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EFFECT OF THE LINGUAL MARGIN CONFIGURATION ON THE FRACTURE STRENGTH OF CLASS IV RESIN BASED COMPOSITE RESTORATIONS UNDER STATIC LOADING

by

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of the requirements for the Master of Science
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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

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has been approved by the Examining Committee for
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To my children Daniel and Sara, two Angels who have witnessed this journey with their love, patience and joy.
To my parents and siblings who from the distance brought me support and wisdom with their unconditional love.

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ABSTRACT

Resin-based composite for Class IV restoration is a conservative alternative for maxillary incisor fracture. Little is known about the effect of lingual margin configurations on the longevity of these restorations. This *in vitro* experiment compared the mean fracture strength among four lingual margin configurations (butt joint, 45˚ bevel, 60˚ bevel and chamfer) for Class IV resin-based composite restorations. A total sample size of n=100 human extracted lower incisors were selected, then the teeth were randomly assigned to one of the four lingual margin configuration groups (n=25) and restored with resin-based composite. After thermocycling (5000 cycles, 5°C-55°C with 30 seconds dwell time), they were subjected to inter-incisal static load (135˚ angulation) until failure (N). Failure mode was determined. In vitro fracture strength was compared among the four groups using one-way ANOVA at alpha=0.05. Mean standard deviation of fracture strength and frequency distribution of failure modes were reported.

Results revealed no significant effect on the fracture strength for the type of lingual margin configurations (F(3,96)=0.13; p=0.9435). The data showed that 71% of failure modes resulted in complete tooth fracture (intact restoration), 11% in total adhesive failure, 7% in adhesive only facial, 6% in total cohesive, 4% in cohesive only facial, 1% in avulsion. Fischer’s exact test revealed no statistically significant association (p>0.05) between the margin configurations and failure modes. Within the limitations of this study, it can be concluded that any of the four lingual margin configurations are acceptable in Class IV preparation in terms of fracture strength under static load.

PUBLIC ABSTRACT

Dentistry includes restoring teeth for both esthetics, and function. In cases of upper teeth chipping, the dentist offers different treatment options including the use of resin material that is bonded to the remaining tooth structure. In order to improve the retention of the material, a tooth preparation is required, including smoothing margins and beveling the edges. Little is known about the longevity of these restorations related to the different bevel preparations. This study compared the fracture strength among the four types of bevels that retained the resin composites on upper anterior teeth. One hundred teeth were selected and then divided into four experimental groups (twenty-five teeth per group). Teeth were subject to thermocycling and static forces until they broke. Fracture strength and failure mode were recorded and compared. There was no difference in fracture strength and failure mode among the four designs for bevels. This study concludes that the proposed margin configurations to restore upper human incisors with resin did not affect the fracture strength.

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CHAPTER I

INTRODUCTION

Human maxillary incisors accomplish both esthetic and functional requirements of the anterior guidance. Anatomic structures on upper incisors play an important role during this dynamic scheme. The incisal edge is the active and functional area where eccentric anterior movement depicts the protrusive pathway, following the length of the maxillary incisor tooth as a pattern that guides the movement of the mandible (Heinlein, 1980).

When the patient experiences anterior tooth fracture, this biomechanical complex could be interrupted and create a non-functional pathway. Incisal edge fracture is a frequent problem in restorative dentistry, especially among the younger population. Depending on the fracture mode, different restorative options are applicable in modern dentistry to replace this missing segment of the tooth. These restorative procedures must follow biological and biomechanical requirements to provide longevity and adequate function, without altering the natural occlusion of the patient. Different treatments for anterior teeth fractures have been proposed in the literature, such as: fragment rebonding, full crowns, veneers and Class IV resin based composites (Stellini, Stomaci, Stomaci, Petrone, & Favero, 2008),(Coelho-de-Souza, Camacho, Demarco, & Powers, 2008). The range of these restorative options includes both indirect and direct techniques. One of the most common alternatives in modern restorative dentistry is the Class IV resin based composite restoration; this technique is affordable for the patient, and the biomaterial can satisfy both the esthetic and functional needs of incisors.

Limited clinical trials in Class IV direct restorations have been reported in the literature. Van Dijken and Pallesen (2010) conducted a 14-year longitudinal follow-up study by comparing resin based composite material and resin modified glass ionomer for Class IV restorations. Results revealed in this study that resin based composite material showed the lowest failure frequency compared with glass ionomer material. Van Dijken and Pallesen (2010) claim that the use of adhesion can improve the retention in a more conservative approach compared with mechanical retention (i.e. the use of bevels). However, information in this paper is limited regarding the type of bevel and its location (facial or lingual).

On the other hand, in a retrospective cohort study conducted by Alrefeai et al (2015) the median and mean survival time of Class IV composite restorations is 7 years and 8.9 years; the Kaplan Meier survival rate was 29.7%. Authors obtained information from electrical health records from a dental academic institution; for these reasons, information like margin configurations specifications and type of resin based composite were not available in the records.

Fracture and chipping of the restoration under stress on the incisal edge is reported in previous studies. In contrast to van Dijken and Pallesen (2010), other authors state that one of the possible reasons for chipping is the lack of mechanical support on the restoration (Xu H, 2012) (Coelho-de-Souza et al., 2008). Since Class IV restoration requires macro and micro mechanical support, factors have to be considered when designing the preparation, including: occlusion pattern of the patient, tooth substrate, adhesive protocol, adhesive system, and retentive design.

When considering retention for direct restorations, the margin configuration could play an important role to improve the support of the material and also provide satisfactory esthetics. Bevel architecture is part of the margin configuration of the tooth, and different angulations during the tooth preparation include 30°, 45° or 60°(Coelho-de-Souza et al., 2008) (University of Iowa, 2010).

In-vitro studies by Coelho-de-Souza et al (2008), Stellini et all (2008) and Xu et al (2012) have been conducted to evaluate the fracture strength and stress distribution on specific margin preparations including facial chamfer, butt joint and different facial bevel designs.

Coelho-de-Souza et al (2008), Xu et al (2012) all agree that beveling preparations on facial can improve the fracture strength of anterior resin based composites. However no previous studies in the literature have compared specifically lingual bevels and their effect on the fracture strength of resin based composites on human incisors when they support interincisal loads.

Purpose of the Study

The purpose of this *in-vitro* study was to compare the mean fracture strength among four lingual margin configurations for Class IV preparations (butt joint, 45° bevel, 60° bevel and chamfer). Human extracted incisors were sectioned and restored with resin based composite (Filtek ™Supreme™ Universal Restorative, 3M ESPE). The specimens were subjected to aging and controlled static loads on the average human interincisal angulation of 135°. The outcome of failure was measured by the force in Newton.

Furthermore, the possible association between the margin configuration and the type of failure modes were evaluated. The projection of this study, including method and findings, can direct a new understanding of the mechanical behavior of the complex tooth-restoration when it is subject to anterior occlusal loads and different margin configurations. This investigation opens new possibilities to further studies of biomechanics of bevels in adhesive dentistry when they are integrated to simulate human occlusion.

Research Hypotheses

Null Hypothesis 1: There is no significant difference in fracture strength among the four lingual margin configurations in Class IV resin composite restoration under static loading.

Null Hypothesis 2: There is no association between the types of lingual margin configurations for Class IV resin based composite restorations and the failure mode.

CHAPTER II

LITERATURE REVIEW

Tooth Structure

Enamel

Enamel is a mineralized and crystalline tissue. It is the external layer that protects the anatomic dental crown. This tissue is found to be the hardest complex of the mammal species (He & Swain, 2008). Mature enamel is composed of 96% mineralized tissue, 1% organic minerals and 3% water. The mineralized tissue is composed of hydroxyapatite rods that are oriented to have the capacity to withstand occlusal forces. The mineral composition also contains small amounts of carbonate, magnesium, sodium, fluoride and potassium (Bath-Balogh, Fehrenbach, & Thomas, 1997). When a light beam is directed towards the enamel, it shows rods oriented in band shapes or rod groups called Hunter-Schreger bands (Avery & Steele, 2000). Enamel is the hardest tissue of the human body, and has the physical properties of brittleness and low tensile strength and high elastic modulus. In conjunction with the dentin enamel is capable of withstanding occlusal forces and lowers the probability of mechanical failure. The orientation of the enamel rods is relevant for load absorption and distribution and contributes to the resistance of dentin-enamel tooth substrate.

According to Berkovitz (2009) the hydroxyapatite rods are formed by crystallites which are 70nm width and 25nm thick. The geometric shape of those crystallites is hexagonal in cross-section.

The orientation of the enamel rods begins at the dentinoenamel junction towards the external surface. Each rod is composed of four ameloblasts in the following distribution: one ameloblast is at the head of the rod, two ameloblasts are in the neck, and the fourth ameloblast is located in the tail. The rod has an external layer called the rod sheath, which surrounds the core (Avery & Steele, 2000). The distribution of the enamel rods has three pattern in human enamel: in pattern I the shape is circular, in pattern II the rods are parallel, and in pattern III the rods are distributed in alternating rows (Berkovitz et al., 2009).

The organic material composition consists of 1-2% organic matrix including amino acids (glycine and glutamic acid) and proteins (amelogenins and enamelines). The highest amount of protein is deposited in the enamel tufts at the dentinoenamel junction. These tufts are microscopic structures of the enamel appearing as an “anomaly” of the crystallization that lack clinical significance (Bath-Balogh et al., 1997).

Dentinoenamel junction

The connection zone between enamel and the dentin is known as dentinoenamel junction (DEJ). This interface line takes different shapes depending on the anatomic area. A scalloped-like shape is found in areas where occlusal forces are directed. In proximal, buccal or lingual surfaces the dentino-enamel junction is smoother. The structures that are located in the DEJ are: tufts, lamellae and enamel spindles. Tufts are hypomineralized irregular structures located in the enamel area of the DEJ. Lamellae are histological defects that extend along the enamel, but can be observed only in a cross-sectioned cut. Spindles are also irregular deficiencies of enamel that are misaligned with the enamel rods.

These spindles are thought to be odontoblastic processes that were retained in the enamel during its formation (Avery & Steele, 2000; Berkovitz et al., 2009).

Dentin

Dentin is also a mineralized structure, which encompasses the extension of the tooth. Provenza (1988) describes the dentin as a "hard connective tissue", composed of collagen, proteins, glycosaminoglycans, and hydroxyapatite. Dentin is a complex tissue, which is not exposed to the oral environment in normal clinical conditions. This structure is composed of 70% inorganic matrix, (calcium hydroxyapatite crystals), 20% organic materials and 10% water. The hydroxyapatite nanocrystals contain carbonate, fluoride, and minimal amounts of calcium. Their distribution goes into the collagen fibers (Berkovitz et al., 2009) with a dimensional measurement 20nm and 3.5nm thickness. The scaffold of the dentin is composed of mineralized collagen disposed in parallel alignment crystals that extend along the main axis of the fibrils. Dentin and enamel crystals are both similar and are oriented parallel to each other (Fang, Lam, & Beniash, 2011). The dentinal tissue initiates its perpendicular extension from the pulp, extending along the dentin to the DEJ.

Dentinal tubules are complex structures in the dentinal tissue; their average diameter is 1µm near the DEJ and 1.5 close to the pulp tissue. The average of number of tubules in the dentin is around 20,000 to 60,000 tubules per mm^2, increasing in number with proximity to pulp. These tubules are covered by mineralized dentin known as peritubular dentin (Ryou, Romberg, Pashley, Tay, & Arola, 2012).

Peritubular dentin does not have collagen fibrils, but is composed of phosphorylated proteins, glycosaminoglycans, and proteoglycans (Bertassoni, Marshall, & Swain, 2012).

Dentin tissue is also composed of intertubular dentin. This tissue contains mostly organic matrix and is less mineralized than peritubular dentin (Bertassoni et al., 2012) Intertubular dentin is composed mainly of 90% collagen fibrils, classified in two main groups: Major fibrils (Types I, II, and III collagen) and Minor fibrils (Types V and XI collagen which are expressed in odontoblasts). Collagen I and II are the most predominant type in dentin (Hamada et al., 2010). Proteolytic enzymes are also embedded in the organic matrix, including Matrix metalloproteinase (MMPs). These enzymes have been found in dentin and odontoblasts and are directly related to resin based composites degradation (Perdigão, Reis, & Loguercio, 2013; Tjaderhane et al., 2013). The difference in composition of both peritubular and intertubular dentin has a biomechanical implication due to the gradient of elastic modulus based on the amount of mineral and organic content. This discrepancy could affect some mechanical behavior in restorative dentistry. This heterogeneous disposition provides the dentin anisotropic behavior. This condition refers to the ability of one tissue to provide heterogeneous physical response within its microstructure due to the gradient of elastic modulus and the orientation of the forces applied. Due to the fibrilar distribution of the collagen scaffold in the dentin, the force transmission differs from peritubular and inertubular dentin; peritubular dentin is highly mineralized, however it is shown to have an elastic behavior gradient on forces when compared to intetubular dentin. One of the possible explanations is the presence of two zones in the orientation of the collagen fibrils.

This fibrilar disposition shows two zones at a nanoscale: gap zones and overlapping zones in-between the fibrils; these two zones allow the collagen distribute in heterogeneous disposition with consequent mechanic dissimilarities (Bertassoni et al., 2012).

Pulp tissue

Human dental pulp tissue is a complex structure composed mainly of mesenchymal tissue and odontoblasts among other cell groups. This connective tissue is confined by dentin around its periphery. The odontoblastic process mantains the connection between the pulp and dentin tissue. Capillary and nerve supply both enter the pulp from the apical foramen and extend along the pulp canal, expanding towards the pulp chamber. Dental pulp is a regenerative tissue that reacts to a variety of injuries like chemical, bacterial, thermal or mechanical (Demarco et al., 2011). For that reason, a number of factors are involved in this response, including inflammatory, vascular or lymphatic. Additionally, time is a relevant variable during the inflammatory process, which makes an impact on the type of response and reaction of the pulp to the injury (G. Rex Holland & Botero, 2014).

The odontoblast is a post-mitotic cell which is highly reparative (Demarco et al., 2011). During the final phase of the dentinogenesis, the odontoblast initiates its embryologic development, until it becomes a highly organized cell capable of producing collagenous and non-collagenous matrix.

The odontoblast has a secretory function, creating mineralized secondary dentin throughout life (Demarco et al., 2011; G.Rex Holland, 2014). This cell contains a process that enters into the dentinal tubule and is responsible for transferring all complex sensory stimuli to the pulp (Arana-Chavez & Massa, 2004).

Anatomy And Function Of A Maxillary Incisor

The incisor tooth is trapezoidally shaped from incisal edge towards the gingival area; it is formed mainly by the following structures: facial ridges (mesial, central and distal), and facial grooves in-between the three ridges. The mesial and distal ridges form the line angles that play an important role in esthetics. On the lingual surface, this tooth is structured to provide an adequate functional pathway with lingual ridges (mesial and distal) separated by the lingual fossa (Nelson & Ash, 2010). The incisor teeth group is an important part of the masticatory system. This complex of teeth also acts as mechanical support for the anterior guidance, forming half of the functional occlusal system, In this system, mutually protected occlusion occurs as anterior and posterior protection: posterior teeth (beginning from premolars extending towards the last molars) protect anterior teeth when static loads such as closing or maximum intercuspidation occur; for instance, the anterior group protects posteriors when dynamic loads such as protrusion, laterotrusion and laterality occurs in the patient (Dawson, 2007).

The three main components of anterior guidance in the upper incisor teeth are: the facial contour, the lingual contour and the incisal edge. The facial contour acts as lip support and is essential for esthetics in the patient smile. The lingual contour is the functional aspect of the tooth, because the lower incisor edges slide along the lingual ridges of the upper teeth, depicting a protrusive functional pathway. The incisal edge integrates both esthetics and functional aspects. Esthetics is influenced by texture, shape, color and anatomy and function is reflected by phonetic activity of the patient (Heinlein, 1980). Maxillary incisors are more susceptible to fracture because of their position and inclination in the arch. They receive tangential undesirable forces from the opposing lower incisors that could lead to undesirable overloads or mechanical failure as fracture of the incisal edge (Sorensen & Martinoff, 1984).

Fracture Mechanics In The Upper Anterior Teeth

Since the incisor teeth provide both esthetics and function, it is important to understand their biomechanical properties based on histology and anatomy. Enamel is the hardest tissue in human beings. During its formation and maturation, a special protein known as ameloblastin is concentrated and deposited on the incisal edge. Ameloblastin, which is responsible for forming the enamel prism sheath, has an important function during occlusal loads: the irregular shape of the enamel prism helps protect enamel from cracks and protects the tooth from crack progression and possible clinical fracture. Enamel also has a small amount of water that serves to soften stress.

On the other hand, apatite crystals are able to absorb deformation, giving the enamel anisotropic characteristics because rods absorb the loads to varying degrees depending on the vector orientation. Dentin has both apatite crystals and collagen. For this reason, dentin has more elastic properties. Dentinal tubules, which play a mechanical role during masticatory function, also help by distributing the loads along the axis of the tooth (Hong, 2008).

Although both enamel and dentin can provide both elastic and anisotropic behavior, sometimes these complex structures are subject to failure due to overloads or para-axial loads, resulting in chipping or fracture of the tooth. According to Miura et al (2009) the cervical facial area is the most brittle part of the incisor tooth. Macrofractures are originated from microcracks that are present in the enamel rods and enamel sheath. This is also supported by Lee et al (2009) who state that micro cracks do not progress when they remain supported by the organic component of the dentin. Lee et al (2009)also suggest that the organic composition of enamel and dentin protects the tooth crack progression (Lee et al., 2009).

In clinical cases when the patient does not have adequate posterior support, all anterior vectors of forces are directed towards the lingual face of upper incisors, producing cracks or fractures over time. In those cases, the occlusal instability could turn chronically unstable and some anterior tooth wear is shown as a sign of overload (Okeson, 2003). However, unexpected tooth injury also occurs in patients, especially in young subjects (sports or automobile accidents). In a study by Gassner (2003), 9,543 patients were questioned to find the main cause of dentofacial trauma.

The authors revealed that dental injury occurred in 49.9% of cases. The five main causes for injury were: daily routine activities, violence, sports, vehicle crashes, and job accidents (Gassner et al., 2003).

Static Versus Cyclic Loads In Mechanical Tests

Mechanical *in vitro* studies in dentistry are part of the evolution of bioengineering applied to dental materials and tissues. The technology present in modern laboratories allows researchers to utilize calibrated equipment to simulate oral environmental conditions and their effects on materials and tissues. These tests promote a better understanding that can lead to improved physical properties of dental materials. Although research in dentistry allows micro tests to evaluate these physical properties in a small scale, macro tests also are part of the engineering component applied in dentistry (Armstrong et al., 2010). Macro mechanical tests are part of the field of research in engineering applied to dentistry and include: fracture strength, flexural strength, fracture toughness and fatigue test, among others. Programmed forces in laboratory studies evaluate the physical response of a tissue or material under certain conditions of load (Huerta, Corona, Oliva, Avilés, & González-Hernández, 2010). Different types of forces can be programmed to simulate the human masticatory system, taking in consideration the limitations of an *in vitro* study (saliva, bacteria growth and pH among others).

A universal testing machine is the equipment used mechanical engineering to test physical properties of materials. It is also used in dentistry to evaluate forces applied to hard tissues and biomaterials. Programmed loading schemes can be applied on a determined object to analyze the physical response of the tested object under this scheme of vector of forces (i.e. magnitude, frequency and orientation). Universal testing machines include time as one variable to determine the type of experiment and the outcome. A static loading test refers to a one specific load application experiment in which the vector of forces is applied on the object until it fails. This static load is programmed on a certain speed. By contrast, cyclic load is a time-dependent test in which established number of cycles, load intensity (minimum and maximum) and speed are variables that have to be controlled. The main difference is the outcome: in static load the outcome is Newtons to fracture, and cyclic load test (fatigue test) the outcome is failure at determined cycle of load (Berkovitz et al., 2009).

Research in dentistry utilizes static and dynamic tests as part of laboratory experiments. Combination of mechanical experiments can help the investigator and dental materials manufacturers evaluate important aspects of dental materials and tooth structure and their mechanical properties. In order to claim that a material is considered adequate for clinical trials, it is necessary that *in vitro* experiments can be conducted previously, to test all possible outcomes and variables under controlled conditions. Studies have been reported in the literature regarding fracture mechanics for dental materials and dental hard tissues (Bajaj, Sundaram, & Arola, 2008; Koottathape, Takahashi, Iwasaki, Kanehira, & Finger, 2014; Kotousov, Kahler, & Swain, 2011).

Considering the outcome and the design of each study, the material and/or tooth specimen can be tested and subject to multiple challenges. Authors like Poitevin et al(2010) and Scotti et al(2011) compared static loads versus cyclic loads to evaluate some physical properties of dental materials. Other challenges can be applied to the specimens like bacteria environment, pH changes and thermal cycles, among others. These additional challenges intend to simulate the human oral environment into the limitations of an *in vitro* test.

Literature presents studies where resin based composites have been subject to thermal challenges pervious to static forces tests to evaluate the fracture resistance (Gandhi & Nandlal, 2006; Pusman et al., 2010; Shafiei, Tavangar, Ghahramani, & Fattah, 2014).. This type of combined in vitro mechanical test was also proposed by Coehlo et al (2008) and Xu et al(2012) for Class IV resin based composite restorations bonded to human extracted teeth. Considering the integration of these two *in vitro* tests, this experiment design allows the investigator to evaluate the physical response and some properties of the tooth-restoration complex under critical conditions such as temperature fluctuations and controlled static forces. This type of study is one of the valid alternatives of mechanical test for dental materials and/or tooth structure. It could bring a better understanding of their mechanical behavior and physical properties as part of other *in vitro* experiments, *or* in some cases preceding future clinical trials.

Thermocycling For *in vitro* Experiments

Restorative dentistry requires constant research and evolution of dental materials. For this purpose, laboratory equipment can simulate and approximate oral environment conditions by using programmed cycles to test thermal changes on tooth structures and biomaterials. Besides macro and micro mechanical testing, thermal challenging is also part of the protocol for researchers to evaluate the properties of materials or the response of tissues under thermal conditions. Since both dental materials and tooth structure are subjected to thermal changes, researchers design and utilize thermocyclers in dental research to simulate changes of temperature and the aging process in the oral cavity.

These devices can be programmed to complete a specified number of cycles and can cool and heat. The sample alternates between two containers with hot and cold solutions at different temperatures controlled by a thermostat. Using these methods, dental materials and tooth structures can be evaluated, with the understanding of the limitation of an *in vitro* experiment. Thermal changes are part of mechanical tests, further challenging the material or tooth structure (Kamel, 2014). Some authors disagree with the use of thermocycling in resin based composite experiments, claiming there is dissolution of the adhesive (Hashimoto, 2010). However, Maryam (2013) revealed in an *in vitro* study that the bonding strength of 2-step adhesive systems is not effected by thermocycling. Fracture strength and thermocycling are two complementary *in vitro* experiments to challenge teeth or materials, as reported in the literature (Coelho-de-Souza et al., 2008; Gandhi & Nandlal, 2006; Stellini et al., 2008; Xu H, 2012).

Direct Restorations For Maxillary Incisors Fracture

Since upper incisor fracture is one of the most common reasons for seeking dental care, different designs have been developed in order to optimize esthetic results, but also to meet patients’ mechanical support and functional needs. Direct composite resin build up restoration is common in restorative dentistry. This procedure can give the patient final results in one appointment, with adequate cosmetic and functional results. The appropriate material for direct restorations is composite resin. It is composed of organic matrix with inorganic filler, which gives the material its strength.

Resin Based Composite Material

The first resin composite in the market was proposed by Bowen and was composed of BisGMA which has high viscosity and UDMA on the organic matrix (Byoung I., 2013).

Resin based composite is the most commonly used direct restoration in restorative dentistry. This dental biomaterial is composed of: organic matrix (polymer based), filler particles, initiators and a coupling agent. Organic matrix contains Bis-GMA (bisphenol-A-glydicyl methacrylate), UDMA (urethane dimethacrylate) and TEGDMA (triethylene glycol dimethacryclathe). Inorganic fillers consist of glass, zirconium and aluminum in order to improve physical and optical properties. This composition can differ between manufacturers, or depending on the purpose of the material for clinical outcomes (i.e. high esthetic results or higher wear resistance). The coupling agent is silane to induce adhesion between the inorganic and organic matrix. Resin based composite requires an initiator to induce the polymerization reaction under a visible light with a range of 460-480 nm wavelength. Resin composites can be classified depending on the filler particle size which can vary depending on the manufacturer and the fabrication process.

Its physical and optical properties also can differ from one size of filler to another. Besides the particle size of the filler, other components can be modified among the available resin based composites in the dental materials industry (Summitt, 2006).

For anterior teeth restorations, resin based composite material manufacturers provide possibilities in terms of adequate optical and physical properties, including biocompatibility as well. Microfill and nano-particle reinforced resin based composite can be acceptable for restoring Class IV direct restorations. However, nano-particle reinforced composite provides better physical properties by increasing the Young modulus because the addition of the nano-clusters. According to Hua (2013), by only adding 5% volume fraction of nano-particles to the organinc matrix of the composite resin, the Young modulus could increase 9.9%. It can explain the capacity of this material to withstand the occlusal forces through distributing the load within the matrix, nano-particles and nano-clusters (Hua et al., 2013). By contrast, microfilled resin based composite material offers adequate optical properties due to the size of the glass particle, which provides excellent light reflection, letting the polishing procedure yield satisfactory esthetic results. However, in terms of mechanical support, this particle size and distribution in the polymer matrix is not able to withstand the occlusal forces as well as nano-particle resin based composite. This can lead to early wear of the restoration and short survival time compared to the nano-particle composite restorations. Under occlusal stress, the propagation of the crack differs from nano-particle and micrifill resin based composite. Nano-clusters deflect the crack, releasing the stress and increasing the capacity of withstand unexpected overloads (Watanabe, Khera, Vargas, & Qian, 2008).

Since microfill resin based composite lack clusters, propagation of the crack can take different directions, leading to higher stress and more probability of failure (Watanabe et al., 2008).

Filtek™ Supreme Universal Restorative material (3M ESPE, USA) is a resin based composite with a nano-particle structure ("3M ESPE's Filtek™ Supreme Ultra: offering clinicians exceptional strength, esthetics, and handling," 2013). The inorganic filler in the polymeric matrix is composed of quartz, silica glass nanomers with a range 5-20nm size (8%wt), strontium and zirconium. Also, it contains nano-clusters of zirconia-silica (71 wt%). This material provides a range of elastic modulus of 5-7 GPa (Vouvoudi & Sideridou, 2012). These particles are joined by covalent bonds, allowing the material yield excellent mechanical properties. This particular disposition of particles diminishes the interstitial space between the nano-clusters and nano-particles; for instance Filtek™ Supreme Universal Restorative material (3M ESPE, USA) is adequate for anterior teeth restorations in cases that demand adequate mechanical support and satisfactory esthetic outcomes (Vouvoudi & Sideridou, 2012).

Adhesion

The term "adhesion" is defined as "*energy between atoms or molecules at an interface that hold two phases together*" (Summitt, 2006). Bonding or adhesion in dentistry began with Buonocore (1955) when he analyzed the use of phosphoric acid to bond paints and resins to metallic substrates. This discovery helped dentistry develop a new philosophy in restorative techniques. Traditional retentive methods described by Black (Henderson, 1961) as "extension for prevention" started to evolve to a new philosophy with scientific support. With adhesion, tooth preparations do not require retentive designs as described by Black (Henderson, 1961). Also, the restoration can be macro and/or micro retained, and bonding systems can improve micro retention and chemical bonding to substrate. After Buonocore (1955) discovered enamel adhesion, Fusayama complemented this adhesion philosophy adding denting adhesion as part of the bonding system between tooth and composite resin (Byoung I., 2013) (Summitt, 2006).

Berlotti (1991) presented his investigation about total etch systems in which enamel is etched at the same time as dentin. Some advantages of adhesion are described by Summit (2006): it diminishes the probability of microleakage if the adhesive protocol follows the step by step procedures, resulting in less risk of staining of restorations and secondary caries. Additionally, the adhesion surface is able to distribute occlusal loads, and the restorative material can be integrated as part of the tooth.

Several factors can affect the strength of the bonding including: the physical and chemical characteristics of the material, the wetting capacity of the bonding agent, the superficial energy of the tissue or substrate, the field control during the process, the occlusal conditions of the patient, and some systemic diseases that could affect the acidic environment of the mouth, causing dissolution of some parts of the adhesion complex (Summitt, 2006).

Classification of adhesives

New adhesive systems have evolved following Buonocore publishing his investigation in 1955 regarding adhesion to enamel surfaces. (Soderholm, 2007). Adhesive systems can be classified by their adhesion strategy Summit (2006). However, classifying the adhesives by generation provides a better understanding of the evolution and its clinical implications. First generation adhesives are the first system developed by

Bowen in 1965 composed by N-Phenylglycine and glycidyl methacrylate intended to bond the restorative material to dentin. Unfortunately, these adhesives provide bonding shear strength values around 1-3 MPa. Second generation adhesives were presented in 1970 with the introduction of Bis GMa-HEMA adhesive providing ionic boning between halophospohorus esters and Calcium ions.

After this generation, Fusayama and Nakabayashy proposed the third generation of adhesive that was intended to etch dentin while removing or modifying the smear layer in 1982 (Soderholm, 2007).

The fourth generation includes the three-step etch-and rinse adhesive. This technique includes the application of an acid etchant, rinsing, placement of the primer agent and application of the adhesive resin. OptiBond Fl (KERR, Orange, CA, USA) belongs to this fourth generation system. It is composed mainly by 37.5% etchant acid, the primer that contains HEMA= 2-hydroxylethylmethacylate, GPDM= glycerol phosphate dimethacrylate; PAMM= phtalic acid monoethyl methacrylate, ethanol and water. The adhesive resin contains TEGDMA (triethylene glycol dimethacryclathe), UDMA (urethane dimethacrylate), GPDM (glycerol phosphate dimethacrylate), HEMA, BIS-GMA (bisphenol-A-glyicyl methacrylate), hydrophobic dimethacrylate fillers (15%). This system is proven to have adequate clinical results with greater than 10 years of clinical service on clinical trials (Walter, Swift, Boushell, & Braswell, 2011).

Fifth generation adhesives are composed of two-step-etch-and-rinse system, which differs from the previous generation by combining the primer and adhesive in one bottle. Sixth generation adhesive systems are self-etch adhesive systems, which introduce the acidic primers and eliminate the use of etchant from the adhesive procedure. This generation simplifies use by reducing the number of steps. However, this systems has not surpassed the bond strengths values of the fourth generation adhesives that include the three-step procedure (Soderholm, 2007). Seventh and six generation is an “ambiguous” classification according to Summit (2006) because it is related to the manufacturer nomenclature. This adhesive systems are commonly recognized in the market as “all in one” adhesives (Soderholm, 2007), claiming simplified clinical procedures; however there is a need for more research about this systems compared to the “Gold Standard” stated by Peumans et al (2012).

Preparation Designs For Direct Restorations

Direct composite resin veneer

This type of restoration is a conservative technique that requires little or no tooth preparation. In some cases, resin veneer restores missing structures of the tooth crown, improves esthetics by masking discolored teeth, or re-establishes adequate tooth alignment. Depending on the clinician’s criteria, the biomaterial used can be microhybrid, nanocomposite, or nanohybrid resin based composite material.

Class III

This technique was established by G.V.Black, who was described by Henderson “The grand old man of dentistry” (1961). Direct restorations preparations were related to the caries lesions location. Class III refers to proximal preparations (mesial and distal) of anterior teeth without preparing the incisal edge.

Class IV

This restoration refers to proximal preparations in anterior teeth group when it is necessary to restore the incisal edge as part of the restoration design; these types of restorations are common in clinical cases of dento-alveolar trauma. Class IV restorations include proximal, incisal, facial and lingual reconstruction. Resin based composite is an alternative material for those cases. Different margin configurations have been proposed on the literature, in order to achieve cosmetic results and mechanical retention especially in the lingual area where occlusal forces can directly impact the restoration (Summitt, 2006; University of Iowa, 2010; Xu H, 2012).

Margin configurations in Class IV direct restorations

Bevels are part of the margin configuration when Class IV direct restorations is selected as the alternative treatment for the patient in restorative dentistry (Summitt, 2006). Beveling is universally defined as the action of “giving some object the sloped edge” ("Definition of "bevel",""). The glossary of Prosthodontic terms defines bevel as “ the process of slanting the finish line and curve of a tooth preparation” ("The Glossary of Prosthodontic Terms Seventh Edition (GPT-7)," 1999).

The three main purposes of beveling are: minimize the shrinkage of the composite resin restoration, improve esthetic outcomes of restoration, and increase adhesion of the restoration. Because bevels increase the interface, they compensate for shrinkage risk in a composite resin restoration. When Class III or Class IV composite restorations need to give highly esthetic results, a bevel can play an important role to let the material blend into the enamel surface without over contouring.

Finally, bevels can increase adhesion of a restoration when the bevel configuration can expose the enamel prism to the surface in a cross section, therefore increasing the surface adhesion area (Swanson, Feigal, Tantbirojn, & Hodges, 2008). Literature claims that bevels configuration for Class IV restorations can also withstand biomechanical forces during function on the lingual surfaces (Coelho-de-Souza et al., 2008) (Stellini et al., 2008) (Xu H, 2012).

Classification of margin configuration for Class IV direct restorations

In order to give appropriate esthetic and retention properties in Class IV direct restorations, margin configuration can be classified by angulation, extension and location on the tooth.

Classification by angulation

The rounded margins of the preparation can provide different angulations including 45° and 60° (Coelho-de-Souza et al., 2008; Gandhi & Nandlal, 2006; Stellini et al., 2008; Xu H, 2012). When preparing a margin configuration for Class IV restoration, if the cervical margin is located beyond the contact point area, protocol dictates preparing 45° bevel in that area. This 45° bevel provides mechanical retention on the lingual margin configuration (Coelho-de-Souza et al., 2008; University of Iowa, 2010). Bevels with 60° angulation can be configured on the facial aspect to provide adequate esthetics, allowing the resin based composite material to blend into the exposed enamel rods and give appropriate optical properties on the final restorations (University of Iowa, 2010).

Classification by extension

Both the angulation and extension depend on the purpose of the bevel. In cases of Class III restorations, the bevel extension can be prepared as 0.5mm in length and at 45° inclination. This scheme provides the appropriate marginal seal on the lingual surface. For Class IV restorations, the facial surface requires a different margin configuration since the facial aspect is part of the restorative design. For that reason, the extension is suggested to have 2 mm length including the dentino-enamel junction (DEJ). Some authors propose a 45° bevel (University of Iowa, 2010).

In such cases, the bevel is scalloped without a continuous margin line in order to let the material to better blend into the bevel and provide better shade matching. On the lingual surface, the purpose of the bevel is more retentive than esthetic; thus it must have the adequate angulation and extension (1.0-1.5mm). In some cases, the cervical area of the preparation goes beyond the proximal contact. In this situation, a 45° bevel is necessary to create appropriate retention(University of Iowa, 2010).

Classification by location

Another important aspect to consider when selecting margin configuration for Class IV restorations is the location of the margin. On the facial aspect of the preparation, the margin configuration can affect the final esthetic results of the restoration.

For that reason, it is important to select the adequate margin to achieve the planned objectives of the restoration on the facial aspect. A 60˚ bevel with 2mm extension is suggested for facial margin configuration to provide satisfactory esthetic outcomes, besides the optical properties of the material (Tan & Tjan, 1992) . On the lingual aspect, mechanical retention is crucial when selecting the margin configuration. Butt joint margins, chamfers and bevels with different lengths and angulations produce different results in terms of fracture resistance when the authors compare lingual margin configurations (Coelho-de-Souza et al., 2008; Gandhi & Nandlal, 2006; Stellini et al., 2008; Xu H, 2012). However, limited information is provided in the literature regarding the effect of the lingual margin configuration in the fracture strength of Class IV resin based composite restorations.

Chamfer in Class IV resin based composite

The glossary of Prosthodontic terms provides the following definition for "chamfer: "the surface found by cutting away the angle of intersection of two faces of a piece of material: a beveled edge". In other terms, this Glossary defines chamfer as a type of bevel.("The Glossary of Prosthodontic Terms Seventh Edition (GPT-7)," 1999).

Besides bevels and butt joints, chamfers provide mechanical retention for margin configuration for the lingual and facial aspect (Gandhi & Nandlal, 2006; Xu H, 2012). In the past three decades, restorative dentistry researchers chamfers were the selected margin configuration even for the facial aspect, providing adequate mechanical retention and esthetic outcomes (Davis, Roth, & Levi, 1983). Summit (2006) states that lingual aspect of the preparation should provide mechanical retention.

For that reason, one alternative for margin configuration should be chamfer because this configuration provides adequate retention under occlusal forces, especially in cases of reattached fractured incisal edges.

Several factors can affect the strength of the bond between the tooth and the resin composite restoration: These include the type of restorative material and adhesive system, the skill of the operator, the occlusal forces and the patient’s oral habits. Little is known about the effect of the margin configuration at the tooth-restorative interface on the strength and long term integrity of class IV resin composite restorations.

CHAPTER III

METHODS AND MATERIALS

Sample Selection

Based on the power analysis on data from the pilot study, a total sample size of one hundred human extracted lower incisors (n=25/per group) to detect a significant difference among the four groups with 80% power and an effect size of 0.12 using one-way ANOVA. Conveniently lower human incisors were selected due to their availability and less variation in dimensions than upper incisors, but they were used as centrals incisors for all testing purposes. The following inclusion criteria were required for sample selection: intact anatomic crown without visible fracture, chipping, caries or restorations, as well as intact anatomic roots without endodontic treatment. The teeth were selected with all specifications for safety control. They were immersed in water with thymol solution after their extraction. The total sample size selected had an average dimension of 5.14 mm mesio-distally by 3.33 mm facio-lingually calibrated at 3mm from the incisal edge, to maintain standardization in the experiment. All the specimens were brushed (GUM® tooth brush, USA) under distilled water and scaled to remove all visible soft tissue, stains and calculus. The teeth were rinsed again with distilled water and stored in Chloramine T + artificial Saliva solution (5000ppm) at 4°C during the experiment, changing the solution every two weeks.

Mounting Procedure

1mm depth retention grooves were made on the root surface of each specimen for mechanical retention purposes prior to the mounting process. A distance of 3mm was measured from the cemento-enamel junction using a digital caliper (Mutitoyo Digital Caliper®, Japan) to simulate the biological width and have consistent measurements in all samples at the crown level. This space was blocked with thermo-plastic wax to prevent acrylic resin from invading this space. Each specimen was embedded in a self-cure acrylic resin with the lingual aspect facing upwards and inclined at 45º angulation with relation to the horizontal plane. This position of the specimen in the cylinder simulates the average maxillary human incisor pro-inclination, allowing a 135º inter-incisal angulation at the moment of the contact with the opponent incisor (fig 1). This position simulates the average human inter-incisal angulation (Bimler, 1985; Ellis & McNamara, 1986; Fish & Epker, 1980). With this orientation of 135º interincisal vector of forces, it is possible to obtain a better understanding the physical behavior of the complex tooth-restoration under human interincisal forces in an *in vitro* study (Alonso, 1999). Both lingual and incisal aspects of the specimen were impressed with polyvynilsyloxane putty in order to obtain a lingual matrix with the original anatomical information of each specimen and replicate it at the moment of the restoration.

Figure 1.Mounted teeth in self-curing acrylic resin

Experimental Groups

The total of one hundred mounted teeth were randomly assigned in four experimental groups of twenty-five teeth per group as follows: lingual Butt joint, 45° lingual bevel, 60° lingual bevel, and lingual chamfer. These groups were assigned based on the preparation they would receive.

Sectioning and Restoring Procedures

Twenty-four hours before the sectioning and restoration procedure, the teeth were rinsed twice and stored in distilled water at 37°C. A mesio-distal line mark was made (Mutitoyo® Digital Caliper, Japan) at 3mm apical from incisal edge. The incisal third was sectioned axially using an ultra-thin diamond disk with a medium coarse finish (20000RPM) with adequate refrigeration following the mesio-distal line mark. The area of the platform was calibrated in all samples (fig 2 and 3).

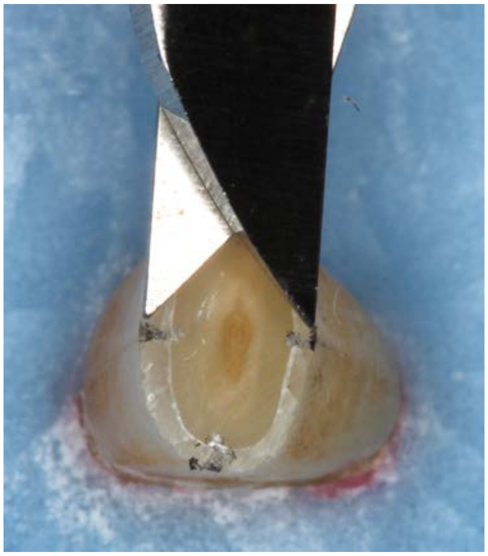

Figure 2. Calibration of the axial platform

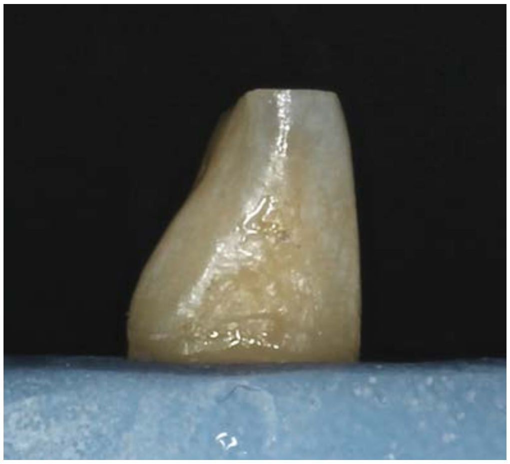

Figure 3. Lateral view of the sectioned specimen

Margin Configurations And Preparations

Group 1. Lingual Butt Joint

For this first experimental group, the lingual platform was maintained on the lingual aspect as a butt joint margin. This area was smoothed with dark orange - coarse grit Soflex™ Extra-Thin Finishing Disc (3M ESPE, USA) at low speed (15000 RPM) with refrigeration maintaining the flat shape of the platform (fig 4). For the facial margin configuration, a 60˚ bevel was prepared in all samples to maintain as constant variable in the total of sample size.

Figure 4. Configuration of the preparation for experimental Group1 (Butt joint). The lingual aspect is on the left side of the picture

Group 2. 45˚ Bevel

In order to standardize the extension of this bevel, a 1mm depth was arbitrary selected as the initial measurement on the axial platform for all specimens (Mutitoyo® Digital Caliper, Japan). This distance was taken from the most external edge of the platform by extending the digital caliper 1mm internally (fig 5). With this standardized distance, trigonometric formulas were necessary to calculate the length of the bevel for this experimental group.

From a lateral view, a right angle was formed between the external wall of the specimen and the axial platform. The location was oriented at a 90˚ angle based on trigonometry. Figure 6 displays the orientation of the caliper. The red dot mark indicates the location of the 45˚ angle as the orientation of the expected bevel for the experimental Group 2.

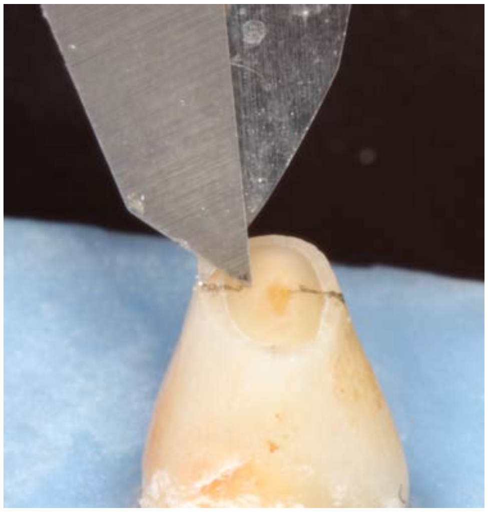

Figure 5. Calibration of 1mm depth on the platform

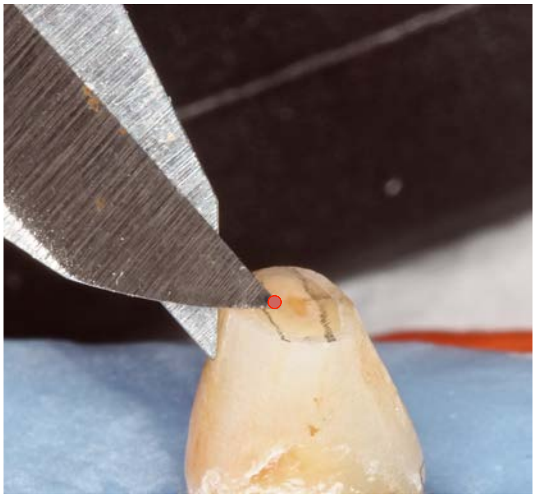

Figure 6. Right angle formed by the two sides of the specimen. The red colored dot indicates the location of the 45˚angulation.

Since the configuration of the bevel preparation is based on length and inclination of the bur used to prepare it, a trigonometric formula was necessary to standardize the extension of the margin. Since this is a 45˚ x 45˚ x 90˚ right triangle, a Pythagorean trigonometric rule √2 can be used to obtain the hypotenuse (fig.7). This hypotenuse corresponds to the expected length of the internal bevel.

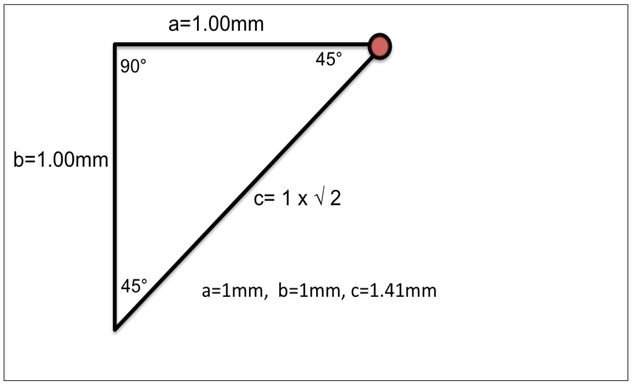

Figure 7. Right triangle with calculations for experimental Group 2. “c” indicates the length of the bevel.

The 45˚ bevel was prepared using a long bur Fine Grit Flame Diamond ((Ref. 6878K018, BRASSELER USA) with slow speed (20000 PMR) and adequate refrigeration (fig 8). The calculated length for all the specimens, a 1.41mm extension in this case, was maintained in all samples.

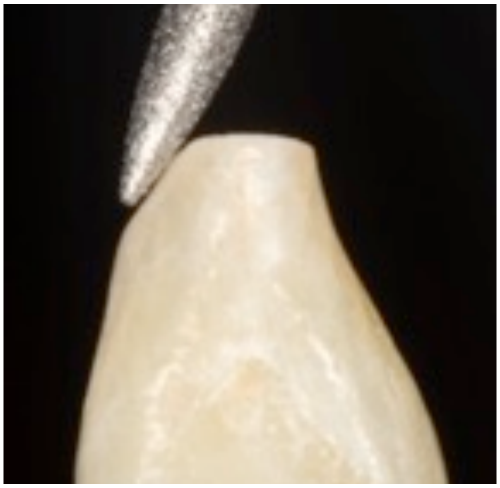

Figure 8. Orientation of the bur for 45˚ bevel configuration.

Group 3. 60˚Bevel

For this group, the axial platform (Mutitoyo® Digital Caliper, Japan) was used to obtain the standard depth of 1mm for all specimens (as the measurement protocol for experimental Group 1). The caliper was used to orient the location of the external right triangle. The 60˚ angle for this group was located internally (fig 9).

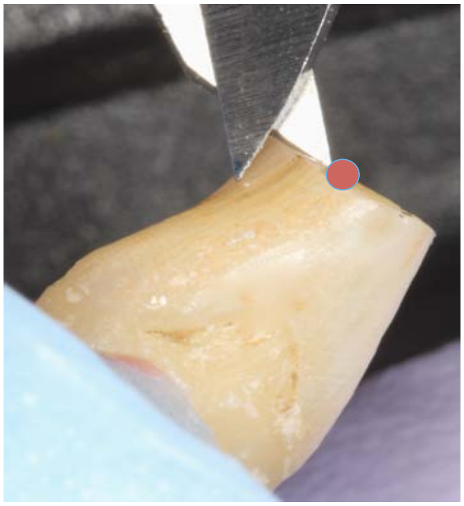

Figure 9. Calibration for the 60˚ bevel for experimental Group 3. The red dot indicates the location of the 60˚ bevel.

In order to standardize the length of the 60˚ bevel, the trigonometric Sine Law and Pythagorean law were used (fig 10). In this particular case, the hypotenuse of the right triangle corresponds to the expected length of the 60˚ bevel.

The bevel was prepared with a hand piece at slow speed (20000 PMR) with a long bur Fine Grit Flame Diamond ((Ref. 6878K018, BRASSELER, USA), following the measurements calculated in the trigonometric formulas. The burs were replaced every five preparations.

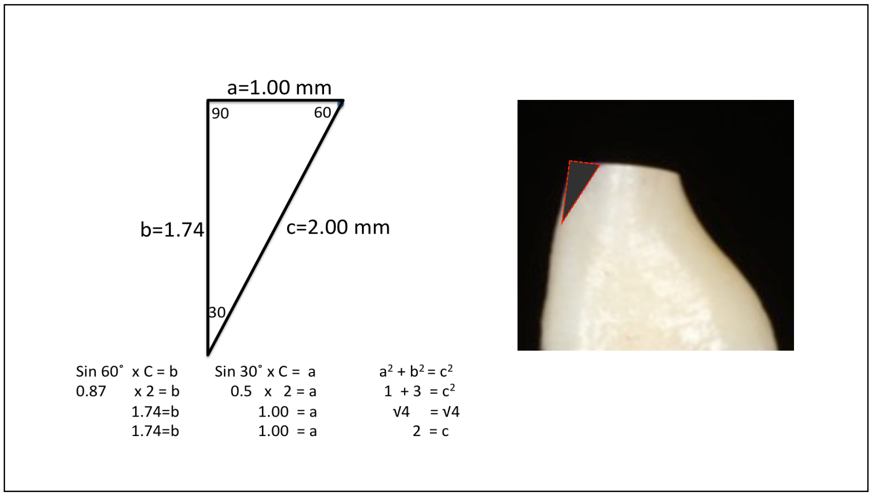

Figure 10. Trigonometric calculations for 60˚ bevel. The picture on the right side displays the orientation of the right triangle with a 60˚ bevel.

Group 4. Chamfer Margin

For this experimental group, identical 1mm depth reduction was calculated as standard on the axial platform as used in all experimental groups. Since this margin architecture differs from the previous groups, an arbitrary 1mm apical extension was selected for the margin preparation as depicted in figure 11. A Chamfer bur (Brasseler USA® Ref 018-6878K) was selected to prepare the teeth in this experimental group, using slow speed (20000 PMR) with adequate refrigeration. The bur was replaced every five preparations. All four experimental groups were prepared with 60˚ bevel on the facial aspect as the standard margin, as per the mathematical formula. Figure 12 depicts the four experimental groups with the corresponding margin preparations.

Figure 11. Chamfer configuration for experimental Group 4. A 1mm apical reduction was selected.

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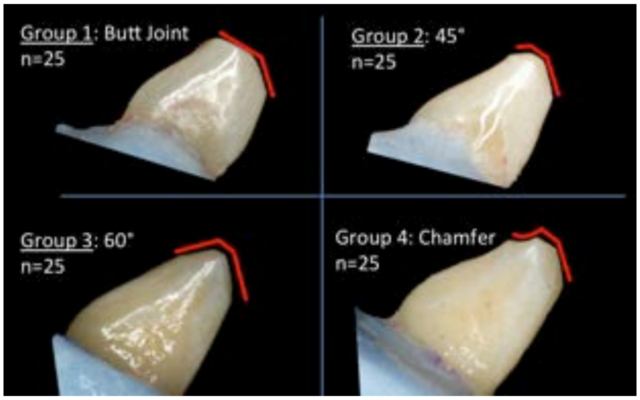


Figure 12. Margin preparations for the four experimental groups.

Adhesive Procedure

Each tooth was ground marked and tagged with the corresponding group number and specimen to identify it. The corresponding lingual polyvinylsiloxane putty matrix that was made previously was placed on each specimen to restore the missing incisal third to provide the original anatomy (Fig 13). The enamel was etched for 15 seconds with 35% phosphoric acid and the dentin was etched for 10 seconds. The tooth was rinsed with water spray for 20 seconds and water excess was removed using slight air pressure and a paper towel to maintain the moisture of the dentin. The dentin was primed with OptiBond™ Fl Prime (KERR, USA) for 30 seconds with a microbrush and air was gently applied to evaporate the solvent. The adhesive system OptiBond™ Fl Adhesive (KERR, USA) was applied with a microbrush and excess adhesive was removed with a new microbrush. This material was light cured with Optilux 500 Demetron light curing unit (KERR, USA) for 30 seconds, and a minimum intensity of 400mw/cm^2.

Figure 13. Lingual polyvinylsiloxane matrix placed on the lingual aspect of the specimen.

Restorative Procedure

Filtek Supreme™ Ultra Universal Restorative (3M, ESPE, USA) shade C2B was selected as the resin based composite material to restore the incisal edge that was previously sectioned. The initial layer was placed on the lingual aspect, with the polyvynilsyloxane lingual matrix in place with the Almore™ Placement Instrument and light cured with Optilux 500 Demetron light curing unit (KERR, USA) for 40 seconds with a controlled 2mm distance between the tip of the light and the specimen, .The output intensity was calibrated to provide at least 400mw/cm^2 and 18J energy delivered. The following increment was placed with the Almore™ Placement Instrument and contoured with Flat Brush (Munster, Indiana) while maintaining the lingual matrix. Excess was removed with an IPC instrument. The resin based composite was light cured with Optilux 500 Demetron light curing unit (KERR, USA) for 40 seconds. Margin adaptation and anatomy were evaluated after finishing the restoration.

Polishing Procedure

Samples were polished after the restorations were finished with Soflex™ Finishing Discs (3M, ESPE) with a slow speed hand piece (15000 RPM). Dark orange, medium orange, light orange and yellow discs were used in this sequence to obtain the adequate polished and lustered surface. Samples were returned to storage containers in Chloramine T + artificial Saliva solution (5000ppm) at 4°C once they were polished and finished. Storage timing was standardized for all specimens (Fig.14).

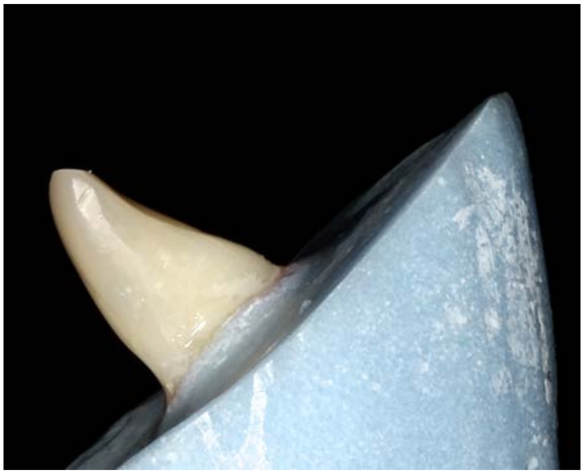


Figure 14. Restored and polished specimen

Aging Process

Specimens were subject to a thermocycling process in the Thermocycling Machine (Willytech Ref. GmbH, Germany) until completing 5000 cycles. Each water container of the thermocycler was filled with distilled water to the allowed level. The device was programmed to provide alternating times and temperatures between 30 seconds at 4˚C and 30 seconds at 55˚C, with dwell times of 10 seconds. Restored specimens were totally immersed in the containers following the programmed cycles until finishing. The water content, temperature of both containers, and the total immersion of the specimens in the containers was controlled constantly during the aging process. Once the total cycles were completed, the samples were rinsed with distilled water and then proceeded to the fracture test.

Mechanical Test

The Universal Testing Machine (ElectroForce 3300 Test System BOSE, USA) was selected for the fracture strength experiment at the final phase of this study. Since the loading tip of this device did not provide adequate contact area with the specimen, it was necessary to create an anatomical tip for this test. A maxillary incisor was designed in CEREC®CAD/CAM system (SIRONA) and milled in a lithium disilicate glass-ceramic block (IPS e.max CAD, Ivoclar Vivadent, Germany). The base of the ceramic tip was etched with 9.5% hydrofluorhydric acid for 10 seconds (PORCELAIN ETCHANT, BISCO, USA), rinsed with water, and dried. One coat of Porcelain Primer (BISCO, USA) was applied with a microbrush for 30 seconds. One layer of Porcelain Bonding Resin (BISCO, USA) was applied with a microbrush on the previously primed surface. The metallic loading tip was sandblasted with 50-micron aluminum oxide at 10 psi, rinsed with water, and dried. One coat of Porcelain Primer (BISCO, USA) was applied with a microbrush for 30 seconds. One layer of Porcelain Bonding Resin (BISCO, USA) was applied with a microbrush on the previously primed surface (fig 15.).

A 2mm layer of resin based composite material Filtek™ Supreme shade C2B (3M,ESPE, USA) was applied to bond both the ceramic tip to the metallic loading tip; this resin based composite was light cured with a LED curing light VALO™ (Ultradent, USA) for 30 seconds, delivering minimum 1000mW/cm2 radiant emittance and 17J of energy delivered. High curing energy values were necessary in this laboratory procedure during the photopolimerization, since this tip acted as the opponent mandible during the mechanical test on one hundred samples; in that way it was possible to avoid unexpected adhesive failures of the loading tip during the mechanical test (fig.15).

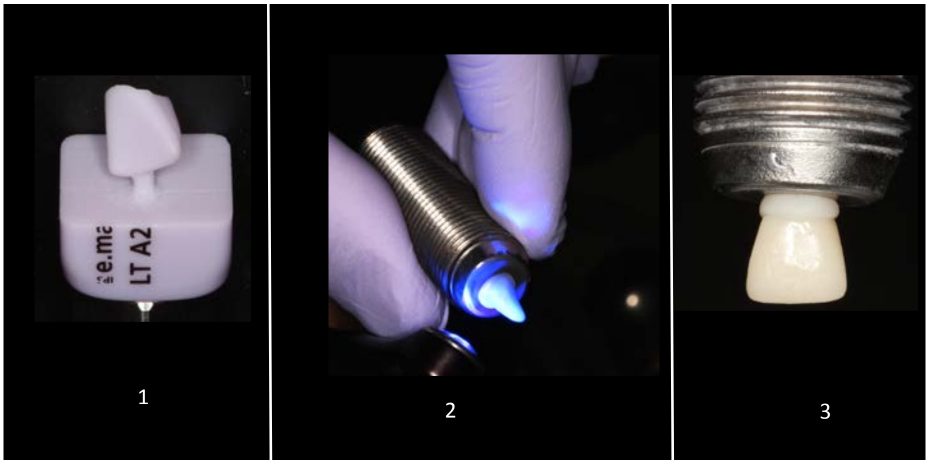


Figure 15. Process of adapting the lithium disilicate CAD/CAM milled crown to the loading tip. Picture 1 depicts the milled crown before sintering process. Picture 2 depicts the bonding process after sintering. Picture 3 depicts the crown in place bonded to the loading tip

This loading tip was inserted and screwed in the upper arm of the Universal Testing Machine (ElectroForce 3300 Test System, BOSE, USA). Each mounted tooth was inserted and screwed firmly in the loading cell, verifying adequate adjustment without movement or any possible balancing. In order to standardize a precise loading application point, all incisal edges from the total of sample groups were flattened with dark orange Soflex™ Disc (3M, ESPE, USA). The point of application was marked and standardized on the center of the incisal edge for all teeth (Fig.16).

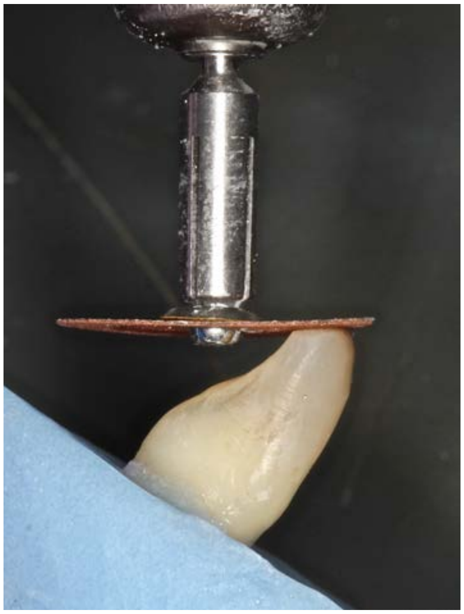


Figure 16. Flattened surface.

Both the tooth and the loading tip were aligned to have adequate orientation of the loading point. The angulation between loading tip axis and tooth long axis was reviewed and was determined to be a 135˚ angulation (which corresponds to the average human inter-incisal angulation) (Fig.17). The software (BOSE Win Test Software, Bose Corporation – EnduraTEC Systems Group) was programmed to initiate the static load at 25N with controlled speed of 1,00 mm/minute. During the load application, the computer recorded displacements of the tooth and load units in Newtons. The software was also programmed to finish the force application when the load cell detected a failure. Once the tooth failed, the magnitude of force was registered in Newtons. The tooth was removed from the load cell and observed with a magnifying system to analyze the mode of failure.

Figure 17. Orientation of the loading tip.

Analysis of the failure

Three main modes of failure were observed under magnification with detailed analysis: adhesive (at the tooth-restoration interface), cohesive (at the restoration) and tooth fracture.

Statistical analysis

For this study, there were three variables, including fracture strength, margin design (butt joint, 45˚, 60˚ and Chamfer) and failure mode.. Descriptive statistics were conducted for the variables of interest. One-way ANOVA was performed to evaluate any significant difference in the mean fracture strength of Class IV resin based composite restorations among the four lingual margin configurations, while Fisher's exact test was used to evaluate the association between the types of lingual margin configurations and failure modes.

Power analysis

To develop this final study, an initial pilot experiment was previously conducted, selecting a total sample size of n=24, divided in the 4 experimental groups of n=6. Based on the results of the pilot study, the power analysis revealed that a sample size of 100(n=25 per group) would be required to detect a significant difference among the four experimental groups with 80% power and an effect size of 0.12 using one-way ANOVA at the 0.05 level of significance.

CHAPTER IV

RESULTS

A total of 100 human extracted lower incisors were selected for this study, and they were randomly equally distributed to four lingual margin configurations (butt joint, 45˚, 60˚ and chamfer) (n=25/ per group). Teeth were sectioned and restored to original anatomy with resin-based composite. After thermocycling, they were subject to static loading until failure (N). Fracture strength values (N) of the four lingual margin configurations were recorded. In order to analyze the mode of failure, frequency distribution of failure modes was also obtained. Table 1 presents the descriptive statistics for the fracture strength. Frequency distributions of modes of failures were reported in Tables 2 through 7.

Results from the one-way ANOVA revealed that there was no significant effect of the lingual margin configuration on fracture strength of Class IV resin based composites (F(3,96)=0.13; p=0.9435) [Table 1]. Mean and standard deviation values for the four groups were: group 1 (Butt Joint) 341.68±105.64N; group 2 (45˚ bevel) 338.21±132.93 N; group 3 (60˚ bevel) 318.23±79.45 N; group 4 (chamfer) 333.02±109.19N. Although group 1 (Butt joint) experienced the highest mean value of fracture strength and group 4 (60˚ bevel) had the lowest mean value of fracture strength, there was no significant difference among the four lingual margin configuration groups.

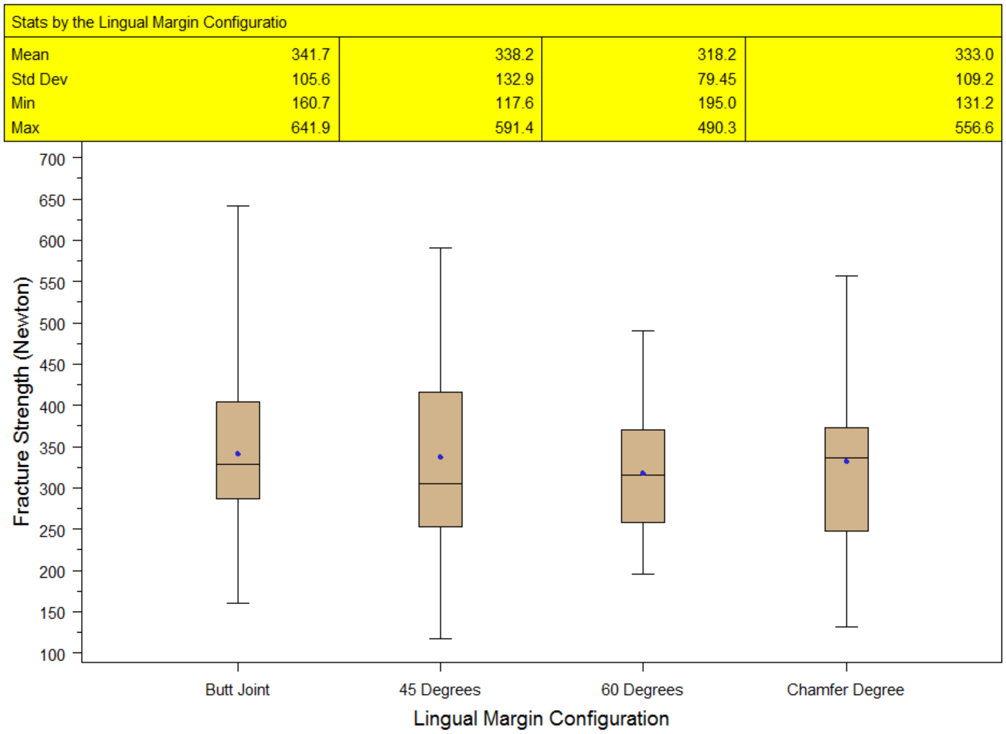
Descriptive statistics of fracture strength are depicted by the four lingual margin configuration groups in Table 1 and illustrated in figure 1. It is observed that the four groups showed similar mean failure strength values. The second group (45˚ bevel) showed the highest standard deviation (132.9N).

In this group, three teeth surpassed the maximum pre-set loading on the Universal Testing Machine (ElectroForce 3300 Test System, BOSE, USA) for this experiment (above 550N), indicating a high variability in fracture strength. The third group revealed the lowest standard deviation (79.45N), showing more constant and stable patterns of fracture strength values. However, no significant difference was found between those two groups.

```
------------------------------------------ Group=Butt Joint ----------------------------------
                         Standard
  N        Mean        Deviation      Minimum       Maximum        Median
  ------------------------------------------------------------------------------
  25      341.68        105.64        160.68          641.90       328.64
  ------------------------------------------------------------------------------

------------------------------------------ Group=45 Degree--------------------------------
                         Standard
  N        Mean        Deviation      Minimum       Maximum        Median
  ------------------------------------------------------------------------------
  25      338.21        132.93        117.56          591.36       304.61
  ------------------------------------------------------------------------------

------------------------------------------ Group=60 Degree--------------------------------
                         Standard
  N        Mean        Deviation      Minimum       Maximum        Median
  ------------------------------------------------------------------------------
  25      318.23         79.45       195.01          490.28        315.32
  ------------------------------------------------------------------------------

------------------------------------------ Group=Chamfer -------------------------------
                         Standard
  N        Mean        Deviation      Minimum       Maximum        Median
  ------------------------------------------------------------------------------
  25      333.02        109.19        131.15         556.61          336.47
  ------------------------------------------------------------------------------------------
```

***Units for the fracture strength are Newtons.

Table 1. Descriptive Statistics for the fracture strength by the four lingual margin configurations.



Stats by the Lingual Margin Configuratio				
Mean	341.7	338.2	318.2	333.0
Std Dev	105.6	132.9	79.45	109.2
Min	160.7	117.6	195.0	131.2
Max	641.9	591.4	490.3	556.6

Figure 1: Displaying the Mean Fracture Strength (Newton) by the Lingual Margin Configurations

Figure18. Mean Fracture Strength (Newtons) by Lingual Margin Configurations

Table 2 describes the frequency distributions of failure modes that were coded. Cohesive failure was defined as failure at the restorative material interface, observed on both aspects (facial and lingual). Facial adhesive/lingual intact failure was the partial failure of the tooth-restoration interface observed only at the facial aspect, however the lingual aspect the restoration remained intact. Tooth fracture was the complete fracture of the tooth at the root level with the restoration remaining intact.

Total adhesive failure was the complete failure of the restoration on both facial and lingual aspects of the specimen. Facial cohesive/lingual intact was coded as the failure at the restorative material interface, only on the facial area, but the lingual aspect including the restoration remained intact. Finally, tooth avulsion was coded as the complete dislodgement of the intact tooth from the acrylic socket.

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Type of failure	Cumulative frequency	Percent (%)
Cohesive	6	6.00
Facial adhesive/lingual intact	7	7.00
Tooth fracture	71	71.00
Total adhesive	11	11.00
Facial cohesive/lingual intact	4	4.00
Tooth avulsion	1	1.00

Table 2. Frequency distribution of failure modes.

As revealed on Table 2, 71% of the total sample size resulted in tooth fracture, followed by 11% of the samples with total adhesive failure. The mode of fracture maintained a horizontal pattern at the interface between the tooth and the acrylic socket, with consequent dislodgement of the complete coronal portion of the tooth. Only one tooth (group 3) showed avulsion from the acrylic socket at 245.14 Newtons. Table 3 depicts the frequency distribution of failure modes for group 1 (Butt Joint). 72% of the tooth experienced complete fracture, followed by 16% of the total sample size revealing total adhesive failure.

Type of Failure	Cumulative Frequency	Percent (%)
Cohesive	2	8.00
Tooth Fracture	18	72.00
Total Adhesive	4	16.00
Facial Cohesive/lingual intact	1	4.00

Table 3. Frequency distribution of failure modes for Group 1 (Butt Joint).

Type of Failure	Cumulative Frequency	Percent (%)
Cohesive	1	4.00
Facial Adhesive/lingual intact	2	8.00
Tooth Fracture	20	80.00
Total Adhesive	2	8.00

Table 4. Frequency distribution of failure modes for Group 2 (45˚ Bevel).

Table 4 depicts frequency distribution of failure modes for group 2 (45˚ bevel), revealing tooth fracture as a frequent mode of failure among this sample group as well. For the 60˚ bevel margin group, all modes of failure coded in this study were present (Table 5). Finally, for the group 4 (chamfer), 15 teeth corresponding to 60% of the total sample group resulted in tooth fracture, followed by Facial adhesive/Lingual intact mode of failure (16%). Table 6 depicts the data for this group 4, showing also 8% with cohesive failure, 8% for total adhesive and 8% for Facial Cohesive/Lingual Intact.

Type of Failure	Cumulative Frequency	Percent (%)
Cohesive	1	4.00
Facial Adhesive/lingual intact	1	4.00
Tooth Fracture	18	72.00
Total Adhesive	3	12.00
Facial Cohesive/Lingual intact	1	4.00
Tooth avulsion from socket	1	4.00

Table 5. Frequency distribution of failure modes for Group 3 (60˚ Bevel).

Type of Failure	Cumulative Frequency	Percent (%)
Cohesive	2	8.00
Facial Adhesive/lingual intact	4	16.00
Tooth Fracture	15	60.00
Total Adhesive	2	8.00
Facial Cohesive/Lingual Intact	2	8.00

Table 6. Frequency distribution of failure modes for Group 4 (chamfer).

Additional analysis was conducted to explore whether there was a significant association between failure modes and the lingual margin configuration under static loading, using Fisher’s exact test. This analysis revealed no statistically significant association between failure modes and the lingual margin configuration (p=0.784) (Table 7).

Failure Modes	**Group1** **Butt Joint** **(%)**	**Group2** **45°** **(%)**	**Group3** **60°** **(%)**	**Group4** **Chamfer** **(%)**	**P-Value***
Adhesive (N=18)	4 (22.2)	4 (22.2)	4 (22.2)	6 (33.4)	0.7840
Cohesive (N=10)	3 (30.0)	1 (10.0)	2 (20.0)	4 (40.0)	
Tooth Fracture (N=71)	18 (25.3)	20 (28.2)	18 (25.3)	15 (21.2)	
*Frequency missing N=1					

***Not statistically significantly t (p>0.05) using the Fisher's exact test**

Note: n=1 specimen was excluded from the experiment.

Table 7. Frequency distribution of failure modes by the four lingual margin configurations.

CHAPTER V

DISCUSSION

Resin based composite material for Class IV restorations is one of the treatment options for maxillary incisor tooth fracture which provides the patient an economical, conservative approach with adequate physical properties and esthetic outcomes. In addition to the physical and optical properties of the resin based composite material, the margin configuration of the preparation is a key factor to provide the final restoration both mechanical and optical properties. Different margin configurations and bevel designs have been proposed in the literature in order to analyze and evaluate the retention of the restorations on Class IV restorations and possibly prevent unexpected clinical failures (van Dijken & Pallesen, 2010) (Xu H, 2012).

The purpose of the present *in vitro* study was to compare the mean fracture strength among four lingual margin configurations for Class IV resin based composite restorations on human extracted incisors. The restorations were thermally challenged for 5000 cycles at a temperature of between 5°C-55°C with a dwell time of 30 seconds. Subsequently, the samples were subjected to static loading until failure at an inclination of 135˚ interincisal loading (simulating the average human interincisal angulation under normo-occlusion). A previous investigation conducted by Xu et al (2012) tested the fracture strength of Class IV direct resin based composite restorations on five lingual and facial margin configurations (1mm bevel, 2mm bevel, step-stair bevel, chamfer and butt joint as negative control) with positive control group (intact tooth).

However, it is unclear how the authors standardized the measurement of the margins during the preparations. The present investigation was consistent with the measurement protocol for margin preparations to standardize the four experimental groups. Each tooth was previously measured and the margin was equally calculated to obtain standard design on each sample group. This process provided consistency during the restorative process.

Coehlo-De-Souza (Coelho-de-Souza et al., 2008) analyzed the mean fracture strength among four margin configurations for Class IV restorations on human incisors restored with two techniques direct and indirect bonded resin based composite material. Each group was sub-divided in bevel and no-bevel subgroups. The bevel group was provided 45º with 1mm extension. More information should have been necessary to clarify the process for preparing the margin configuration and the area of the preparation (facial or lingual).

The present investigation standardized all the facial margin designs to 60˚ bevel and modified the four groups on the lingual aspect of the teeth on each group. For the 45˚ bevel, the reduction was 1mm facio-lingually, and the standard measurement for that bevel required 1.41mm length, which was calculated from the trigonometric formula.

Effect Of Margin Configuration On Fracture Strength

Results of this *in vitro* experiment revealed no statistically significant effect of lingual margin design for Class IV resin based composite restorations when a 135˚ angulation load is applied on the lingual restorative area under static loading. There was no statistically significant association between lingual margins configurations and failure modes. This study compared the three most common lingual margin configurations used in clinical practice for anterior teeth preparations including 45˚ bevel, 60˚ bevel and chamfer (Coelho-de-Souza et al., 2008; Summitt, 2006; University of Iowa, 2010; Xu H, 2012) Also this study included butt joint as other margin configuration among the four experimental groups. With this range of margin configurations it was possible to compare their physical behavior under standardized scheme of forces. According to Santana et al (2014) and Paphangkorakit (1998) human incisors have average bite forces in the range of 214-268N under normal masticatory function.

The present *in vitro* experiment considered the human occlusal scheme as part of the method, described in the literature (Alonso, 1999; Dawson, 2007; Eduard, 1986). An average of 135˚ interincisal angulation was calculated by human cephalometric measurements (Ellis & McNamara, 1986; Fish & Epker, 1980). No other *in vitro* studies have evaluated the effect of lingual margin configuration on the fracture strength of resin-based composites by simulating human interincisal load orientation with standardized facial bevel.

The present experiment maintained consistency by controlling variables as: constant minimum load, speed and point of application. Each tooth received the load point at the center of the restored incisal edge on a flat surface that allowed the ceramic tip to contact the tooth and distribute the forces along the tooth axis. These mechanic schemes were intended to simulate the anterior occlusion of human masticatory system.

Frequency Of Distribution Of Failure Mode

Results revealed that the tooth fracture occurred in 71 teeth from the total of samples. The fracture occurred at the contact area between the root and the acrylic resin of cylinder (3mm apical to cement-enamel junction). Under detailed observation, the restorations remained intact after the failure of the tooth, with complete adhesive interface. Taking into consideration the orientation of vector of forces (in this study were controlled in a linguo-facially direction, beginning from the incisal edge), the resulting forces were directed towards the cervical third on the facial aspect of the tooth. Following that pathway of the resulting forces, all stresses ended on the thinnest facial enamel as observed by Magne (1999). With this scheme of forces in mind, the present study ensured that the force vector was directed towards the facial bevel. According to Santana-Mora et al (2014) and Paphangkorakit(1998) , the average force range of forces of human intact incisors is 214-268N under normal masticatory function. Based on the results of the present investigation all samples surpassed this range reported in the literature, regardless the margin configuration among the four experimental groups. Based on frequency of distribution analysis, 71 teeth fractured at the root level surpassing 330N without adhesive or cohesive failure of the restoration. These results emphasize the relevance of the adhesion in mechanics of composites. The adhesive system integrates the composite material to the tooth and provides micro-mechanical retention, regardless the geometry of the preparation.

Considering all groups in terms of fracture mode, the 60˚ margin sample group revealed a more constant pattern of fracture strength compared to the three remaining groups (butt joint, 45˚ and chamfer). One of the possible reasons is that this group received 60˚ bevel on both faces (facial and lingual), with a 60˚ facial bevel in all samples as a standardized margin. If the restoration is bonded on a preparation that maintains a constant length of margin on both facial and lingual surfaces, the distribution of forces and pattern of fracture could also continue as constant. Considering this, a 60˚ bevel could be considered a “standard” bevel for Class IV composites due to its 2mm extension and its constant pattern of fracture under static load. There are no articles reported in the literature that evaluate the fracture strength of 60˚bevel on Class IV restorations under interincisal angulations.

Effect Of Thermocycling In Fracture Strength

The thermocycling protocol used for this study followed the standard requirements as used by Cohelo De-Souza (2008) and Kamel (2014) to age all the teeth in all the experimental groups. Thermocycling is an *in vitro* accelerated aging process that simulates the clinical evolution of a material under controlled time cycles and temperature intervals. A number of studies have been conducted using thermocycling as an aging method regardless the limitations. Some authors argue the use of thermocycling for fracture strength tests stating that water absorption could lead to slow resin degradation in laboratory experiments (Maryam Khoroushi, 2013) , as also stated by Kamel (2014). However, aging and thermal cycling has *in vitro* limitations taking those factors as limitations. One of the advantages of this *in vitro* laboratory experiment is the consistency of the protocol and controlled variables included in the experiment. In the present study, the total of teeth were subject to controlled temperature and number of thermal cycles before static load was applied in order to replicate a clinical service of the resin based composite in a human masticatory system.

Effect Of The Adhesive System In Fracture Strength And Failure Mode

Adhesion is part of the daily practice in modern dentistry. It plays an important role in the success of a restoration during lifetime in terms of providing adequate marginal seal, optical properties and mechanical support. Some variables such as cavo-surface margin and the adhesive interface are involved in the retention and adequate seal of anterior direct restorations. However, adhesion plays relevant role in micro-mechanical retention and integration of two structures to become only one that supports loads over time. For these reasons, adhesion was considered a key factor in the results of this experiment. In the present study, one adhesive system (Optibond™ FL, Kerr) was used in order to control the variables and only modifying the margin design. Similar studies were conducted to compare the fracture strength of bevel designs, however, they differ from the present study on the type of adhesive system. Gandhi (2009) compared the mean fracture strength of resin based composites among three groups of margin configurations (step-chamfer, bevel and chamfer) in bovine specimens using the one step self-etch adhesive system Adper Prompt Self Etch (3M ESPE, USA).

Results of this study revealed significant differences among the three groups ($p<0.005$) showing step-chamfer having the highest fracture strength. However, the forces applied were oriented perpendicular to the specimen. Results from this study differ from the present study mainly based on composition of the adhesive system. Adper Prompt Self

Etch (3M ESPE, USA) is a 6th generation adhesive system with a pH 0.4; this system has advantages compared with the three step adhesive system used in the present investigation (Optibond™ FL, KERR, USA) literature reports that self-etch adhesive system can simplify the clinical technique in terms of timing and steps to accomplish the adhesive protocol; however, its acidic monomers could lead to degradation of traces of water could remain in the adhesive interface(Summitt, 2006). Optibond™ FL (Kerr, USA) is a 4th generation adhesive system that is considered three-step etch-and-rinse system. Studies presented Optibond™ FL (KERR SYBRON, USA) as the "gold standard" material, showing successful survival over time and highest values of shear bond strength (Ricardo, 2011), (Peumans, 2012). The present investigation used Optibond™ FL (KERR SYBRON, USA) as one adhesive system for all four experimental groups, since the purpose of the study was to evaluate only the lingual margin configuration under consistent restorative protocol.

Xu (2012) developed another protocol and conducted a similar study comparing stress distribution and fracture strength among 6 types of margin groups (45° 1mm, 45° 2mm, chamfer, step-stair, butt-joint against control intact tooth as control group). The investigators selected Tetric N Bond (Ivoclar Vivadent, Germany) as the adhesive system in all samples, which was different from the study we conducted. Tetric N Bond (Ivoclar Vivadent, Germany) is a nanofilled etch-and-rinse single- component bonding agent. Results from this study revealed that intact teeth had the highest fracture strength under perpendicular forces application under perpendicular static loading ($p<0.05$).

This study and its results differ from the present investigation; the type of adhesive is one of the variables that could yield different results when comparing both studies.

Literature reports have presented different adhesive protocols evolved along time from one generation to other. The three step adhesive system remains as the “gold standard” procedure in adhesive dentistry since its shear bond strength and time of survival (M. M. Peumans, Jan D, 2012). Other adhesive systems like one-step or two-step self etch adhesives could be acceptable in terms shear bond strength as well. However, literature presented Optibond™ FL (Kerr, USA) as the appropriate material for this standard, revealing successful survival rates over time and highest values of shear bond strength (M. M. Peumans, Jan D, 2012; Walter, 2011). For that reason, this material was selected as the adhesive system for the present experiment. In the present study, results revealed that with this adhesive system, 71 teeth experienced tooth fracture and intact adhesive interface. No failure was observed upon detailed examination. The gold standard adhesive system (three step adhesive system, in this case Optibond™ FL, KERR SYBRON, USA) could have contributed in some part to the amount of teeth resulting in intact adhesive interface. This adhesive system is proven to bring adequate adhesive interface, integrating the composite material to the tooth structure (Walter, 2011; Walter et al., 2011). In the present study this adhesive system could have provided the restoration the fracture strength able to support static loads under interincisal occlusal forces, surpassing 330N without adhesive or cohesive failure under the limitations of the study. In this case, the tooth was subject to failure at the cement-enamel junction. It can be suggested that using other adhesive system or upper incisors they might exhibit different results in terms of fracture strength under static loading.

Effect Of The Resin Based Composite In Fracture Strength And Failure Mode

Contemporary resin based composites can provide excellent results in terms of mechanical support, biocompatibility and esthetic outcomes for Class IV direct restorations. The criteria for selecting the adequate biomaterial depend on the clinician's experience, learning curve and scientific support. Previous *in vitro* studies have been conducted to evaluate the physical properties of the biomaterials and their results in laboratory studies. Class IV restoration studies have shown that nano-fill resin based composites can provide adequate optical properties during finishing and polishing and satisfactory mechanical support due to its inorganic fillers based in nano particles and nano-clusters fillers with pre-sintered nano-particles of 5-20nm. With this size of particles, which is composed of zirconia-silica, the mechanical response of this material can provide better mechanical support through crack pinning between the fillers when the restoration is under stress (Vouvoudi & Sideridou, 2012). Filtek™ Supreme Universal Restorative material (3M ESPE, USA) was selected as the restorative material for all four experimental groups, maintaining consistency with the restorative protocol.

A similar study conducted by Coehlo et al (Coelho-de-Souza et al., 2008) used Filtek™ Z250 (3M ESPE, USA) as the resin based composite to restore Class IV preparations and Adper Single Bond (3M ESPE, USA) as the adhesive system. The author divided the total of samples in four experimental groups: two groups with direct restorations subdivided in groups of non-bevel and bevel group, and two groups with indirect cemented restoration subdivided in groups of non-bevel and bevel group. The teeth were subject to aging and static loading. Results of the study showed that bevel groups for both direct and indirect restorations had the highest fracture resistance after 180 days of aging and thermocycling. These results differ from the present investigation, although the rationale and some of the methods employed were similar. One of the differences between both studies is the restorative material used for the Class IV resin based composite restorations. Filtek™ Z250 (3M ESPE, USA) is a hybrid resin based composite material with zirconia particles of 3.5µm and 78% Wt. Filtek™ Supreme Universal Restorative Material (3M ESPE, USA), which was the selected material for the present investigation, is a nano-filled resin based composite material. Its inorganic filler is composed by zirconia and silica particles (20nm) agglomerated in nano-clusters (0.6-1.4µm) (Watanabe et al., 2008).

Filtek™ Supreme Universal Restorative Material (3M ESPE, USA) has shown not only satisfactory esthetic results in anterior restorations but also acceptable physical properties as well. This material provides adequate mechanical support based on the distribution of the nano-clusters able to distribute the forces throughout the matrix and its nano-clusters (Hua et al., 2013; Watanabe et al., 2008). By comparing similarities and differences between the present investigation and Coehlo et al study (2008), it might be possible to produce different results if another material would be used in the present study, based on the nature of the restorative material and its physical properties.

Type of force applied and its effect on fracture strength and failure mode

Anterior incisors support one segment of the occlusal forces of the masticatory system and distribute loads through the tooth structure and surrounding tissues. In the absence of posterior teeth, they are subject to high stress, especially in static load.

Anterior teeth force distribution depends on the magnitude and orientation of the contact point. That is how occlusal contacts take importance in restorative dentistry during diagnosis and treatment planning. In maxillary class IV direct restorations the location of the contact point is a relevant factor to consider, in order to avoid possible mechanical failures such as chipping or fracture. This contact point turns into a component of forces that travel along the restoration, leading to both compressive and tensile forces on tooth structure, restorative materials or adhesive interfaces. In maxillary incisors in normo-occlusion, the load point is applied at the lingual surface. The vector of force can take a specific pathway depending on the tooth inclination, its position and occlusal scheme. This lingual point acts as tensile force on the structure, and the vector of forces follows a facial pathway towards where a compressive load occurs. This statement is consistent with Pascal Magne (1999) who evaluated the mechanical implications of the anatomic structures on upper incisors under controlled forces, providing a better understanding of the distribution of forces and its results from occlusal loads. Magne (1999) demonstrated that the enamel on the facial surface on upper incisors is subject to compressive loads under lingual contact (tensile forces). The cervical third of the facial aspect is more brittle, meaning that the vector of forces takes this direction linguo-facially and incisal-cervically.

Considering this scheme of vector of forces applied on the lingual aspect, the present investigation simulated a normo-occlusion with anterior interincisal angulation ant 135° angulation force. When a force is applied vertically the vector is the tangent product of the two axes (*x* and *y* axis) surrounding it. This vector has a magnitude, an orientation and a direction, and is usually represented by an arrow (Zimba, 2009). The present investigation applied mechanics of vector of forces to analyze the physical response of the complex tooth-restoration under static loading. Figure 19 represents the distribution of the vector of the force applied on the lingual aspect of the tooth as it occurs in a maxillary incisor’s occlusal scheme.

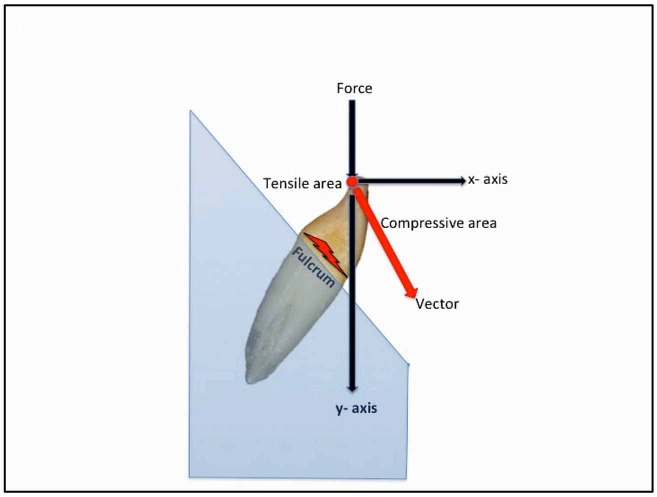

Figure 19.Illustration of the vector of forces applied on the lingual aspect of the mounted tooth on the loading cell.

During the fracture strength test, the force was applied on the lingual aspect of the resin based composite restoration. It led to a composition of one vector and two axis of forces *x* and *y*, all directed towards the facial aspect. The *x* and *y* components of forces surrounded the vector that brought velocity, magnitude and direction. In this specific scheme of force, the tooth recieved the direction of the vector and revealed different failure modes.

Seventy-one teeth fractured at the root level where the interface tooth-acrylic cylinder exists. Considering the mechanics of vectors and their implications, in maxillary incisors forces are directed towards the facial area during closing movements and static loads in normo-occlusion. However, when the forces surpass average of tolerance of the tooth, the stress could be directed towards the weakest point, causing undesirable failures.. A finite element analysis will prove valuable in conceptualizing the stress concentrations areas. Very possible that under the testing conditions the force has been directed to other area that the interface. In this case, the weakest point was located at the fulcrum center. In the scheme of the sample mounting of the present study, the fulcrum was located at the interface tooth-acrylic cylinder (Fig 19) where the fracture occurred.

Considering the type of force applied on the restored teeth, adhesion could play a role by providing adequate adhesive interface. In that way, the stress could be transmitted along the resin based composite, adhesive interface and tooth structure. With this integrated structure, the restored teeth were able to respond as intact teeth under this scheme of forces. It might explain the reason why the number of teeth fractured at the fulcrum point surpassed the level of tolerance of forces of intact teeth of more than 300N (Paphangkorakit & Osborn, 1998; Santana-Mora et al., 2014).

Other modes of failures were present during the fracture strength test. From the total sample size of n=100, 28 teeth exhibited facial failure, including both cohesive and adhesive modes of failure. Considering the direction of the force applied on the teeth, the vector was directed towards the facial aspect on the cervical portion, leading to different failure modes (without significant difference). There might have been a high stress concentration at the facial aspect where compressive forces take place. This statement is consistent with the study of Magne et al (1999) who analyzed the mechanical implications of the human incisor anatomy . At the cervical third of the incisor, the enamel becomes thinner and brittle, causing a higher stress concentration.

Another important aspect to consider during the fracture strength test is the tooth anatomy. This *in vitro* study selected mandibular incisors for testing. During the tooth selection process, it was observed that lower incisors provided more consistent measurements of the crown diameter and length compared with maxillary central incisors. The average mesio-distal and bucco-lingual length of the samples was 5.14mm by 3.33mm, respectively, measured at 3mm from the incisal edge. The following variables were standardized to approximate a clinical situation to a maxillary incisor scheme of forces: selecting similar size of intact incisors, blocking 3mm space from the cement-enemel junction to simulate biological relevance during the mounting phase and controlling the point of application of the loading at the lingual aspect of the incisal third of the teeth.

Differences in anatomy shape (i.e. crown-root ratio and length of roots) were considered during this study since human samples were selected. This variability could modify the force received by the loading tip. The fulcrum point of each tooth depended on its crown length and the distance from the point of application. When a force is applied on a body, there is a trend of rotation around the fulcrum. The acceleration depends on the magnitude of the force, the distance and time. Newton's Second law explains defines this phenomenon as the linear momentum of the force (Mansfield, 2012). The longer the distance the force travels, the less power needed to cause movement on the body. In this study, linear momentum might have varied from one tooth to other based on their natural anatomy.

However, results revealed no significant difference in the fracture strength among the four lingual margin configurations. A possible explanation for this relies on the tooth-restoration bonding being capable of transmitting the forces along the tooth as an intact tooth and the type of resin based composite used in this study. Further investigations are necessary to compare the lingual margin configurations with different adhesive systems.

In order to challenge the teeth during the mechanical test, it was proposed to design a loading tip with a higher elastic modulus compared to the tooth-restoration complex. With this gradient, it was possible to evaluate the physical response of this tooth-restoration complex under static loading and possible overloads. This mechanical test may be more realistic to the oral environment.

A CAD CAM milled lithium disilicate loading tip was arbitrarily selected to apply the static loading to the restored tooth. This loading tip was bonded to vertical axis of the Universal Testing Machine (ElectroForce 3300 Test System, BOSE, USA) with Porcelain Bonding Resin (BISCO, USA) and resin based composite material Filtek™ Supreme Universal Restorative Material shade C2B (3M,ESPE, USA) was applied to bond the ceramic tip on the vertical axis of the Universal Testing Machine (ElectroForce 3300 Test System, BOSE, USA).

Similar studies have conducted fracture strength tests on Class IV resin based composites with different margin configurations (Coelho-de-Souza et al., 2008; Gandhi & Nandlal, 2006; Stellini et al., 2008; Xu H, 2012). Taking into consideration the physical properties of the materials, hard tissues and their implications, the Young modulus is a variable to consider relevant when forces act on a body.

For the fracture strength test, it is necessary that the material of the loading tip provide a higher Young modulus than the body that is receiving the force. Studies like Stellini et al (2008) and Gandhi et al(2006) reported using a stainless steel crosshead loading tip to apply the force on the resin based composite restoration. By comparing the gradient of Young modulus, stainless steel material has 190-200GPa (Belin-Ferre, 2010), nano-filled resin based composite has 18.5GPa (El-Safty, Akhtar, Silikas, & Watts, 2012), enamel is in the range 40-80GPa (He & Swain, 2008), and the Young modulus of dentin is 17GPa (Miura et al., 2009). For that reason, the loading tip in these studies had to surpass the Young modulus of the tooth-restoration complex for the fracture strength test.

One of the objectives of the present investigation was to mimic a clinical situation while knowing the limitations of an *in vitro* study. Unlike previous studies, the present investigation selected lithium disilicate material as a loading tip, which is a glass ceramic with 95 GPa Young modulus (Petra Bühler-Zemp, 2005). This glass ceramic has a lower value compared with stainless steel (190-200 GPa). By modifying the Young modulus of the loading tip (with a biomaterial applicable to a clinical situation), this *in vitro* study could be more realistic to the oral environment. In that way, it was possible to analyze physical behavior of the tooth-restoration complex under human occlusal forces in normo-occlusion Moreover, Ceramic or lithium disilicate is common nowadays an a anterior restoration in restorative Dentistry. It could also have been possible to use a resin based composite tip, however the purpose of the mechanical test was to use a loading tip with a higher elastic modulus than the tooth-composite resin complex, in this case lithium disilicate tip was proposed as an option due to its physical properties and it could be more realistic to a clinical situation.

Another possible option considered to use as a tip was a natural tooth; however, under the dry conditions of the mechanical test and the probability of frequent fracture of this tip could be high. It might be a probability that only one single tooth will not survive testing 100 samples (under dry conditions); also, changing the teeth or using multiple teeth will only add more variability to the experiment. For these reason it was decided not to use natural tooth tip.

Effect Of Load Angulation In Fracture Strength And Failure Mode

Human incisors are subject to interincisal loads depending on their position in either the mandibular or maxillary arches. *In vitro* studies in dentistry are intended to simulate clinical situations despite the limitations of laboratory conditions. Previous studies have loaded human incisors in a Universal Testing Machine (ElectroForce 3300 Test System, BOSE, USA). However, some of the authors use 90˚ angulation load application, which is not related to a real a clinical situation. Some other authors don't specify the position of the specimen in the testing machine. The present experiment controlled the angulation during the mounting phase of the samples in order to provide an interincisal angulation of 135˚ corresponding to the inter-axial angle between upper and lower incisors (Ellis & McNamara, 1986). This is an advantage over previous studies (Coelho-de-Souza et al., 2008; Stellini et al., 2008; Xu H, 2012), in which the angulation between the crosshead of the testing machine and the incisal edge of the restoration was 90˚. In these experiments, the orientation of the load could conduct different results possible due to the different direction of the vector of forces, because these studies did not consider the average interincisal human angulation as oriented to the point of load.

A similar study by Baghery (1985) tested three facial bevel extensions by orienting the tooth at a 45˚ inclination with the crosshead. This orientation differs from the present experiment as well. Although an *in vitro* mechanical test is not a clinical trial, some variables can be controlled to mimic a clinical condition. In this case, by controlling the interincisal angulation at 135˚ the vector of forces distributes the load appropriately along both tooth structure and restoration as real clinical conditions. For that reason, the results of this biomechanical *in vitro* trial are based on occlusal human schemes, though static loads were applied in this experiment as one of the limitations.

A similar study was conducted by Tan et al (1992) where the investigators evaluated the effect of seven margin configurations for Class IV resin based composite restorations (Herculite HR, KERR, USA). The authors performed the fracture strength test by mounting the samples in a 45˚ inclination device and designed a vertical “plunger tip” (Tan & Tjan, 1992) to apply the force on the restoration. Similarities were found between this study and the present investigation in terms of interincisal angulation, although information about the loading tip is missing in Tan et al study(1992). However, the shape of the plunger tip differs to the anatomical shape selected for the present study.

Clinical Implications

Class IV restorations are supported by both micro and macro retention based on adhesion and margin configuration. Adhesion and tooth preparation both provide adequate support and esthetic results. A number of studies with scientific support have validated the effect of bevels and margins on fracture strength (Bagheri, 1985; Swanson et al., 2008; Tan & Tjan, 1992). This present study adds to this line of investigation in biomechanics of direct restorations, providing a better understanding of margin configurations in clinical practice of dentistry. Tooth preparation depends on the operator’s skills, learning curve, clinical experience and academic philosophy. However all tooth structure reductions imply adequate analysis of the clinical case, diagnosis and endpoint of the results. Occlusal analysis is necessary during the diagnosis phase of the clinical case in order to plan the location of the lingual margin, considering the load distribution as an impact factor in the survival time of the restoration. Inadequate location of the margin could affect the load distribution and lead to mechanical failure if occlusion is not considered during the treatment plan.

According to Baratieri et al (2005), modern adhesive systems can provide adequate micro-retention of direct restorations, providing a more conservative approach during tooth preparation. The author claims that bevels for anterior restorations are not necessary for all cases. By correlating this statement with the results of the present investigation, the clinical approach could be oriented towards an integration of both margin configurations and adhesion as part of the retention of Class IV resin based composite restoration. However, these configurations should be evaluated with a conservative approach to offer the patient less invasive procedures by reducing less tooth structure. Further clinical trials might be suggested in this line of investigation. The results of this study may indicate that the lingual preparation may not be as important so any margin configuration could be use. The clinician should use other factors as: conservation of tooth structure and ease material placement to decide what lingual configuration to use.

Limitations Of The Present Study

The present experiment followed the protocol of the scientific method with standardized procedures and consistency with each stage of the experiment. However, limitations like only one operator for the overall experiment, lower incisors instead of upper incisors, and static load application instead of cyclic forces were detected as shortcomings. Other possible limitations of this experiment could be that only one resin based composite (Filtek™ Supreme Ultra Universal Restorative, 3M ESPE, USA) and one adhesive system (Optibond™ Fl, KERR, USA) were tested.

Although mechanical *in vitro* studies can provide some information about evaluating the physical properties and response of teeth under occlusal forces, they are limited compared with clinical studies. One example of a limitation in the present study is the simulation of the tooth-periodontal complex. Although the acrylic cylinder provided adequate support and resilience during the mechanical test, the absence of simulated periodontal ligament, vital pulp and trabecular bone-like material were also part of the limitations of this study. Periodontal ligament is relevant in laboratory experiments, in order to approximate a clinical situation like proposed Soares et al (2005). With these limitations, the response of the tooth-periodontum complex under counteracting forces could yield different data compared with an *in vivo* study. Regarding the margin configuration one possible limitation of the present study is the absence of positive and negative control groups within the experimental groups. The design of the present investigation was based only in the comparison of the fracture strength among the four lingual margins configurations without including intact tooth as positive control.

Another possible limitation of this study is the absence of a Finite Element Analysis study, parallel to the mechanical test, in order to evaluate the stress distribution and displacement of the tooth-restoration complex.

Strengths Of The Present Study

This *in vitro* experiment has no precedent in the literature by investigating the lingual margin configurations by simulating the interincisal angulation measurements and standardized facial bevel. Furthermore, regardless of the anatomic differences of the 100 human teeth selected for this test, the average maintained a constant measurement for the restoration and the point of application of the load also was applied at a standardized area. Using human teeth could provide a better understanding real clinical behavior of a human incisor under incisal static loads and the mode of failure.

Although no significant difference was seen between the lingual margin configurations, this study explores a new concept in biomechanics of anterior resins based on anterior occlusion and biomechanics of masticatory system.

This static test could precede a next phase of cyclic testing of lingual bevels under interincisal angulation to continue to evaluate the importance of macro and micro mechanical retention of margins in tooth preparations for direct restorations.

Possible Bias

Since one operator performed these experiments, a possible observer bias could be present in this study in terms of sample selection, preparation and restoration. However, all protocols were standardized and consistent in all phases of the experiment by controlling measurements, timing, materials, and storage temperature among other variables.

Recommendations And Conclusions

Within the limitations of this *in vitro* study, it can be concluded that there is no significant difference in the fracture strength among the four lingual margin configurations for the Class IV resin composites. For this reason, the first hypothesis is accepted. Also, there is no association between the type of lingual margin configurations and the failure modes, so the second hypothesis is accepted.

Margin configurations continue to be part of the preparation for Class IV resin based composites due to scientific and clinical support (Donly & Browning, 1992; Geitel et al., 2004; van Dijken & Pallesen, 2010). The purpose of this mechanical *in-vitro* study was to focus on lingual margin configurations for Class IV preparations (butt joint, 45° bevel, 60° bevel and chamfer). However, further clinical trials or *in vitro* comparisons between different materials could be necessary to evaluate the mechanical behavior and fracture strength of these specific margin configurations under different conditions.

Future Study Directions

Since this study explored a new concept of mechanics of direct restorations based on analysis of vector of anterior masticatory forces, further studies should be considered to continue this line of investigation. Studies related to 3D-FEA Analysis could be appropriate to evaluate stresses and stress distribution of the whole component tooth restoration by comparing different margin configurations.

Furthermore, fracture strength analysis of facial bevels needs continuous investigation since the resulting vector forces was directed to this compressive area and different margin configurations could be compared. With the inclusion of a simulated periodontal ligament in the methodology of the experiment the *in vitro* study could be more realistic with tooth/periodontum complex environment. Finally, cyclic load test could be a better test to the present study because it closely imitates real life failures, including time, magnitude of force and frequency as variables in mechanical test for resin based composites.

APPENDIX

LIST OF INSTRUMENTS AND MATERIALS

NAME	MANUFACTURER	REFFERENCE
Digital Caliper	Mutitoyo Corp, Japan	03066565
Exaflex®Vinyl Polysiloxane impression material	GC America Inc., USA	1540208
Fastray™ Liquid	Harry Bosworth Company, Illinois	Self-curing acrylic material. Monomer
Fastray™ Powder	Harry Bosword Company, Illinois	Self-curing acrylic material. Blue color powder
Fine grit flame diamond bur	Brasseler, USA	8862.31.014
Chamfer bur	Brasseler, USA	6878k-018
Ultra-Etch® Phosphoric Acid	Ultradent Products, USA	35% gel
Optibond™ Fl Prime	Kerr Sybron, USA	4911439
Optibond™ Fl Adhesive	Kerr Sybron, USA	4790301
Almore Placement instrument	Almore, USA	96041
Royal Flat Brush	Royal Brush Co. Munster Indiana	#SG3010-2
Filtek™ Supreme Universal Restorative	3M ESPE, USA	6029C2B

Sof-Lex™ Extra-Thin Contouring and Polishing Discs	3M ESPE, USA	70200523929
Optilux 500 Demetron Light Curing Unit	KERR, USA	5803031
LED curing light VALO™	Ultradent Products, USA	AF908
Porcelain Etchant	BISCO, USA	4% gel
Porcelain Primer	BISCO, USA	B-2223
Porcelain Bonding Resin	BISCO, USA	B-3110P

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