm with buccal pressure, 30.7µm - 98.7µm with occlusal pressure and 31µm – 117µm with lingual pressure. The marginal gaps measures in this study that more closely resemble those within other studies are the values measured when occlusal pressure was applied. Should other studies have taken into consideration the tilt that may be found when cementing off axis, they may have measured larger results. The other factor not taken into consideration in other studies is measuring the marginal gap buccally and lingually separately. Gassino et al. (2004) found that to obtain an accurate overall marginal gap measurement one requires at least 18 points around the circumference of the tooth to be measured. However, this again did not take into account the tilt and used an average of all measurements to arrive at a marginal gap. Considering that a larger marginal gap will be found on the opposite side to the pressure being applied it is necessary to measure the buccal and lingual sides separately, to yield an accurate result that resembles the correct fit of the crown.

A lengthy process is required to make a Zirconia crown. Although it has high strength, it is milled much larger than its actual size and has to be sintered which shrinks it to the final crown size. These steps can allow for greater inaccuracies before the crown is finalised. Enamic being a poly infiltrated ceramic block, would possibly be more difficult to mill when compared to Brilliant Crios which is a reinforced composite. In this study, the material that yielded the largest marginal gap and the internal fit was Zirconia, followed by Enamic followed by Brilliant Crios, which would be expected, based on the material structure, possible inaccuracies during crown manufacture, and the characteristics of the material itself. However further studies need to be done to clarify whether the strength of the material would affect the accuracy of the milling process.

Before CAD/CAM technology, crowns had their luting space manufactured entirely arbitrarily and manually by a dental technician; this was usually done by painting a die spacer on the model. With CAD/CAM, however, the luting space can be programmed by the milling parameters on the software. The internal fit of a crown is just as important as the marginal gap, as it enables the seating of the crown and expression of cement, while also aiding in retention and resistance (Beuer et al., 2008). It has been found that there is a general increase in the marginal gap measurements following cementation (Byrne, 1992; Quintas, Oliveira, and Bottino, 2004). The way in which a crown is cemented can lead to the poor seating of the crown, resulting in an inadequately closed margin (Gu and Kern, 2018). This is true when cementing off-axis, resulting in one side of the crown having a large marginal gap and the other side where the pressure is applied having a small marginal gap (table 2). In this study, it was found that when cementing with occlusal pressure a smaller marginal gap can be obtained with a 100 µm luting space when compared to a 200 µm luting space (table 5). This may be possibly due to the tighter fit of the crown internally aiding the seating of the crown and thus resulting in less tilt, better seating and hence a smaller marginal gap.

5.3. Limitations

In this study, three materials were used, but considered representative of materials with different strengths, as strength and hardness may affect the milling preparation and accuracy during crown manufacturing.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

Within the limitations of this study, the following can be concluded:

- Cementing off-axis at 5 degrees buccally or lingually results in a larger marginal gap, specifically the marginal gap will be larger on the opposing side to which pressure is applied.
- When cementing axially/occlusally the smallest marginal gap is obtained, and the smallest internal fit is achieved.
- The material being used does not affect the marginal gap when cemented off-axis or occlusally.
- 3D measurements are larger than 2D measurements and were larger overall by 13.4µm, the difference, however, was not significant.
- The largest internal gaps were measured for Zirconia crowns, then Enamic and then Brilliant Crios.
- When cementing occlusally a smaller marginal gap is obtained with a 100µm luting space when compared with a 200µm luting space.
- None of the measurements when cemented axially or off-axis were larger than 120µm. However, when cementing off axis, the largest gap was 117µm as opposed to cementing occlusally which yielded a maximum marginal gap measurement of 98.7µm.

6.2 Recommendations

The following recommendations can be made:

1. Future studies should measure the marginal gap buccally and lingually separately and not just use an average to obtain an accurate measurement

2. A method needs to be devised to cement crowns axially in the clinical environment to provide the best fit possible and minimise complications.
3. More studies need to be carried out to determine what internal milled luting space will yield the smallest marginal gap.
4. An investigation needs to be done to determine if the strength, structure and type of material would affect the milling and accuracy of a CAD/CAM restoration.
5. The study did not investigate the effect of different luting cements, and this should also be investigated in further studies.

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APPENDICES
APPENDIX A: ETHICAL CLEARANCE

Human Research Ethics Committee (Medical) **50 years 1966 – 2016**

Research Office Secretariat: Faculty of Health Sciences, Phillip Tobias Building, 3rd Floor, Office 301,
29 Princess of Wales Terrace, Parktown, 2193 Tel +27 (0)11-717-1252 /1234/2656/2700
Private Bag 3, Wits 2050, email: zanele.ndlovu@wits.ac.za
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UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

Ref: W-CJ-171114-1 14/11/2017

TO WHOM IT MAY CONCERN:

Waiver: This certifies that the following research does not require clearance from the Human Research Ethics Committee (Medical).

Investigator: Dr G Babiolakis (student no. 458852).

Project title: The effect of off-axis seating on the marginal adaptation of full coverage crowns.

Reason: This is a laboratory study. There are no human participants.

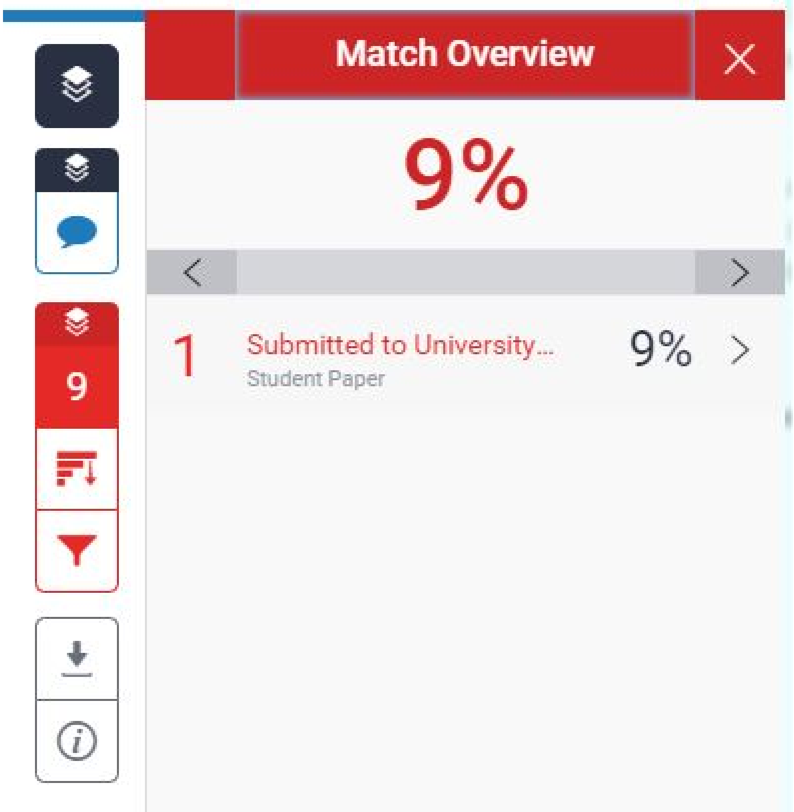
Professor Peter Cleaton-Jones

Chair: Human Research Ethics Committee (Medical)

UNIVERSITY OF THE WITWATERSRAND
PROF PE CLEATON-JONES
HREC (MEDICAL)
2017 -11- 14
JOHANNESBURG

Copy – HREC (Medical) Secretariat: Zanele Ndlovu, Rhulani Mkansi, Lebo Moeng.

APPENDIX B: TURNITIN REPORT



Example of matches in the above, illustrating that the matches are from the use of similar literature to that of the paper:

Several methods have been used to evaluate the marginal gap including the use of an optical microscope (Yeo, Yang and Lee, 2003; Akbar et al., 2006; Lee et al., 2008; Beuer et al., 2008; Alghazzawi, Grenade, Mainjot and Vanheusden, 2011; Liu and Essig, 2012; Jayaraman et al., 2015); using a profile projector (Nakamura et al., 2003); profilometry (Mitchell, Pintado and Douglas, 2001); embedding in epoxy resin and sectioning and measured with a three-dimensional microscope (Tsitrou, Northeast and van Noort, 2007; Han et al., 2011; Souza et al., 2011; Biscaro et al., 2012; Sachs et al., 2014); cementation and use of microCT (Seo, Yi and Roh, 2009; Rungruanganunt, Kelly and Adams, 2010; Alfaro et al., 2015); and the use of a silicone luting replica technique (Nakamura et al., 2003; Kokubo et al., 2011; Tsitrou, Northeast and van Noort, 2007; Lee et al., 2008; Rungruanganunt, Kelly and Adams, 2010; Moldovan et al., 2011; Scotti et al., 2011; Anunmana, Charoenchitt and Asvanund, 2014).