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Jacobs Journal of Dentistry and Research

Research Article

Digital Dynanometer for Cementation and its Influence on the Film Thickness of Ceramic Restorations

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Received: 08-21-2014

Accepted: 09-16-2014

Published: 09-27-2014

Abstract

The aim of this study was to develop a standardization technique of cementation force. Firstly, a digital dynamometer for clinical application was developed for standardization of the cementation force. Next, the accuracy of the dynamometer was verified through a comparative evaluation of the internal adaptation of all-ceramic crowns cemented under digital force or using the device. Ten human extracted molars were prepared for full crowns, and received all-ceramic crowns fabricated using an injection-molded system (IPS Empress 2) veneered by IPS e.max Ceram. A manikin containing the adapted teeth was mounted to an artificial head with a mask to simulate lips and cheeks. At the moment of the test of simulated cementation, each crown was filled by a freshly mixed, PVS material specifically designed for this purpose, and immediately seated at the final position on the respective tooth. In the Mechanical Group, the fork of the dynamometer was inserted into the oral cavity, and the tip protected by the silicone was placed over the ceramic crown. The patient was asked to stabilize the bite force for 3 minutes when the dynamometer's digital display indicated ~20.0N. Three graduate students performed the procedures for the Manual Cementation Group. Cross-sections of replicas were obtained, after serial cuts in the labial-lingual and mesiodistal directions. Three local measurements were taken (cervical, axial, and occlusal). Mean final film thicknesses were 86.48 µm for the Mechanical group, and 103.58µm, 103.05µm, and 104.49µm for the Manual Cementation group. In spite the results revealed no statistically significant differences, the cementation using the dynamometer standardized the cementation force. In addition, its use reduces the need of the aid by a dental assistant, and takes the hands free to remove excess material, for checking accuracy fit, and stabilization of the indirect restoration, including at the light-curing step.

Keywords: Ceramics; Dental Marginal Adaptation; Bite Force

Introduction

The development of stronger and more versatile ceramics systems, together with the adhesive technique, has provided the application of metal-free ceramic restorations in teeth in both anterior and posterior with esthetics, preservation of periodontal health and restoration of function. However, regardless of the system, the success of metal-free ceramic restorations is related to a series of clinical and laboratory steps that must be performed with high standards and with a consistent quality control [1]. In this sense, considering that there was success in planning, preparation, impression-taking and fabrication of the restoration, the outcome of the whole procedure will only be successful if the luting is suitable. It requires from the dentist and assistant, exceptional training and coordination, in addition to knowledge on the

materials and the technique. It should be noted that what makes the cementation so important is the fact that it cannot be remade without prejudice to the restoration [2].

During the process of cementation, some factors such as the force applied on the ceramic restorations for cementation, can affect significantly the marginal adaptation [3,4]. If the force is excessive, it may cause fracture of the margins or even the entire ceramic restoration [5]. On the other hand, if the force is insufficient or even off the path of insertion, it can result in misadapted restorations, influencing significantly the occlusal adjustment, the retention of the restoration, the premature staining of the margins and marginal leakage [6].

For a long time the force of cementation is evaluated and controlled *in vitro* studies [4,7-14]. However, the control of the force is difficult in clinical evaluations and routine professional activity, and it is up to each professional to manually establish the force of cementation he/she believes to be appropriate.

To consider that the importance of the force of cementation can be reduced by the use of adhesive cementation technique is currently premature and unreliable. Although resin cements are less susceptible to dissolution, one must consider that they are not completely wear resistant, even in minor marginal discrepancies [15].

In addition to the conventional resin cements, adhesive cementation can be accomplished with adhesive systems filled or unfilled, self-adhesive resin cements, resins of low viscosity (flowable) [16]; heated composites [17,18], under different modes of activation. Despite the wide range of materials, the cementation technique has changed little. The force and form of application of pressure are also similar to those performed for the centennial zinc phosphate cement.

A new device that would allow for higher time for seating, with stable and continuous force, allowing the professional to release both hands for checking the margins, for removal of excesses and the proper light activation of the luting material can provide better marginal adaptation and resulting decreased labor in the following steps, ie, the occlusal adjustment, finishing and polishing the margins.

The aim of this study was to propose standardizing the force of cementation technique in the cementation. For this, the procedures were divided into two phases: first, the development of a digital dynamometer for clinical use which allows standardization of the cementation force, and the second stage, a comparative evaluation of the internal adaptation of cemented crowns with manual force and the developed dynamometer.

Material and Methods

Developemnt of the Dynamometer

In order to develop the dynamometer, it was required to design an arch. Using computer-aided tools (CAD, i.e., Computer Aided Design) and FEA (Finite Element Analysis) was essential for both the three-dimensional visualization of the product as for the calculation and simulation of the device (Figure 1).

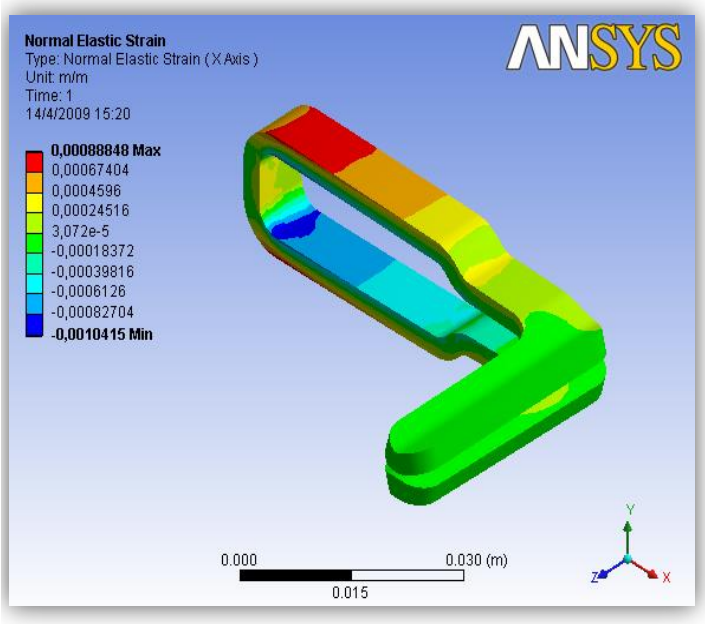

Figure 1. Graphic representation of the elastic strain according to the finite element analysis of the dental contact arch prior to its fabrication.

After the initial design of the bow, the most suitable material for its production has been selected. To meet the basic requirements, we chose to use stainless steel to make the arc of dental contact, more specifically, ABNT 420 steel, for the good mechanical properties and because it is the metal used for application in hospital, surgical, and dental instruments, and therefore, capable of sterilization.

After fabrication of the stainless steel arch, the components were selected to make up the dynamometer. To mount the dynamometer, devices such as strain gauges, transducers, load cell, multi-display panel and switching power supply have been used.

The extensometers were selected according to the material to be deformed - in this case, ABNT 420 steel- and connected following the scheme of a full Wheatstone bridge. Four strain gauges are connected to the arc of stainless steel.

During the stages of development of the dynamometer it was designed an aluminum cable for ease of handling and grip

for using of the stainless steel arch. This cable was designed to be hollow, allowing for the input and output of the wires from the four gages. A plastic box was used (PB 220/140, Patola, Sao Paulo, Brazil) to receive the load cell transducer, the multi-panel and switching power supply. In order to facilitate the sterilization it was developed two stainless steel removable adapters for the dental contact area. Each adapter has received a detachable disposable silicone cover for the contact area (Figure 2).

Figure 2. Frontal view of the dynamometer ready to perform the tests.

Calibration and Maximum error of the Dynamometer

System calibration was performed using nine standard masses of 0.5kg up to 4.5kg, with intervals of 0.5kg. For each load three measurements were carried out, and displayed by the multi-panel indicator. The acceleration of gravity was g= 9.79117 m/s^2. The value used as a constant correction was obtained by the average of three measurements. The average value of 0.0815 was inserted into the multi-indicator panel. The estimated maximum error was ± 0.5 N.

In Vitro Test

Collection and selection of teeth

This research project was submitted to the Committee of Ethics (Nº 1090). To prepare this study we selected 10 healthy human third molars, with shape and size with first or second molars. The teeth were stored in a 0.1% thymol -containing solution, to prevent bacterial growth.

The root portion of teeth was scraped off with the help of periodontal curettes (Hu-Friedy, Chicago, IL, USA) and cleaned with rubber cups impregnated with a slurry of pumice and water. After cleaning, the teeth were inspected with a stereomicroscope (Carl. Zeiss, Göttingen, Niedersachsen, Germany), with 20x magnification, in order to exclude teeth with cracks, defects, and structural changes, which could compromise the results.

Cavity preparations

The cavity preparations were made for full crown with chamfer margins, with 1.5mm axial occlusal reduction and 2mm. These were performed with tapered round end diamond points (# 4137, 4137 F and 4137 FF, KG Sorensen, Barueri, SP, Brazil). The points were replaced every five preparations by new ones, to maintain the efficiency of cutting. All preparations were carried out with slight pressure and copious air / water coolant to avoid heating of the dental structure.

For polishing the preparation,, silicone, rubber and silicon carbide mounted points were used (Vigodent SA Industry and Commerce, Rio de Janeiro, Brazil, Batch 002/09).

Then, each tooth was submitted to impression technique with silicon single step addition of putty consistency (Virtual, Ivoclar Vivadent, Schaan, Liechtenstein, Batch JL 4169) and light-body consistency silicone (Virtual, Ivoclar Vivadent, Schaan, Liechtenstein, Batch HL 4133).

Manufacturing of ceramic crowns

The clinical and laboratory steps for the fabrication of the crowns, using the injection system (IPS Empress 2), are explained in Table 1.

Laboratorial steps	Technique/Material
Impression	Simultaneous technique Heavy and light body silicone (Virtual, Ivoclar Vivadent)
Gipsum dies	Special type 4 stone (Tuff Rock, Talladium of Brazil)
Spacer	Approximately 40µm using a die spacer (Die Spacer, Talladium of Brazil)
Ceramic	IPS Empress 2 ingots (Ivoclar Vivadent)
Sintering/Glazing	Sintering (EP 5000, Ivoclar Vivadent) Washing liquid (IPS e.max Glaze, Ivoclar Vivadent)

Table 1. Main laboratorial steps for fabrication of the ceramic crowns.

After accomplishing the preparation of 10 crowns, the cementation procedures and the evaluation of the film thickness were initiated.

Internal adjustment

For internal adjustment the of each crown was used silicone low viscosity (Tokuso Fit Tester, Tokuyama Corp. Dental., Tokyo, Japan, Batch 012087). After manipulation according to the manufacturer's instructions, the material was taken to the interior of each crown with a brush. Each crown with the silicone was immediately adapted on their respective preparation and kept under digital force for 3min. After polymerization, each crown was carefully removed from the preparation, and the intaglio aspect of the crown with the silicone film was evaluated. The contact areas were identified by transparency or the discontinuity of the film. Thus, these areas were marked with graffiti # 0.5. The film was removed, and the points of contact, were removed with a spherical diamond tip # 1013, mounted in high-speed under refrigeration. The process was repeated twice for all the crowns.

Adaptation of the teeth to the manikin

For each natural tooth root portion was made similar to a homologous of the manikin plastic (Prodens Top , Carapiá Industry and Commerce of Products Dental Ltda., São Gonçalo, Rio de Janeiro, Brazil). According to the anatomy of the tooth, the homologous of the manikin was selected to serve as a copy, following the exposed in Table 2.

Tooth identification	Anatomy	Position in the mannikin
A, E	Left mandibular second molar	37
B	Left mandibular first molar	36
C, J	Left maxillary first molar	26
D, G	Right maxillary second molar	17
F, I	Right mandibular first molar	46
H	Right maxillary first molar	16

Table 2. Distribution of the teeth by anatomy and position in the mannikin.

The impression of tooth root portion of the plastic was carried out with silicone addition medium consistency (Virtual, Monophase Fast Set, Ivoclar Vivadent, Schaan, Liechtenstein, batch NL4008), injected into a plastic bottle. Then the root portion of the manikin tooth was inserted at the center of the vial. After polymerization of the silicone, the tooth was removed from the impression and it was filled with acrylic resin (Dencrilon, Dencril Commerce of Plastics Ltda., Pirassununga, Sao Paulo, Brazil) (Figure 3).

The root portion of the natural tooth has been adapted to the impression filled with the acrylic resin, so that the gingival margin of the preparation was placed slightly above or at the level of plastic gingiva of the manikin (Figure 4).

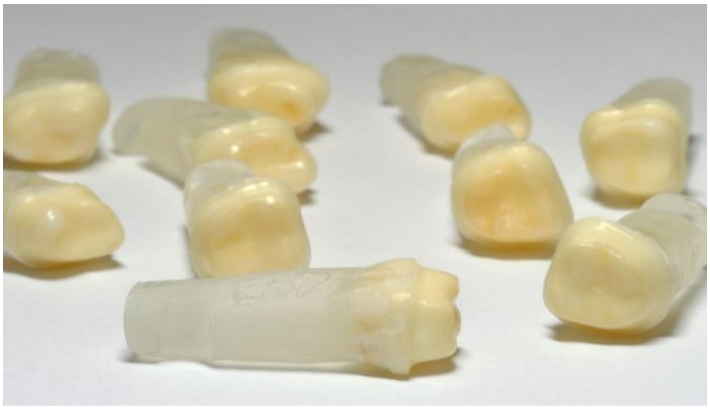

Figure 3. After the cavity preparations, the natural teeth were embedded in self-curing acrylic resin to simulate the root portion.

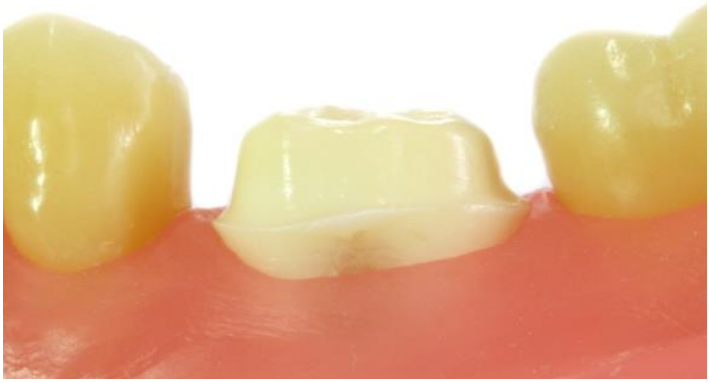

Figure 4. Buccal view of tooth "B" placed in the manikin.

Cementation

Prior to accomplishing the cementation steps a few adjustments were carried out on the manikin (Prodens Top , Carapiá Industry and Commerce of Products Dental Ltda., São Gonçalo, Rio de Janeiro, Brazil). It was necessary to attach two metal plates in the region corresponding to the condyles of the mandible until the rami to avoid the displacement of the mandible during bite, by interposing of the dynamometer.

An acrylic resin with a metal flip was attached to the lower pin of the jaw to allow a cushion for the bolt of the chin of the patient simulator. By turning the screw against the flip, the jaw was moved against the maxilla, similar to the function of the jaw elevator muscles.

Cementation with controlled force

The cementation was performed using the dynamometer for standardizing the force of cementation. Initially the crown was placed in the corresponding cavity preparation (Figure 5) and marginal adaptation was analyzed in terms of possible in-

terference on proximal contacts that could interfere with the adaptation, considering that the internal adjustment was performed previously.

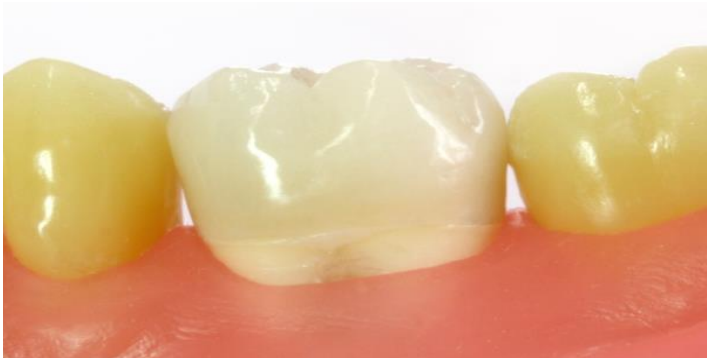

Figure 5. Buccal view of the ceramic crown and tooth "B" placed in the mannikin.

Next, the manikin was attached to the patient simulator, and the flexible mask has been adapted. For the cementation simulation, it has been selected a specific addition silicone (Tokuso Fit Tester, Tokuyama Dental Corp., Tokyo, Japan, Batch 012087). Equal parts of the base and catalyst pastes of the silicone were dispensed. A digital chronometer was used to tracking the time of handling, insertion and polymerization of the silicone. The PVS material was mixed for 20s using a #24 spatula (DUFLEX, SSWhite, Rio de Janeiro, Brazil). The crown was filled with freshly manipulated PVS material and was immediately adapted to the respective tooth Following, the tip of the dynamometer was inserted into the oral cavity, and the tip with silicone protection was placed on the ceramic crown.

The lifting of the mandible was performed by threading the screw (Figure 6). The act of screwing continued until the multi-panel dynamometer indicate approximately 20.00 N (Figure 7). Time spent from the beginning of manipulation to the final threading of the screw was about 40s. Excesses of light silicone Tokuso Fit Tester were removed with a brush (Figure 7). The handle of the tip was kept stable for 3min. Then the screw was losen to lower the mandible and the tip dynamometer, flexible mask and manikin were removed from the patient simulator. The natural tooth was removed with the ceramic crown. Carefully, the crown and the film were removed from the tooth.

Cementation with manual force

To perform this step, three evaluators were asked to contribute - graduated for more than five years, with majors in dentistry or dental prosthesis and master's degrees in dentistry.

A single operator manipulated equal parts of base and catalyst pastes of the silicone for 20 seconds. Immediately, each crown was filled with this material and seated by the new evaluator on their respective prepared tooth. Each evaluator applied manual force, in their usual clinical routine (Figure 8). The evaluator was also guided to maintain the force for 3 minutes and to remove excess silicone from the buccal and palatal surfaces.

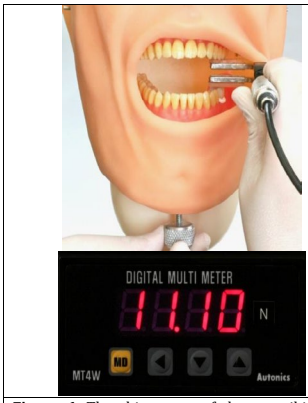

Figure 6. The chin screw of the mannikin was tightened until reaching a value next to 20 N. This step was monitoramento at the digital multi-indicator panel of the dynamometer.

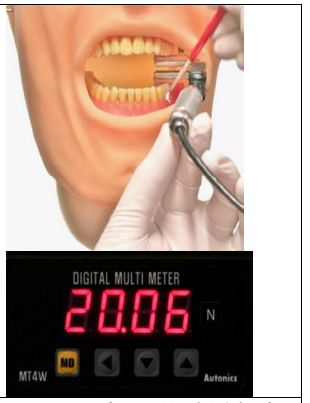

Figure 7. Upon reaching a 20N (±0,5N) value, tightening was ceased and excess of silicone was removed with the aid of a brush. The force was maintained stable for 3 minutes.

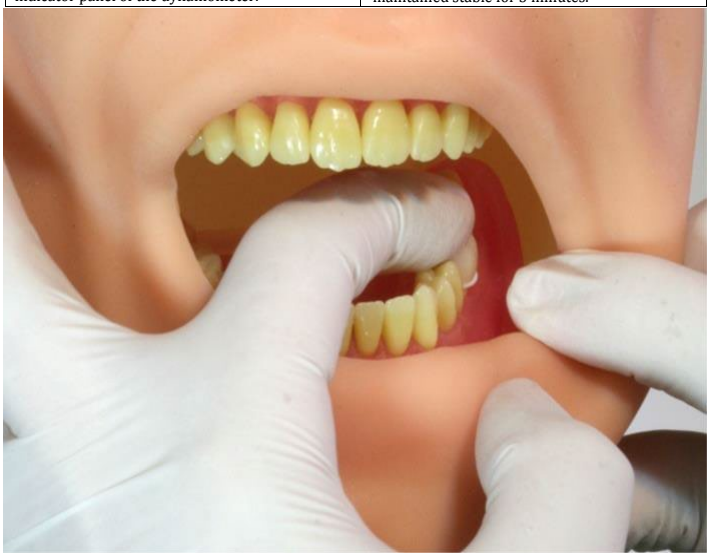

Figure 8. In Group B, the ceramic crown was maintained under manual (digital) force for 3 min.

Because of the short time of polymerization of the silicone any excess of the interproximal has not been removed and, therefore no floss or yarn were not used. The flexible mask and manikin were removed from the patient simulator. The natural tooth was removed with the ceramic crown in position. Subsequently, the crown, with the film was carefully removed from the tooth.

Obtaining of silicone replica

For the capture and stabilization of the silicone film a medium consistency addition silicone was selected (Virtual Monophase Fast Set, Ivoclar Vivadent, Schaan, Liechtenstein, Batch

NL4008), because of its dark-blue color, which contrasted white color of Tokuso Fit Tester. This difference in color facilitated the subsequent measurement of film thickness. The body consistency addition silicone was injected into one of the cutting devices specially designed to standardize the sections in mesial-distal and buccal-palatal directions (Figure 9). Then, the silicone was injected with the same auto-mixture tip on the film of Tokuso Fit Tester, which is still adhered internally in the ceramic crown (Figure 9). The filled crown was inserted into the cutting device containing blue silicon.

Figure 9. A regular body consistency silicone (Virtual Monophase Fast Set, Ivoclar Vivadent) was injected firstly inside the metal device, then inside the crown.

After 5 minutes, the ceramic crown was removed, the film was adhered to the Fit Tester silicon Virtual Monophase Fast Set and a new injection of the same silicon was performed to complete the inclusion of the film. After further 5 minutes, the external labels of the device were transferred to the exposed silicon. The identification was made by the initial letters of the corresponding face on the external sides and the letter of the tooth/crown assembly in the center.

After the polymerization, transversal cuts were made in the replica, which was previously stabilized in the metallic device (Figure 10), in the buccal-lingual and mesio-distal directions, using a #22 scalpel blade (Feather Safety Razor CO., LTD., Osaka, Japan, batch # 06010850) Figure 11.

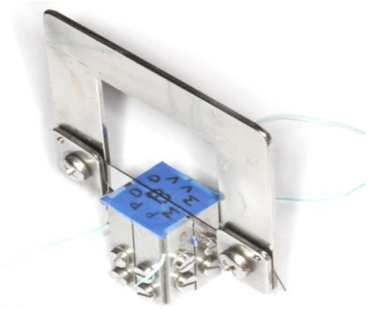

Figure 10. Sectioning the replica in the mesio-distal direction.

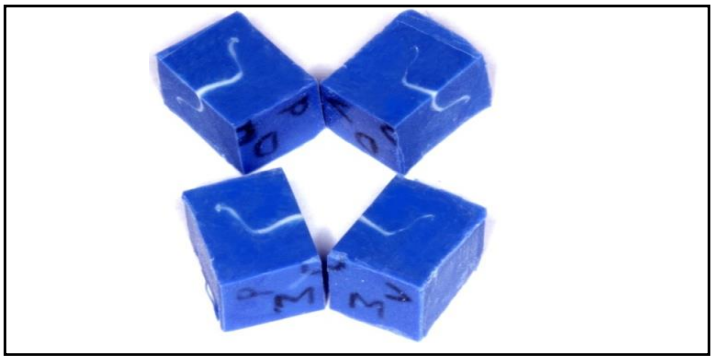

Figure 11. View of the replica after the removal of lateral excess.

Measurement of film thickness

Images of the cervical (4 sites), axial (4 sites) and occlusal (2 sites) regions were obtained from each of the four segmentos – buccal, lingual, mesial and distal, 24h after the fabrication of the replicas, using an optical microscope (Leica DM 4000M, Leica Microsystems, Wetzlar, Germany), with 2,088 x 1,550 pixels resolution and 50x magnification.

An image analysis software (Image Tool 3.0 for Windows, University of Texas, Health Science Center San Antonio, Texas, USA) was used for measurement of the film thickness.

For each section of obtained from cutting in the buccolingual direction, three measurements were made at five different places of the film length. Three more measurements at five different locations were made for sections obtained from mesio-distal sectioning, at the same locations of measurement. Thus, 30 measurements were performed for each crown. The mean of three measurements was considered as the final value for each location.

Data obtained were plotted using a spreadsheet software (Excel 2008, Microsoft Office) and the statistical analyzes were performed using a statistical package (Statistica 8.0, Statsoft, USA) ($p \leq 0.05$).

Results

To evaluate the internal adaptation, the mean from three individual measurements of film thickness was obtained in different regions (cervical, axial and occlusal).

The statistical analysis of the groups was performed considering the values of the cement film thickness in micrometers (μm). Firstly, data were submitted to Kolmogorov-Smirnov test to verify the homogeneity of distribution.

Mann-Whitney test was applied to evaluate if there are statistically significant differences of values of film thickness between groups.

The p value was higher than 0.05 for all conditions, revealing that there are no statistically significant differences between the manual and experimental methods.

Figure 12 presents the results of the mechanical technique and three manual techniques.

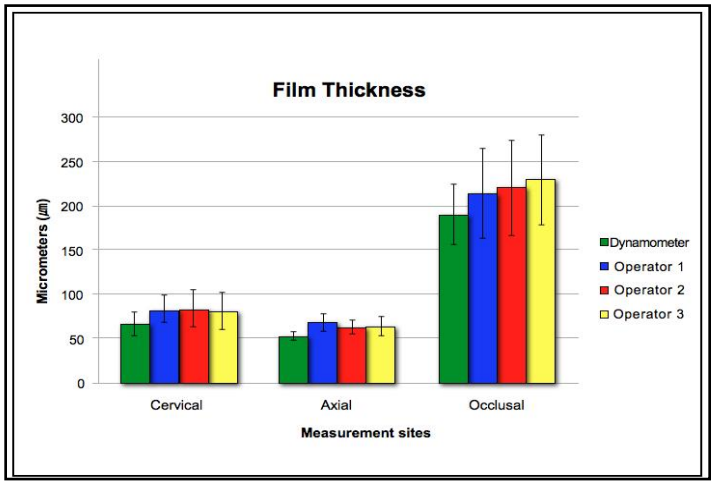

Figure 12. Film thickness (mean and standard desviations), according to measurement sites (cervical, axial and occlusal) and cementation techniques (dynamometer and manual). Vertical lines represent the data dispersion.

Discussion

Cementation is the crowning moment of all the previous steps and what makes it so important is that it cannot be repeated without prejudice to the restoration. This importance justifies the several studies that led to the development of new materials and techniques of cementation. Nevertheless, the cementation continues to be a critical and stressful step for the dental team [2].

In clinical terms, the cementation of ceramic restorations is accomplished by a force exerted by the fingers of the professional. In this technique, this included a plethora of variables such as experience, the mood of the professional, position of the tooth in the arch, the patient's position in the chair, patient cooperation and interference of soft tissues. These individual factors, or in combination, may be sufficient to produce poorly adapted restorations, bascule movement, cracking or even fracture of the ceramic restoration.

Determining and standardizing the weight values or the strength of cement is a fundamental requirement in vitro study, because it interferes directly on the film thickness of the cement [3-5, 7-14,19,20]. However, in vivo studies, the concern to standardize the values of weight or the force of cementation is rare. In the vast majority of clinical evaluations, it is up to the professional to determine the force applied for seating the indirect restoration.

A way to eliminate or even attenuate these multiple variables is the primary objective of this study. The idea to standardize and stabilize the cementation force was based on the clinical control the force exerted by the bite of the patient. For this it was designed and developed a device to measure the bite force of the patient and show the value in real time through the digital display. With it, the patient can control the force exerted by his bite and to determine and maintain the established value.
Different from the dynamometers already proposed by the scientific literature the device developed in this research aimed to standardize the initial force of cementation of ceramic restorations on their respective abutment teeth, for use in clinical situations [21-29]. Parallel to this initial goal, other benefits were achieved.

Excessive force during cementation can be detrimental to the ceramic structure. Damage such as internal cracks or even fractures may be overlooked during cementation and cause premature failure of the restoration. On the other hand, insufficient force may cause misadaptations that, in turn, will demand or increase the amount of adjustment of occlusal interferences, making the restoration more brittle by the inclusion of microcracks, which are inherent to adjust. Moreover, the adjustment can reduce the thickness of ceramic, compromising the clinical performance of the restoration. The cementation technique with the aid of the dynamometer developed is able to reduce these undesirable situations, by the control and standardization of the force of cementation.

In the conventional cementation, after the insertion of the restoration previously filled with the resin cement, the professional should: a) carry out and maintain the force of cementation with a hand while, with the other hand, must perform the removal of excess with disposable applicators and / or manual tools; b) remove the interproximal excess with dental floss c) check the adjustment of margins, and d) perform the light curing. Generally, the professional needs an assistant to perform the tasks, and regardless of the skill, he/she lacks the professional training to detect and solve possible complications. Further, this would demand an unreachable stability hands-free the application of force during cementation by the operator. Thus, using the dynamometer facilitated this procedure, which is one of most important – the adhesive cementation. In addition to reducing or even eliminating the dependence on the assistant, the instrument releases both hands of the dentist so he/she can remove excess cement, evaluating the marginal adaptation, remove the retraction cords and also perform light curing, because the handle of the dynamometer tip can be operated by the patient based on previous instructions.
One feature of the adhesive cementation is the great variability of film thickness of the materials used [16,30]. Another com-

plicating factor in relation to the film thickness is the variability of presentation of these materials: filled and unfilled adhesive systems; conventional, and self-adhesive resin cements, low viscosity composite resins, heated composite resins, and also chemically or physically activated, or the combination of both modes, which is known as dual-activation. In each type of material there is a variety of manufacturers and between the products of the same manufacturer. Recently, some authors have recommended the use of composite resins for adhesive cementation [17,18]. Although these resins may provide greater strength and less polymerization shrinkage, there are questions about the values of film thickness when using composite resins [31]. According to CHIEFFI et al., [32], in addition to the selection of a composite resin heatable composite resin, a plausible solution to reduce the film thickness may be the application of a consistent force of cementation by the operator for a longer time to allow the flow of composite resin along the margins of the indirect restoration. The use of the dynamometer allows greater seating time, which is very relevant for the cementation using composite resins, as this may provide higher leakage of excess cement and lower film thickness.

To prevent the destruction of crowns and teeth, in this study it was used a replica technique for obtaining the film. Some studies have demonstrated the effectiveness of the technique for evaluating the film thickness without the destruction of the specimens [4,9,19,20,33-43]. The same technique was used for the internal adjustment [44-48].

The force value which was established in this study (20N ± 2.040kgf) was based in the works of Nakamura et al. [10,11], Reich et al. [19] and Barbosa [7], that used a 20N force for seating indirect restorations on abutments using addition silicone (Table 1). According to Wilson et al. [13] and Wilson [12], low-viscosity silicones present a viscosity of 10.6Pa, which is similar to the viscosity of freshly-mixed zinc phosphate cement (0.3cm^3 of liquid per 0.8mg of powder). However, it was not established until today a standard viscosity for resin cements [16].

When compared to the conventional technique, the cementation technique using standardized cementation forces did not show statistically significant differences. However, when the mean values of the group with standardized cementation force is compared to the groups with manual cementation (86.48µm againt 103.58µm, 103.05µm and 104.49µm) it was observed a trend for lower film thickness and ultimately a better adaptation for that group.

A possible reason for the lack of statistical diferences is the number of groups and the type of ceramic used. In this work, IPS Empress 2 was used for the infrastructure and IPS e.max Ceram for veneering the restorations. To avoid possible fractures of the restorations which could compromise the study, it was chosen to perform simulations of the cementation.

Further studies using zirconia based restorations and additional groups for conventional and standardized cementation tecnhiques are suggested, with the same professionals for both conditions considering that the equipment is easy to use.

Conclusion

Within the limitations of this study, it can be concluded that:

a. The film thickness of the restorations were similar, regardless of using or not the dynamometer during the cementation, ie, compared to the group of conventional technique using manual force. However, lower film thickness was observed when the dynamometer was used to help the cementation.

b. The proposed technique for standardized force help the cementation, decreasing the dependence on the dental staff and releasing the professional‘s hands to remove excess, check the margins, and stabilization of the indirect restoration, including during the light-activation.

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