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Force Applied by Dentists during Cementation of All Zirconia Three Unit Bridges and Its Impact on Seating

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Abstract Dental luting cements are important materials in securing FPD to abutment teeth. During the cementation process of FPDs finger force is applied to fully seat the restoration in place. Normally the dentist maintains force on the restoration until the luting cement sets, however, little is known as to the consistency of force application over time. The aim of this study was to compare the force applied by dentists during cementation of all-Zirconia FPD manufactured by CAD CAM and to investigate the effect that this has on the seating and fit of the cemented FPD. Two plastic teeth mounted in Frasaco jaws (teeth 24 and 26 were prepared for a three unit all ceramic (zirconia) bridge to replace tooth 25. Each tooth was prepared in the laboratory with a high-speed hand piece and coolant to a pre-set standard. Ten practitioners were recruited for this study and allocated one SLA model and one all zirconia bridge each. RelyX™ Unicem 2 Clicker™ self-adhesive Universal Resin Cement was used as the luting cement. Each examiner performed the seating procedure six times over a two week period, the participants applied the force for two minutes in each time. To measure the cementation force (Newton), a universal testing machine (Instron) was used. Finally, the internal and marginal fit (µm) was determined using SEM. The results showed high initial force which reduced and plateaued after 30 seconds. Maximum force applied was 88.0 N and the minimum was 8.0 N with a mean value of 27.23 N. SPSS was used to perform statistical analysis. Two-way ANOVA with post hoc test were performed on the force results and showed significant difference between most examiners. One-way ANOVA was performed on the internal and marginal fit results and this showed no significant difference between all examiners. Dentists apply different forces when seating FPDs but this does not affect the internal and marginal fit of FPD.

Keywords: *CAD-CAM, Zirconia, cementation force, fixed prosthodontics*

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1. Introduction

Dental luting cements are important materials in securing indirect laboratory made dental restorations to teeth. Different types of luting cements are commercially available, each type having specific characteristics, advantages, disadvantages and recommendations. During the cementation process finger force is applied to fully seat the dental restoration in place. Normally the dentist maintains force on the dental restoration until the luting cement sets or start to set, however, little it is known as to how much force is applied and the consistency of that force application over time and whether this could influence the fit or seat of the restoration. Some dentists ask patients to “bite on a cotton roll” to maintain seating force during the setting time. Whilst this procedure benefits from the occlusal force produced by the patient, there is no control over the force applied and errors could occur especially in relation to Fixed Partial Dentures (FPD) where pressure may be greater over one abutment compared to another.

There are several types of luting cements on the market with a range of physical and chemical properties, with some having specific uses, for example adhesive resin luting cements for resin retained bridges. Luting cement quality, mixing and application technique can affect the integrity of the cemented restoration and its longevity with some newer materials having improved dispensing and mixing techniques (e.g. encapsulated materials and double helix mixer tips) which to some degree ensure more consistently mixed materials and properties [1].

For indirect restorations that rely primarily on tooth preparation configuration for retention (near parallelism, length of preparation), luting cements are not only required for secondary retention but they are also needed to fill and seal the interface between the restoration and tooth. Ideally the fit of the indirect restoration should be as good as possible limiting the thickness of the cement lute internally and at the margin of the restoration. To achieve this luting cements need to be pseudo-plastic or have low viscosity to ensure flow under pressure and as such they generally have lower filler content compared to their restorative counterpart. This makes luting cements more susceptible to wear and hence the need to keep the marginal gap as small as possible.

The film thickness can depend on different factors, such as the seating force applied and the duration of force application, and alongside other factors play a role in the survival and longevity of the indirect dental restoration. A number of studies have been carried out to evaluate and compare different types of cements in regard to their properties and effect on film thickness, marginal and internal fit [2].

In a study different resins have been tested to see if they maintain a minimum film thickness over 1, 2 and 3 minutes. Two groups of the cements showed acceptable film thickness (under 26 µm at 2 minutes and under 30 µm at 3 minutes) except the resin modified glass Ionomer cements which exceeded the value at 3 minutes. This shows that most luting cements used these days to secure indirect dental restoration are up-to the acceptable and recommended levels [3].

Cementation force has significant potential to affect seating and to the authors best knowledge only two publications have looked at measuring the force applied by dentists during the cementation of dental restorations. These two studies have been on single unit crowns and not FPD and neither related the cementation force to the fit of the restoration.

In these two studies, different instruments were also used to measure the seating force, and both recorded forces between 12N-67N. The highest forces were recorded in the first few seconds, thereafter followed by lower forces [4,5]. Higher forces were also applied to metal crowns when compared with porcelain crowns [4].

Tooth preparation for CAD CAM restorations may differ in that most of the studies have recommended total occlusal convergence angles (taper) in the order of 10° to 15°. This angulation may affect the way in which excess luting cement is vented while cementing the restoration and in turn may influence the force needed to seat the restoration fully onto the prepared tooth. This may also be of greater impact when trying to seat fixed partial dentures where more than one abutment teeth are aligned with each other [6-10].

2. Aims and Objectives

The aim of this study was to compare the force applied by ten different dentists and by the same dentists at different time intervals during the cementation of all-Zirconia FPDs manufactured by Computer Aided Design Computer Aided Manufacturing (CAD CAM) and to investigate the impact that this has on the seating and fit of the cemented restoration.

3. Materials and Methods

3.1. Tooth Preparation

Two plastic teeth (Frasaco GmbH, Germany) were mounted in Frasaco jaws (standard working model A-3), one first pre-molar (tooth 24) and one first molar (tooth 26), and were prepared for a three unit all-Zirconia FPD to replace the second pre-molar tooth (tooth 25) (Figure 1 A). Each tooth was prepared in the laboratory with a high speed hand piece and new chamfer crown preparation tapered diamond bur (Komet dental, Code number 856-314-016) with water coolant to a predetermined standard determined from the literature: consistent deep chamfer finish-line 1-1.5mm in depth around the entire circumference of the preparation, 10°-12° preparation angle and 1.5-2mm occlusal reduction [6-11].

Figure 1 A Prepared teeth (UL4 and UL6) for three unit All Zirconia Bridge

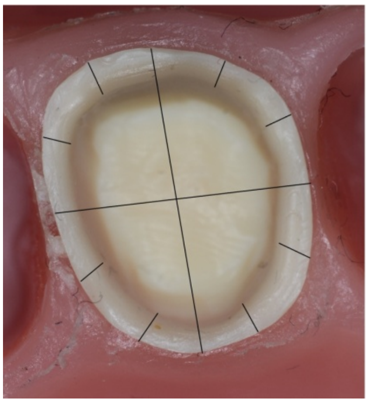

Figure 1 B. Shows measurement of the finish-line

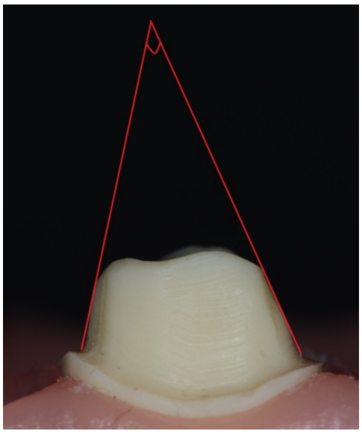

Figure 1 C. Shows measurement of the angle

3.2. Quality Control

Photographs were used to measure the finish-lines (Figure 1 B) and preparation angles (Figure 1 C) of the plastic teeth to confirm that the tooth preparations met the predetermined standard. A Digital Single Lens Reflector camera (DSLR, Nikon D7000) with macro lens (Sigma 105mm f/2.8 EX DG) and ring flash (Sigma MACRO EM-140 DG) was used to photograph the prepared teeth from 9 different perspectives (Mesial, distal, buccal, lingual, buccal-mesial, buccal-distal, lingual-mesial, lingual-distal and occlusal); the first eight were used to measure the total occlusal convergence, and the final occlusal image used to measure the depth of the cervical chamfer at 12 equally spaced positions around the circumference of the tooth. The images were reproduced at 1:1 ratio. Images were imported into ImageJ (public domain Java image processing program) to analyse the finish line and axial wall angulations. The mean total occlusal convergence angle for tooth 24 was 11.5° (min 11.1° - max 11.9°) and for tooth 26 was 11.5° (min 11.2°- max 11.7°), the mean chamfer depth around tooth 24 was 1.2 mm (min 1.0 mm - max 1.3 mm) and tooth 26 was 1.2mm (min 1.0 mm - max 1.4 mm).

3.3. Digital Impression and all-Zirconia FPD Manufacture

Once the ideal tooth preparations were achieved and confirmed through the quality control process, the prepared teeth on the original model were scanned with the Lava™ Chairside Oral Scanner (Lava™ C.O.S, (3M ESPE, Seefeld, Germany) according to manufacturer's instructions to produce ten identical Stereolithography models (SLA models, In 'Tech Industries, Inc. USA). Stereolithography is an additive manufacturing process which employs a vat of liquid ultraviolet curable photopolymer "resin" and an ultraviolet laser to build up models one layer at a time. The data captured with the intraoral scanner was also used to design the all-Zirconia FPD in the CAD system (die spacer 0.095mm extra vertical (occlusal), 0.075 mm extra horizontal (buccal, mesial, distal and lingual) and minimum coping thickness 0.5 mm). This process allowed subsequent manufacture of ten identical three-unit all-Zirconia FPDs using a five axis CAM milling machine (Lava™ CNC 500 Milling System, 3M ESPE) and dry milling process. Semi-sintered zirconia multi blocks were used to fabricate the all-Zirconia FPDs (3M ESPE, Seefeld, Germany, LOT No. 470281, LOT No. 472678 and LOT No. 472678). The semi-sintered all-Zirconia FPD's were placed in a custom furnace (Lava™ furnace 200, (3M ESPE, Seefeld, Germany) to fully sinter the Zirconia framework at 1500°C for 4 hours 48 minutes (LAVA 1500, Non-shaded).

3.4. Force Applied during Cementation Procedure

Ten practitioners were recruited and allocated one SLA model and one all-Zirconia FPD each. All practitioners were qualified dentists: six were consultants in restorative dentistry and four were postgraduate students in restorative dentistry, all having at least five years post graduate experience. RelyX™ Unicem 2 Clicker™ (3M ESPE, Seefeld, Germany, LOT No. 491286) self- adhesive Universal Resin Cement was used as the luting cement. So that repeated cementations of the same bridge could be carried out on different occasions, only the base paste was used to prevent setting of the cement. For each cementation procedure the internal aspect of the two all-Zirconia FPD retainers were coated with the base cement and the practitioners were instructed to seat the bridge with the pressure that they would use clinically to cement a bridge, using two fingers, one over each retainer (as determined in a pilot study of ten dentists' cementation technique) for two minutes.

To measure the cementation pressure (Newtons), the SLA model was placed on a universal testing machine (Instron®, model 4469) table while the all-Zirconia FPDs were cemented by the dentists. A stop watch was mounted on the Instron machine alongside the force display and a video camera captured the force and time for each cementation procedure: cementation force was recorded at 10 second intervals for two minutes. Each examiner performed the seating procedure six times over a two-week period blind to the cementation force and previous recordings: three times each week on alternate days. After each cementation procedure the base cement was thoroughly cleaned from the fit surface of the bridge and the prepared teeth by brushing under running hot water and dried with absorbent paper. On the final cementation, the base and catalyst pastes were mixed and the bridge immediately cemented permanently, excess cement was removed using a micro-brush, the participants applied the force for two minutes and then the cement was light cured at the restoration margins after releasing the pressure from the all zirconia bridge.

The cemented restorations on the SLA models were stored dry and after one week the SLA models and the cemented all-Zirconia bridges were embedded in Orth resin (self-curing, DENTSPLY, DeguDent Gmbh, Germany, LOT NO. 13FEB096 (powder), 12AUG045 (liquid)) to ensure that the bridges and Frasaco teeth did not fragment during the sectioning process. Each model was sectioned bucco-lingually and mesio-distally through each retainer using an IsoMet® 5000 Linear precision saw (Buehler®, a division of Illinois Tool Works Inc.) with an IsoMet® diamond wafering blade (178mm x 0.6mm, Buehler®) under water coolant, for subsequent examination under the Scanning Electron Microscope (SEM). Each retainer and abutment tooth was therefore sectioned into 4 segments (see Figure 2 A).

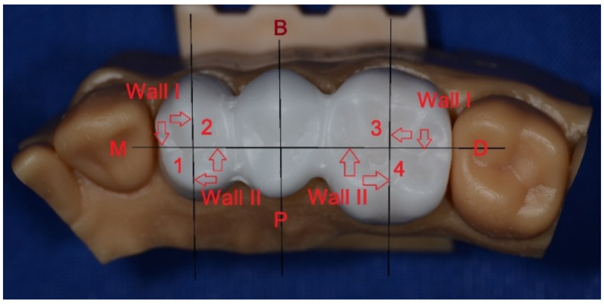

Figure 2 A. SLA model and bridge section lines

3.5. SEM Observation

Sectioned samples were mounted on aluminium studs using double sided carbon tape, then painted with sliver conductive paint (conductive pen, MG chemicals). The samples were then examined under the Scanning Electron Microscope (SEM, Philips XL30 FEG SEM) at 150x magnification operating at acceleration voltage of 15 kV to measure the cement space internally and marginally. The images were viewed on a 19" flat screen using Microscope Control software (Figure 2 B).

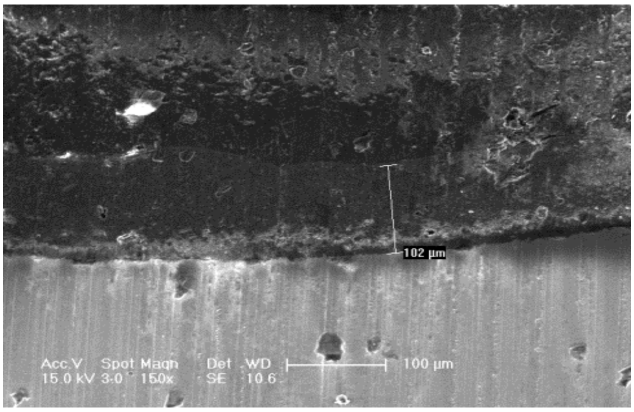

Figure 2 B measurement of internal fit (cement space)

For each bridge (and examiner) there were eight segments (four from the premolar and four from the molar) and each segment had two walls as follows:

Segment	Wall 1	Wall 2
Segment 1 (Premolar)	Mesio-Distal	Bucco-Palatal
Segment 2 (Premolar)	Bucco-Palatal	Mesio-Distal
Segment 3 (Molar)	Bucco-Palatal	Mesio-Distal
Segment 4 (Molar)	Mesio-Distal	Bucco-Palatal

For each wall, measurements for internal fit were recorded at twenty-six randomly selected sites (4 occlusal and 22 axial) and for marginal fit seven measurements were recorded.

3.6. Statistical Analysis

For each practitioner the mean force taken at each 10 second interval for the 2 minutes cementation period was calculated for the six cementation procedures. Two-way ANOVA and post hoc test (Bonferroni) were used to assess the force applied by the practitioners during the six different cementation procedures and to determine if there was any significant difference between the cementation procedures for each practitioner and between practitioners. The final cementation force was investigated using a one-way ANOVA and post hoc (Bonferroni) test to determine if there were any differences in the forces applied by the practitioners for the whole two-minute cementation procedure and at each 10 second interval. The mean internal and marginal fits were assessed for each practitioner using two-way ANOVA and post hoc (Bonferroni) to determine if there was any differences between them (IBM® SPSS® 21). The relationship between the mean internal and mean marginal fits with the final cementation force applied was investigated using Pearson Correlation co-efficient.

4. Results

4.1. Force

4.1.1. All six Cementation Procedures

Analysis of the force applied at every 10 second interval over the two-minute cementation procedure for all 10 practitioners on the six separate occasions, showed that the mean force applied was 27.23 N (min 8.0 N, max 88.0 N).

For each practitioner, two-way ANOVA showed that there was no statistically significant difference between the cementation forces applied in every 10 seconds over two minutes in the six cementation procedures ($p > 0.05$). However, there was a significant difference in the mean force applied over the six, two-minute cementation procedures between the practitioners ($p < 0.001$). Post hoc test (Bonferroni) showed that for most paired comparisons between practitioners there was a statistically significant difference in force applied Table 1.

Table 1. Pot hoc comparisons of finger forces between practitioners (*P ≤ 0.05; **P ≤ 0.001; the yellow boxes show no statistically significant difference) P = Practitioners

P	1	2	3	4	5	6	7	8	9	10
1		*	**	0.155	1	**	0.062	**	1	**
2			**	*	**	**	**	**	0.024	**
3				**	**	**	**	**	**	**
4					*	**	1	*	0.024	**
5						**	*	**	1	**
6							**	*	**	1
7								*	*	**
8									**	1
9										**
10										

Observation of the cementation force overtime showed that individual practitioners consistently applied higher forces during the first 20 second period. Two way ANOVA showed that in the first 20 second period all ten practitioners applied different cementation forces ($p \leq 0.05$), however, the force applied over the remaining time (100 s) periods was less variable between practitioners with post hoc test (Bonferroni) showing that the cementation force was only statistically different between two practitioners (2 and 3; $p \leq 0.01$).

4.1.2. Final Cementation

In the last cementation procedure, the mean force applied for all ten practitioners over the two-minute cementation procedure was 28.24 N (min 13.0 N, max 59.0 N) (Figure 3). One-way ANOVA showed statistically significant differences ($p \leq 0.05$) in the cementation force applied by the ten practitioners over the entire two-minute procedure. However, post hoc test (Bonferroni) showed there to be a statistically significant difference between practitioners only in the first 10 and last 20 seconds ($p \leq 0.05$). The mean force in the first 10 seconds was 38.3 N (min 20.0 N, max 59.0 N) and thereafter 27.32N (min 13.0 N, max 52.0 N (Figure 3).

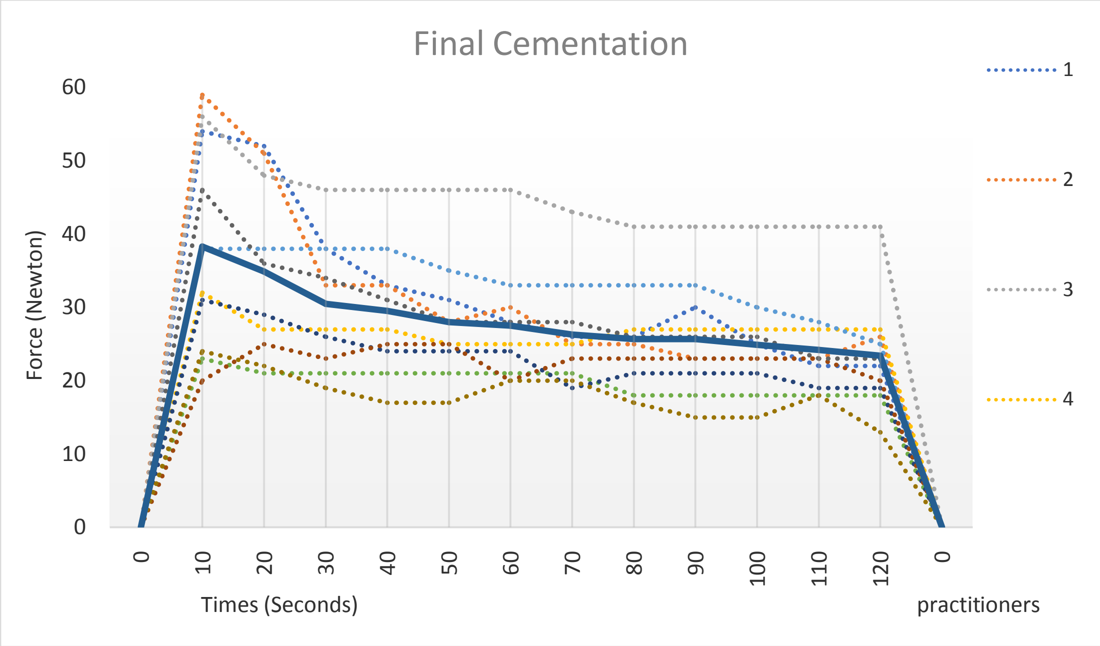

Figure 3. Force and mean force applied from the final cementation experiment

4.2. Internal and Marginal Fit

Analysis of the readings of internal fit results showed a mean gap of 90.42 µm (min 79.4 µm, max 106.7 µm). Two-way ANOVA showed a statistically significant difference in internal fit between the practitioner's cemented bridges ($p < 0.05$); post hoc (Bonferroni) test showed that the results of practitioner 3 only had significant difference from the other practitioners, where all the other practitioners showed no significant difference in internal fit. Where marginal fit was concerned (mean 28.40 µm, min 24.1 µm and max 31.5 µm) there was no statistically significant difference between the practitioners ($p = 0.714$).

Analysis of the marginal gap of the mesial aspects of the premolar and distal of the molar teeth were examined statistically (two way ANOVA) to check if there was any impact which may arise from a different force being applied by each finger on different abutments, the results showed no significant difference ($p=0.897$).

4.3. Force and Fit

Comparison of the mean internal fit and marginal fit with the mean force applied for all participants showed that there was a moderate to strong inverse relationship between force applied and internal fit (Pearson Correlation Coefficient = - 0.69; $P \leq 0.05$) and no statistically significant relationship to marginal fit (Pearson Correlation Coefficient = - 0.28; $P \geq 0.05$). One examiner stood out in applying a greater force for the duration of the cementation; elimination of this examiner from the analysis resulted in no statistically significant relationship in the cementation force and internal or marginal fit.

5. Discussion

Previous studies that have investigated the cementation force used by dentists in seating indirect restorations have focused on single unit crowns. These studies have shown that the forces generally applied range from 12 to 67 N [4,5]. It is possible that when cementing more substantial restorations involving two or more teeth and having a longer span, practitioner could apply different forces, however this study showed that the forces applied are in general comparable, in the order of magnitude of 8 to 88 N. Some dentists ask patients to bite on a cotton rolls placed between the restoration and the opposing teeth to finally seat the restoration [1,2]. This could pose a problem in longer span bridges in that an equal and balanced force over each abutment tooth is required and may not be achieved, especially posteriorly in relation to the hinge movement in opening and closing, when asking patients to bite to seat the restoration. It has also been shown that patients can achieve a much greater maximum bite force of 350 to 850 N between posterior teeth [12,13] and 120 to 350 between anterior teeth [14,15], than was achieved by dentists in this study and previous studies [4,5].

Bite force is also very variable between patients and not only be influenced by position of the tooth in the arch, but also by other factors such as gender (studies have shown males have higher maximum bite force compared to females [14,16,17]), age (the maximum bite force is reached at between 20 and 40 years, and then it starts to decline [18,19,20]), craniofacial variables (different facial types (short, average and long face) produce different bite forces where the highest force has been shown to be achieved by people with short faces, followed by people with average faces and the lowest was recorded from people with long faces [18,21,22,23]), the number of teeth present (complete dentition produces the highest bite forces, followed by fixed partial dentures, then removable partial dentures and finally people with complete denture who demonstrate the lowest maximum bite force [14,24]), periodontal health (poor periodontal health being associated with lower levels of maximum bite force [25,26] although some studies have shown less of an impact in relation to periodontal health [27,28]) and temporo-mandibular disorders (masticatory muscle pain possibly limiting or lowering the maximum bite force of a person [29,30]). It is also unknown how sustained the bite force is over time when used to cement restorations. As such the practice of asking patients to use occlusal force to seat restorations should be discouraged due to its uncontrolled nature.

In studies which have investigated the retention of cemented crowns, sustained uniform seating forces have been applied to seat and secure the restorations. The forces used have ranged from 50 N to 200 N [31,32,33]. The duration over which the seating force is applied when cementing a dental restoration could also have an impact on the flow of cements, the final cement film thickness, fit and retention of a restoration. The effect of applying a constant seating force of 100 N over a five second and three minutes period of time has been investigated when Panavia F was used with and without Clearfil Protect Bond. The prolonged application of constant seating pressure and the use of a hydrophobic light-cured adhesive (Clearfil Protect Bond) both resulted in improved bond strength of resin blocks cemented on natural teeth [34].

Although Rely X Unicem is a dual cured cement, in the final cementation it was light cured to ensure that the cement had set at the marginal gap, this duplicates the clinical procedure. The manufacturer's recommendations for setting time are either 6 minutes for self-cure or around 3 minutes for light-cure but in the real clinical situation it is very difficult and uncomfortable for operator and patient to keep the study force for more than two minutes continually, hence the pragmatic choice of two minutes for seating.

The practitioners applied almost constant pressure after the first 30 seconds in the final cementation and although statistical analysis showed that there was no significant difference in the force applied for each practitioner on six separate cementations, there was a statistically significant difference between the practitioners in the final cementation.

In this study when the cemented retainers and corresponding abutments were sectioned 33 random readings were recorded for each sample wall to assess internal and marginal fit (26 internal and 7 marginal (total 66 reading for each abutment)). This was based on the findings of two previous publications, one of which suggested that 50 measurements were required to study the clinical gap of fixed partial dentures and the second review suggesting that the number of readings should be related to the sample size, which if around 30 specimens, would require 20 to 25 measurements per crown to be acceptable [35,36].

The mean marginal gap in this study was found to be 28.40 µm and the internal gap was 90.36 µm. The results from this experiment can be compared to the readings from other studies. In one study by Bindl and MÖRmann (2005) the marginal and internal gaps were measured for different CAD CAM systems' restorations made for single crown copings and compared to conventional techniques (slip-cast). They found that the marginal gaps from the CAD CAM systems ranged between 17 µm - 44 µm and the internal gaps were between 81 µm - 136 µm, and were comparable to those copings made with conventional techniques confirming their accuracy [37]. In a further study which compared the marginal discrepancy and microleakage around crown margins fabricated using three different CAD CAM systems found that the marginal discrepancies were 62.58 ± 8.98 µm for Procera, 65.54 ±18.56 µm for Kavo system and finally 132.18 ± 27.75 µm for Cerec. The results showed that the Cerec system had higher marginal discrepancy than the other two systems and higher microleakage values [38]. A study compared the accuracy of double layer and single layer all ceramic crowns two different CAD CAM systems (Procera and Cerec 3D) were used, the readings were 72.2 ± 7 µm marginal and 71.4 ± 5.3 µm internal for Procera copings, 89.6 ± 9.5 µm marginal and 68.3 ± 6.9 µm for Procera crowns and finally 94.4 ± 11.6 µm marginal and 109.5 ± 4.7 µm internal for Cerec 3D crowns. They concluded that both systems produced clinically acceptable crowns [39]. The last study compared the internal fit of two CAD CAM systems (Everest and Lava) with Porcelain Fused to Metal (PFM), the results were 60.46 µm for the Everest group, 78.71 µm for the Lava group, and 81.32 µm for the metal-ceramic group. With the different results concluded from this experiments, all results were clinically acceptable [40].

6. Conclusion

Within the limitation of this study, the following conclusion can be drawn:

1. Dentist apply different forces when cementing fixed partial dentures.
2. The initial force is the highest and it starts to plateau after 30 Sec.
3. In the final cementation experiment forces applied were between 13 N and 59 N, leading to clinically acceptable marginal and internal fit of the final cemented three unit FPD.
4. Despite dentists applying different forces when seating FPD, this has no significant impact on the marginal fit of restorations.

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