Effect of Toothbrushing on Surface Roughness and Shade of Extrinsically Stained Pressable Ceramic Restorations

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EFFECT OF TOOTHBRUSHING ON SURFACE ROUGHNESS AND SHADE OF EXTRINSICALLY STAINED PRESSABLE CERAMIC RESTORATIONS

by

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ABSTRACT

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Purpose: The purpose of this study was to investigate the effects of toothbrushing on surface roughness and shade change of extrinsically stained pressable ceramic restorations.

Materials and Methods: Two materials, IPS Empress Esthetic and IPS e.max Press, were studied. For each material, 24 disc-shaped specimens, 10mm (diameter) x 3mm (height) were fabricated. Three different methods (n=8) of applying extrinsic stain was performed on each material: **Glazed (G)**: glazed only (control); **Stain then Glaze (SG)**: stained and fired, then glazed and fired. **Stained and Glazed (T)**: glazed and stained together. Samples where brushed using a multi-station brushing machine.

Each specimen was brushed for 72, 144, 216 and 288 h (equivalent to 3, 6, 9 and 12 years of simulated toothbrushing twice a day for 2 min) with a force of 200 g at a rate of 90 strokes/min using a soft, straight Oral-B #35 toothbrush and a 1:1 toothpaste and distilled water slurry. Roughness and color were evaluated at baseline and every 3 year equivalent up to 12 years of simulated toothbrushing.

Results: No significant difference was found for surface roughness or shade change over time irrespective of technique for the IPS Empress Esthetic (EE) groups. IPS e.max Press (EP) demonstrated an increase roughness over time (P<.01) irrespective of technique (P=.709). Shade change over time depended on the technique (P=.005). The stain then glaze (EP-SG) behaved better over time (P=.039).

Conclusions: Within the limitations of this study it can be concluded that no clinically significant shade change for both IPS Empress Esthetic and IPS e.max Press should be expected after 12 years of toothbrushing.

IPS Empress Esthetic stains and glaze were more resistant to toothbrush abrasion.

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CHAPTER I

INTRODUCTION

Esthetically acceptable restorations have become more attainable due to the improvement in restorative materials.[1] All-ceramic restorations are among the most esthetically pleasing substitutes for tooth structure due to their similar optical properties compared to natural dentition.[2] Despite the esthetic qualities of all-ceramic materials, restorative dentists may have difficulty choosing the optimal shade for a restoration, because of individual differences in shade perception and the ability to match the natural dentition.[3] Therefore, modifications with metallic oxide stains are often required to correct slight shade imperfections when compared to adjacent natural teeth. This process is known as extrinsic staining.[4]

Extrinsic staining is the superficial application of a stain to the outermost layer of a ceramic restoration. It is conventionally applied with a fine porcelain brush in order to recreate the special characteristics required to mimic a natural tooth.[4, 5] A potential major drawback of this technique is that the layer of stain is thinly applied and is directly exposed to the oral environment.[5] Time and function can wear the stained layer, resulting in the loss of color characterization of the restoration.

Toothbrushing is well-known as a preventive strategy for common dental diseases.[6] However, several studies have shown that toothbrushing can affect an extrinsically stained surface of metal-ceramic restorations.[4, 5, 7-10] Anil and Bolay[9] found a significant decrease in weight and roughness as well as shade change of extrinsically stained feldspathic dental porcelain after an equivalent of 8.5 years of toothbrushing. Aker et al.[5] demonstrated that the use of a normal toothbrush with a common dentifrice had the ability to wear away color corrective porcelain stains applied to the surface of metal-ceramic restorations in a period of 10 to 12 years, unless a protective layer of glaze was applied over the stain. Conversely, Bativala et al.[4] found that the extrinsic stain layer was resistant to significant loss from the use of a fluoride dentifrice applied with a soft multitufted toothbrush for at least 8.5 years of simulated brushing. They also found that for periods up to 11.4 years, some of the stain layer remained although the surface was significantly roughened. Currently, there are no studies that have examined the effect of toothbrushing on roughness and shade stability of pressable ceramic restorations.

The purpose of this study was to investigate the effects of toothbrushing on surface roughness, and shade change of extrinsically stained pressable ceramic restorations. In addition, the study investigated the differences among stain and/or glaze application techniques as well as the difference between modifying stains on the two tested pressable ceramic materials. The research hypothesis was formed; there will be no significant change of roughness or shade of the two stained and/or glazed all-ceramic systems (IPS® Empress Esthetic and IPS® e.max Press) after 3, 6, 9 and 12 years of simulated toothbrushing.

CHAPTER II

LITERATURE REVIEW

I. Ceramics

Ceramic is derived from the Greek word “keramos” which means “burned earth”. These materials are inorganic, nonmetallic and possess excellent compressive strength; however, they are weak in tension. Humans learned to make solid objects by baking suitable minerals at high temperature.[11]

History of ceramics in dentistry

In 1774, Alexis Duchateau, a Parisian apothecary attempted to fabricate the first all-porcelain denture. With the help of a dentist named Nicholas Dubois De Chemant, he was successful. So spectacular were these dentures, that they were called "incorruptibles". Soon after, Giuseppangelo Fonzi, an Italian dentist studying in Paris, fabricated the first single ceramic denture tooth. It was more than a hundred years later when Charles Henry Land introduced the first porcelain crown for single tooth restorations. However, this concept lost popularity due to the ceramics’ low fracture strength as well as to the introduction of acrylic resin. Looking to overcome the problem of ceramic brittleness, Weinstein, Katz and Weinstein (1962)[12] introduced the first leucite-containing porcelain that could be used for metal-ceramic restorations. This new technique allowed fabrication of metal-ceramic restorations with excellent strength and esthetics. In 1965 McLean and Hughes [13] introduced the first successful all-ceramic crown. By adding particulate alumina to feldspathic porcelain, they were able to double its flexural strength. However, they found this addition to be technique sensitive and the marginal fit was not considered to be as good as metal-ceramics. Although zirconia had been available in the medical field since 1969, it was not until the early 1990s that its applications extended into dentistry. In 1991, IPS Empress was introduced in the United States. IPS Empress was found to be unsuitable for posterior restorations, stimulating further research and development in this field. In 1998 IPS Empress 2, a lithium disilicate ceramic, was introduced and led to the development of an improved press fit ceramic that is known today as IPS e.max® Press (Ivoclar Vivadent Inc.).[2, 12, 14-17]

Traditional metal-ceramic restorations continue to be popular due to their predictable strength and reasonable esthetics. However the increasing demand by patients for greater esthetics has increased the utilization of all-ceramic restorations.[14]

Classification of ceramics

Ceramics can be classified according to their microstructure, fabrication technique, composition, application, fusion temperature, translucency, or type of restoration.[11] The two most commonly used classifications are from Rosenblum and Giordano:

1. Rosenblum[18] described five categories of all-ceramic systems according to their fabrication technique:

a. Conventional: combination of powder and liquid to form a slurry and applied in increments on a master die to form the contours of the definitive restoration. Powders are available in different shades and translucencies.
b. Castable: solid ceramic ingots, cast using the lost wax and centrifugal casting technique.
c. Machinable: ceramic ingots available in different shades and materials, designed on a computer and milled from solid blocks of ceramic.
d. Pressable: ceramic ingot supplied in different shades and materials, material is melted and injected into a mold using the lost wax technique.
e. Infiltrated: powder and glass, powder forms a substrate to which the glass is infiltrated at high temperature.

2. Giordano[11] classified ceramics at the microstructural level according to the amount of glass-to-crystalline ratio:

In general the more glass present in the ceramic microstructure the more translucent it will be; the more crystalline the structure, the more opaque it will be. The glass based groups are etchable, due to its glassy phase in comparison to the crystalline groups which cannot be etched. There are four basic compositions:

a. Glass based systems: the major component is silica or quartz. They offer satisfactory esthetics but lack strength. Their flexural strength has been reported between 60 and 70 MPa. Therefore, their main use is as a veneering material or as a veneer. They are also known as feldspars.

b. Glass based with added crystals: In this group a crystalline phase is added to a glassy phase to prevent crack propagation. The main crystals used in todays materials are: leucite, lithium disilicate or fluoropatite. This group can be further divided into three subgroups according to glass-crystalline ratios and crystal type.

   i. Low to moderate leucite: known as feldspathic porcelains. They are found in powder and liquid form.
   ii. High leucite: Leucite crystals evenly grow in a multi-stage process directly from the amorphous glass phase. There is a 50% leucite (crystal structure). Empress is an example of this type of ceramic.
   iii. Lithium disilicate glass ceramic: the crystal content is 70%. “The glass matrix consists of lithium disilicate with micron-size lithium disilicate crystals in between creating a highly filled glass matrix.”[11]

   These ceramics offer 360 MPa of flexural strength and high translucency. IPS e.max is an example of this material.

c. Crystalline based with fillers/interpenetrating phase ceramic: in the first stage it consists of a porous matrix which is filled with a second phase material. This group contains products with a great variety of translucencies and flexural strengths. An example of these products include: Vita In-Ceram® (spinel, alumina and zirconia).

d. Polycrystalline solids**:** crystals are sintered together with no matrix. The main example is Procera ® (alumina and zirconia).

Two ceramic materials, IPS Empress® Esthetic (Ivoclar Vivadent Inc.) and IPS e.max Press were used in this study; therefore, the properties of those materials will be further elaborated on.

IPS Empress Esthetic

This is an all-ceramic system available for pressing, as well as for Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) technology. IPS Empress Esthetic consists of pressable ingots made of reinforced leucite. Twelve types of ingots are available in seven levels of translucency. Leucite crystals evenly grow in a multi-stage process directly from the amorphous glass phase. Its composed of 50% leucite, which is used as a crystalline reinforcing phase. It exhibits a flexural strength of 160 MPa and is suitable for fabrication of single fixed dental prostheses, such as inlays, onlays, veneers and crowns. Survival rates for inlays and onlays have been reported to be 90% after 8 years; veneers had a 94.4% survival rate after 12 years; crowns reported a 95.2% survival rate after 11 years. Overall, the material demonstrated a favorable clinical behavior.[16]

However the use of leucite reinforced materials has decreased due to the introduction of lithium disilicate, which has been reported to possess improved mechanical properties, yet still very esthetic.[16]

IPS e.max Press (lithium disilicate glass-ceramic)

This all-ceramic system is available for pressing as well as for CAD/CAM technology. IPS e.max Press consists of pressable ingots made of lithium disilicate glass-ceramic (LS2). The definitive restoration can be monolithic or layered with IPS e.max CERAM layering porcelain. It possesses a flexural strength of 400 MPa.[16] Ivoclar's scientific report vol.02/2001-2013 summarized the results of 6 clinical studies that demonstrated a 97.5% survival rate over a mean observation period of 5.6 years.[19]

Some of its clinical applications are for single fixed dental prostheses such as inlays, onlays and posterior crowns. It is also used as a core material for anterior crowns and fixed dental prostheses. It is available in different opacities such as: high translucency, low translucency, medium opacity and high opacity.

High opacity (HO): is indicated for masking heavily discolored teeth.

Medium opacity (MO): is considered to be opaque and layering is recommended. These materials range from MO 1 to MO 4, as well as, an M0 bleach shade.

Low translucency (LT): is available in nine A-D shades. Pigments are utilized in these ingots to provide the desired shade.

High translucency (HT): possess a characteristic known as the "chameleon effect", which means that the ceramic reflects the shade of adjacent tooth structure.

Initially, all-ceramic restorations were fabricated using a bilayer technique. One of the major disadvantages with this method was susceptibility to chipping in the layering porcelain. Chipping rates were generally higher than those observed with metal-ceramic restorations, which hastened development of monolithic all-ceramic systems.[20] Since there is no esthetic veneering material for monolithic all-ceramics, custom shade matching with surface color correction pigments may be required.

One of the greatest challenges a clinician faces every day is to accurately choose the correct color for a new prosthetic restoration. Matching a restoration with the natural dentition is difficult because most shade guides do not include the vast array of colors found in the natural dentition. An additional challenge is when patients have special dental characteristics such as decalcification or exposed root surfaces. These characteristics require modifications of normal shade selection techniques and restoration design in order to achieve optimal color match. Characterization can be accomplished using metallic oxide stains and color modifiers. These are applied to the surface of the porcelain and fired in a process known as extrinsic staining.[4, 21]

II. Metal oxide pigments

Extrinsic staining is achieved with metal oxide pigments, stains and color modifiers which are essential parts of commercial dental porcelain kits. Stains have a higher concentration of color frit than color modifiers. Color modifiers are mainly used to give the restoration gingival effects, as well as aiding in darkening or lightening the color of restorations. Stains are commonly used as surface colorants, and for creating check lines and decalcification spots. These stains permit the definitive restorations to mimic the natural dentition, improving its final appearance.

In order to create pigmented porcelains, metal oxides must be added to the glass utilized in dental porcelain. The glass is heated to a high temperature and then fritted.

This procedure produces a highly color saturated glass which is then ground into a fine powder.[22, 23] Some of the metal oxides may consist of the following:

- Pink pigment comes from chromium-tin or chromium-aluminum oxide. This pigment helps to give a warm tone to the porcelain and diminish green hues.
- Yellow pigment is derived from indium or praseodymium oxides. It is used for producing an ivory shade.
- Blue pigment comes from cobalt salts. This color is used to produce some of the enamel shades.
- Green pigment is obtained from chromium oxide.
- Grey pigment comes from iron oxide or platinum gray. It is useful for producing enamels or gray sections of dentin.

Pigments can be applied on the restoration according to personal preference as well as clinical situations. Stain and glaze can be mixed together, applied, and fired. Another way is to apply glaze and fire, followed by the application of a stain and fired. This is done when a crown has been glazed and stain needs to be added for correction after try-in. A third method is to apply stain, fire the stain followed by glaze and firing.[5]

Clinicians have relied on the application of external stains for creating natural looking restorations. However, in a study by Anil and Bolay[9] they concluded that in order to ensure the durability of stains they should be placed as deeply as possible in the restoration.[9] The permanence of this corrective layer applied to the external surface of all-ceramic restoration has not been clearly established. Therefore color should be evaluated over time.[14] Lund et al.[10] evaluated the effect of color perception by applying stains at different levels of simulated ceramo-metal crowns. One hundred-thirty porcelain-fused-to-metal samples were divided into the following categories:

1) Control.
2) 40 samples had a layer of stain applied over the porcelain.
3) 40 samples had a layer of stain interposed between 1 mm of porcelain above and below.
4) 40 samples had a layer of stain applied directly to the opaque.

Each group was then divided into four subgroups of 10. Stains were applied using the following colors: red, yellow, and blue/violet. Metal oxide pigment was applied in the following way: 30 samples were placed together on a large white background. Color was applied until samples seemed visually comparable. "It was found that as surface stain was submerged, the hue, value and chroma of the restoration tended to revert to those of the body porcelain. It was also found that some surface stains could increase or decrease the value or the chroma of the porcelain restoration."[10]

III. Color

The two most common systems for describing color are the Munsell system and the CIE (Commission International on Illumination).[1, 3, 9]

Munsell

The Munsell color system has been widely used in the literature.[3] Albert Munsell used the terms hue, chroma and value to describe a given color. Hue was described as the quality of the color represented by red, yellow, green and blue. Value was the lightness or darkness of the color. The third color dimension, chroma, defined the strength or weakness of a color and described intensity or saturation. “The Munsell’s numbers for each coordinate were designed to have equal numeric steps to correspond with equal differences in visual perceptions. Plotting three such coordinates requires a three-dimensional solid. The Munsell’s solid has black in a unique position at the bottom and white at the top. The neutral grays are located along the central axis. The distance outward from the axis is governed by the saturation of color (chroma) with equal perceptual steps numbered outward from the neutral axis. Hues proceed clockwise. The principal hues are red, yellow, green, blue and purple with intermediate hues showing admixtures.”[10] Shade selection depends on understanding how color works. Managing the three dimensions of color as proposed by Munsell should give the clinician the tools to accurately select color. Apart from describing color in a three-dimensional way, the Munsell system is decimal based. This allows a clear communication of the color regardless of what language is spoken or where the practice is. Therefore it is extensively used in art, science, industry and education. [3, 10, 24]

However in order to determine color differences and collection of data a numerical description is needed. The most commonly used color classification system for research is the CIE color system.[3]

CIE (Commission International de L´éclairage)

The International Commission on Illumination CIE (Commission International de L´éclairage) was created in 1931. This system is based on the additive color system. "The CIE is a psycophysical system incorporating a standard observer and coordinate system. This system includes standard light sources A, B, C and D covering a broad color temperature range. It also includes a standard observer, which is a mathematical description of the average normal human visual response to color stimulation."[3] Between 1976 and 1978 the CIE developed a new system, called CIEL*a*b* where L* refers to the lightness, a* corresponds to red and green while b* corresponds to yellow and blue. This system made it possible to classify and correlate color numerically and to calculate the difference between two colors using a formula that gives one number (ΔE) as a value for color differences.[3, 25]

Color differences can be evaluated using the following formula:

$$\Delta E * ab = ([L_1 - L_2]^{2} + [b_1 - b_2]^{2} + [a_1 - a_2]^{2})^{1/2}$$

Color differences (ΔE)

The color differences between two objects can be determined by comparing the coordinate values of each object and calculating the ΔE. In order to understand its clinical significance it is necessary to understand color tolerances such as perceptible tolerances and acceptability tolerances. Perceptible tolerances are the amount of color difference, which might be detected visually. Acceptability tolerances are the alteration of color, which is considered unacceptable to esthetics.[26] Douglas et al.[26] summarizes different studies that evaluate color-matching tolerances with ΔE values as low as 1 but as high as 3.7 determined as limits for matching. However all of the evaluated studies were performed in nonclinical conditions. Therefore he performed a clinical study were he reported perceptibility tolerances to be at ΔE of 2.6 while acceptability was 5.5 ΔE. [26]

In order to consider a restoration to be successful, its color should match the surrounding dentition. However this is no easy task as mismatched color is reported between 44 and 63% of the times.[26]

The perception of color is different between individuals and within the same individual over time. When a color difference is detected between two samples, a disagreement normally occurs whether this difference is acceptable or not. For this reason the use of color measuring devices has been helpful in obtaining objective assessment of color differences.[27]

Color Measuring Devices

Patients' desire for natural looking restorations that match their natural dentition has increased, making the importance of shade matching procedures critical.[28] Choosing the appropriate shade for patients and being able to replicate that color with restorations is an essential step for obtaining a natural looking restoration.[28] Color perception is greatly dependent on individuals as well as illumination, background color, position and shape.[1, 28]

Tooth color selection is performed routinely in dental offices. The most common method of doing this is with the use of shade guides. By using an intermediate tool such as the shade guide for determining color, clinicians are exposed to two potential sources of error: 1) incorrect shade selection by the clinician, and 2) incorrect shade reproduction by laboratory technicians. Historically, shade tabs did not represent all the existing colors found in the natural dentition. Therefore, in 1996 Vita developed an improved shade guide, the 3D-MASTER shade guide. During development of this new shade guide, color differences were standardized by a ΔE of 5, making shade selection easier. However to ensure that the color selections are accurate, the use of colorimeters and spectrophotometers has been encouraged. The use of instruments such as spectrophotometers and colorimeters for shade selection is believed to eliminate some of the variables associated with shade matching.[28, 29]

Spectrophotometer

A spectrophotometer measures the reflected or transmitted light from a specific object and provides measurements corresponding to visible light wavelengths.[30] Spectrophotometers can be divided into clinical and laboratory types.[25]

Stability of color on dental restorations

It has been noted by some clinicians that some restorations lack the same natural appearance they had when they were originally cemented.[5] Although this change might be multifactorial, the removal of the thin layer of color corrective porcelain stains by toothbrush abrasion should be considered.[5] Stains are applied to the outer most layer of a ceramic restoration, and with time, this layer may be worn, resulting in the loss of characterization of the restoration.[9] One of the down sides of the surface staining technique is the layer of stain material is directly exposed to the oral environment.

Durability of extrinsic staining is one of the main factors to consider because color stability is essential to maintain color match and aesthetics.[31] Aker et al.[5] investigated whether externally stained porcelain could be removed by toothbrush abrasion and if different methods of applying the stain might be more resistant to removal than others. The 3 methods used were 1) stain was applied and fired, then clear glaze was applied and fired, 2) stain was applied and fired, and 3) porcelain was glazed and fired, then stain was applied and fired. It was concluded that stains can be completely removed in 10 to 12 years unless a protective layer of glaze is applied. Samples that were prepared by applying a layer of glaze over the stain needed more than twice the amount of time to completely remove some portion of the stain. It is important to consider that the values in this paper are for the complete removal of the stain and not for what is considered a clinically significant color change.

Anil and Bolay[9] looked at the effect of toothbrushing on the material loss, roughness, and color change of internally and externally stained feldspathic porcelain after 8.5 years of simulated brushing. The color change of extrinsically stained samples was significantly affected by the decrease in thickness of stains, and it was recommended that staining be done as deeply as possible. On the contrary, Bativala et al.[4] in 1987 looked at the effect of toothbrushing with dentifrice on stained porcelain samples after

8.5 and 11.4 years of simulated brushing. After analysis with scanning electron microscopy it was concluded that there was no significant color difference between the brushed and the unbrushed samples after 8.5 and 11.5 years. However an increase in surface roughness was observed but not measured.

Toothbrushing and toothpaste

Many types of toothpastes are commercially available for toothbrushing. There is some belief that toothbrush abrasion and recession are the results of toothbrushing. However, there are studies that have proven that abrasion is due to the effect of the dentifrice only and has no relationship to the toothbrush. The purpose for toothpaste is to prevent dental caries, gingivitis, and halitosis. Toothbrushing has been accepted as the most effective way to remove plaque and consequently prevent caries and periodontal disease. Therefore, dentists should prescribe a dentifrice that is the least harmful to natural dentitions.[7]

Abrasion is defined as the wearing of a structure by mechanical force, and from a foreign object. Intraorally, this foreign object is toothpaste. However, this normally does not represent a problem in the dental office unless there are sensitivity, functional, or esthetic complaints. Toothpaste contains insoluble abrasive components such as: silica, calcium carbonate, aluminum oxide, perlite, and pumice. These ingredients are needed to remove debris, stains, and plaque. Abrasiveness of the product is a function of the particle size, hardness, quantity, shape, and distribution.[32] Toothpaste abrasivity is measured using relative dentin abrasivity (RDA). The American Dental Association allows for a maximum RDA of 250.[33] The Colgate total toothpaste used in this study has a RDA value of 70.[33]

Investigating toothbrush bristle stiffness, Kinoshita[7] conducted a study that evaluated toothbrushes with different hardnesses: Perio S, M and H (filament diameter 0.23, 0.33 and 0.40mm). Specimens were brushed 3,000 times using a back and forth stroke movement on a toothbrushing machine for 2 hours at a load of 600g. Surface irregularities were observed by the scanning electron microscope before and after the brushing procedure. Abrasiveness was determined by examining changes in scratch marks, weight loss, profile changes, and luster of the material. Abrasiveness of the toothbrush itself was not observed; however, some slight scratch marks were created by the 0.40 mm filament toothbrush. Regardless of the bristle hardness, it had no abrasive effect on enamel and dentin. Tooth surfaces that were brushed with no dentifrice exhibited no abrasive effects on the enamel or dentin. For the research in this thesis, a soft, straight Oral-B #35 toothbrush was used.[8, 34]

Arai and Kinoshita[6] compared 6 toothbrushing methods and 2 types of electric toothbrushes. When evaluating the toothbrushing methods, the Fones (circular motion) and scrub technique (horizontal) was found to be the most effective in plaque removal. The hard brush was found to be the most effective for plaque removal. Electric toothbrushes were almost equivalent to manual toothbrushes for eliminating plaque. Effective plaque removal is optimum to prevent progression of dental diseases as well as to maintain oral health.[35]

Toothbrushing load

The two main factors that have an effect on plaque and stain removal during toothbrushing are applied force and the duration.[35] Wiegand et al.[36] reported that the average brushing force of a manual toothbrush was 1.6 ± 0.3 N which was equivalent to 163 grams. Van der Weijden et al.[37] investigated the relationship between plaque removal and force during manual toothbrushing and found no correlation between brushing force and plaque removal. The mean brushing force in Van der Weijden's study was 330 to 400 g. McCracken[35] performed a study to determine the effect of different brushing forces on plaque removal. Up to 300 grams were used for the force, and the brushing times included were 30, 60, 120 and 180 seconds. It was concluded that "at 2 min brushing time, the effect upon plaque removal of increasing brushing force above 150g was negligible." For the research in this thesis a load of 200 g was selected. In combination with brushing 2 minutes, 2 times a day as recommended by the American Dental Association.[38]

Kinoshita[7] conducted a study that evaluated the effect of abrasion by commonly used dentifrices on acrylic resin and human teeth. Specimens were brushed 3,000× using a back and forth stroke movement on a toothbrushing machine for 2 hours at a load of 600g. Seventeen toothpastes were used to evaluate abrasivity on acrylic resin, while only 3 toothpastes were used to evaluate abrasiveness on extracted human teeth. A scanning electron microscope was employed to evaluate the surfaces before and after the brushing procedures. Abrasiveness was determined by examining changes in the scratch marks, weight loss, profile changes and luster of the material. The dentifrices showed a wide range (high, medium and low) of abrasiveness. When using a low abrasive toothpaste, scratch marks were confined to dentin. When using a medium or high abrasive toothpaste, scratch marks were found on enamel and dentin. Scratch marks correlated with the size of the particles. When the tooth surface was brushed without toothpaste, its appearance was similar to the before brushing image. Table 1 summarizes the previously discussed studies.

Table 1. Summary of the materials and methods utilized by similar studies:

Author	Brush strokes	Toothbrush	Replacement	Slurry	Load
Anil and Bolay [9]	120,000 (equivalent to 8.5 years)	Hard nylon multitufted toothbrushes (Banat Dental)	Brushes and toothpaste mixture were replaced after every 20,000 brush strokes.	1:1 (75g of toothpaste and 75g of synthetic saliva)	600g
Aker [5]	16,000 toothbrush strokes per hour (equivalent to 1 year twice a day)	Pycopay (Block Drug Co.)	Brushes and slurry where replaced every 15 hours	1:1 (Colgate and distilled water)	450g
Bativala [4]	120,000 (equivalent to 8.5 years)	Soft nylon multitufted (Butler)	Brushes and toothpaste mixture were replaced after every 20,000 brush strokes.	1:1 (crest and distilled water)	250g
Faria [39]	260,000 (equivalent of brushing the whole mouth)	Oral B indicator plus soft bristle toothbrush	Brushes and toothpaste mixture were replaced after every 20,000 brush strokes.	1:1 (toothpaste to deionized water)	5N (500g)
Wataha [8]	48 hours at 90 strokes per minute base don 2min of brushing twice a day for 2 years (representing the whole mouth)	Soft Straight Oral B #35	N/A	1g of Colgate toothpaste to 10ml of phosphate buffer saline	200g

Roughness

Rough surfaces may lead to plaque retention and plaque accumulation.[40] The performance of a restoration in the patient's mouth over the years allows clinicians/researchers to evaluate its quality in subjective ways. Laboratory surface roughness tests provide objective measurements that may have practical benefits for clinicians. Surface analysis, in a laboratory setting, permits evaluation of materials and different techniques before they are used clinically. Measurement techniques can be divided into two main categories, 1) contact type, and 2) non-contact type. Of these methods, the contact type is more popular.[41, 42]

Surface analysis is a method to measure and describe the shape of a surface. The most common terminology used to describe surfaces are:

Ra: arithmetical mean deviation of the profile average of the absolute values of the profile deviations from the mean line.

Ry: the sum of the highest peak and the deepest valley from the mean line.

Rz: average of the five highest peaks and the average of the five deepest valleys. The minimum value of the height and depth of the valley must be 10% of the Ry.

Bativala et al.[4] looked at the effect of toothbrushing with dentifrice on stained porcelain samples after 8.5 and 11.4 years of simulated brushing. Samples were prepared by applying stains until they were visually comparable. Samples were then sectioned in half; one half was brushed and the other half served as a control. The thickness of the stain layer of brushed and un-brushed samples were measured using a light microscope. A scanning electron microscope was used for making a visual assessment of roughness. Following sample analysis, it was concluded that increased surface roughness was observed in brushed samples however no loss of stain was reported.

Anil and Bolay[9] looked at the effect that toothbrushing had on material loss, roughness, and color change of internally and externally stained feldspathic porcelain. It was found that material loss and decreased roughness occurred when brushing the equivalent of 8.5 years. Regardless of the type of stain application, chroma was insignificantly changed; however, the overall color change was significantly affected. Nesarin and Sukran[9] concluded that to ensure the durability of stains, stains should be placed as deeply as possible in the restoration.

Currently there are no studies that have examined the effects of toothbrushing on pressable ceramic restorations; therefore, the objectives of this study were to assess the effect that toothbrushing has on shade and roughness of extrinsically stained ceramic restorations. Four research hypotheses were formed:

Hypothesis 1: There will be no shade change on IPS Empress Esthetic samples after 3, 6, 9 and 12 years of simulated toothbrushing irrespective of technique.

Hypothesis 2: There will be no change in the average roughness of IPS Empress Esthetic between baseline specimens and after 3, 6, 9 and 12 years of simulated toothbrushing irrespective of technique.

Hypothesis 3: There will be no shade change on IPS e.max samples after 3, 6, 9 and 12 years of simulated toothbrushing irrespective of technique.

Hypothesis 4: There will be no change in the average roughness of IPS e.max between baseline specimens and after 3, 6, 9 and 12 years of simulated toothbrushing irrespective of technique.

CHAPTER III

MATERIAL AND METHODS

Using power analysis, it was determined that the sample size of 48 specimens was sufficient to test our hypotheses with power of 80% and the medium effect size.

Materials were composed of two factors, IPS Empress Esthetic and IPS e.max Press while methods had three levels. The study had a factorial design with materials and methods measured repeatedly over time for shade and surface roughness. Each factor combination was tested on 8 specimens for a total sample size of 48 specimens.

The following materials were tested:

Material 1 (IPS-EE): IPS Empress Esthetic ingots ETC1

Material 2 (IPS-EP): IPS e.max Press ingots LT shade A1

Disc-shaped specimens, 10 mm (d) × 3 mm (h) were prepared for both all-ceramic materials according to manufacturer specifications and subsequently modified as follows (Table 2):

Method 1 (G): Specimens glazed at the recommended firing temperature. This was the control group.

Method 2 (SG): Specimens were stained, then fired. In a second procedure, glaze was applied and fired at the recommended temperature.

Method 3 (T): Specimens were stained and glazed together at the recommended firing temperature.

Table 2. Groups studied

Groups				
	Control only glaze (G)	**Stain then Glaze (SG)**	**Stain + glaze (T)**	
IPS Empress Esthetic (IPS-EE)	**8 (1. EE-G)**	**8 (2. EE-SG)**	**8 (3. EE-T)**	24
IPS E.Max Press (IPS-EP)	**8 (4. EP-G)**	**8 (5. EP-SG)**	**8 (6. EP-T)**	24
Total	16	16	16	48

Wax pattern fabrication

A Metal mold fabricated by Sabri Dental Enterprises Inc. (Downers Grove, IL) was used to form round wax patterns. Patterns were 3 mm (h) × 10 mm (d). For sample fabrication a glass slab was used as the flat surface. The glass was cleaned each time using a window cleaner (Windex). Corning white inlay wax (Corning Waxes Co. Inc. Ronkonkoma, NY) was heated in a wax pot. Once the wax was completely molten, a stainless steel measuring spoon was used to pick up and carry the wax into a Bunsen burner flame for 5 to 7 seconds. The wax was then poured into the metal mold. The mold rested on top of a glass slab. After pouring the last specimen, the wax was allowed to cool for 2 minutes. Excess material extruding above the metal mold was removed with a sharp blade making the samples flat. A fiducial mark was carved into the wax patterns so samples could be oriented in the same way for glaze, stain, and brushing. Samples were separated from the glass and stored until all-ceramic specimen manufacture.

Sample selection

Wax patterns were inspected at 10× magnification (American Optical). Patterns without voids or imperfections were selected. This selection process was performed by two examiners.

IPS Empress and IPS e.max Press sample fabrication

Sprueing: Eight gauge wax, 5 mm long, was used to connect the wax patterns to the investment ring. Subsequently Pro-Art® wax (Ivoclar Vivadent Inc.) was used to seal the connection. The length of the 8 gauge wax sprue was 5 mm long. The sprueing angle was 60 degrees (Fig. 1), and a distance of at least 10mm was maintained between the wax

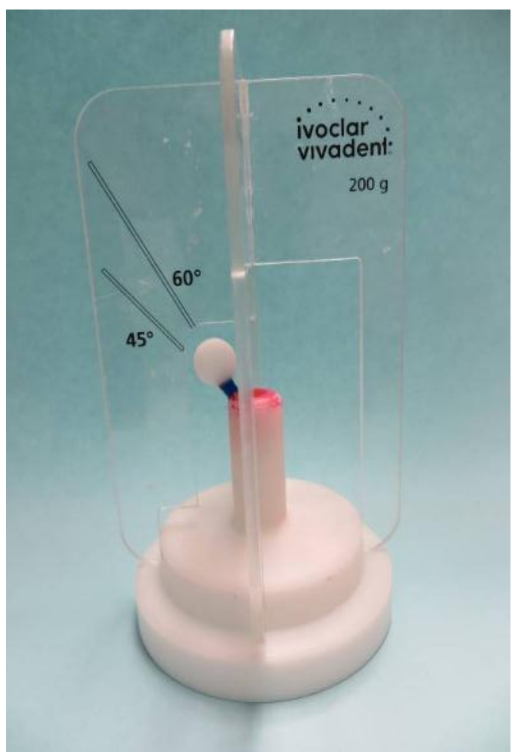

Figure 1. IPS sprue guide.

patterns and the silicone ring. Correct sprueing of the wax patterns was verified with an IPS sprue guide.

Investing: A silicone ring (200 g, IPS Silicone Ring, Ivoclar Vivadent, Inc.) with matching ring gauge was used. The ring base was positioned into place without damaging the wax patterns. Debubblizer was not used as recommended by the manufacturer. Two-hundred grams of phosphate-bonded (IPS®Press VEST Speed for IPS e.max press samples and IPS® Empress Esthetic speed for IPS Empress Esthetic samples , Ivoclar Vivadent Inc.) (Fig.2) was mixed with 32 ml of liquid and 22 ml of distilled water for 2.5 minutes in a vacuum mixer (Renfert Twister Evolution). The silicone ring was filled with investment up to the reference marking. The ring gauge was positioned with a hinge movement. Investment was allowed to set undisturbed for 45 minutes.

Figure 2. IPS VEST Speed phosphate-bonded investment.

Preheating: After setting, the ring gauge and ring base were removed with a turning movement. Rough areas on the bottom surface of the investment rings were removed with a plaster knife. A burnout oven (Jelrus Infinity L30, Whip Mix®) was preheated to 850ºC.

-IPS Empress: IPS Empress Esthetic ingots, IPS Empress Alox Plunger (Ivoclar Vivadent Inc.) and investment ring were placed into the preheated oven.

-IPS e.max Press: Only the investment rings were placed in the preheated furnace, towards the rear wall, tipped with the opening facing down.

Pressing:

Hot IPS Empress Esthetic ingots, room temperature IPS e.max Press ingots and Alox plunger were positioned in the investment ring in the door furnace. The completed investment rings were placed on a Programat EP 5000 press furnace and the press program was started. (Fig. 3)

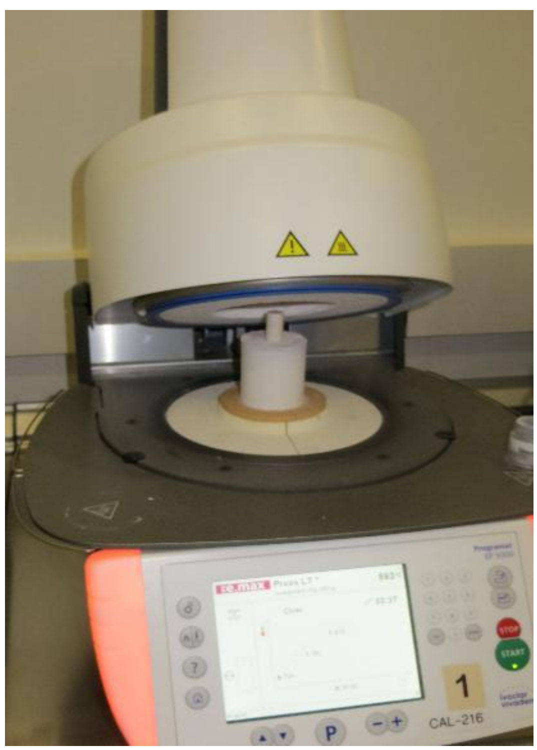

Figure 3. Press furnace Programat EP 5000.

Divesting: After cooling to room temperature, the length of the Alox plunger was marked on the investment ring (Fig. 4). A disc was used to cut through the investment ring at the predetermined line, the investment rings were broken using a plaster knife. Rough divestment was carried out with glass polished glass beads at 0.4 MPa pressure, followed by fine divestment at 0.2 MPa. Sprues were removed using a NTI fine diamond disk. Excess from the sprues was removed by hand using 320 grit paper.

Figure 4. Investment ring with reference cutting line.

Sample preparation: Samples were flattened using 320 silicon carbide paper. Thickness was confirmed with a digital caliper (Westward). Once the surfaces were flat, 2 samples at a time were secured to the tool (Fig. 6). Specimens were then ground down from 3 mm to 2.90 mm (Fig. 5) using silicon carbide paper through 420 grit paper to allow for addition of 100 μm of extrinsic characterization material.

Figure 5 Sample Measurements for stain application.

Surface preparation was performed as follows:

Method 1 (G):

-EE-G: Specimens were glazed with IPS Empress® universal glaze paste (Ivoclar Vivadent Inc.) and fired using the glaze firing program.

-EP-G: Specimens were glazed with IPS e.max® Ceram glaze (Ivoclar Vivadent Inc.) and fired using the glaze firing program.

Method 2 (SG):

-EE-SG: Specimens were stained using IPS Empress® universal shade A4 (Ivoclar Vivadent Inc.) and fired using the stain and characterization firing program. Then, Empress universal glaze paste was applied and fired using the glaze firing program.

-EP-SG: Specimens were stained using IPS e.max® Ceram shade A4 (Ivoclar Vivadent Inc.) and fired using the stain and characterization firing program. Then, IPS e.max Ceram glaze was applied and fired using the glaze firing program.

Method 3 (T):

-EE-T: Specimens were glazed and stained together using Empress universal shade A4 and Empress universal glaze paste and fired using the stain and glaze firing program.

-EP-T: Specimens were glazed and stained together using IPS e.max Ceram glaze and IPS e.max Ceram shade A4 fired using the stain and glaze firing program.

Using the fiducial mark on the underside of the samples, brush strokes for stain application were made parallel to that mark. After addition of stain and/or glaze materials, samples were measured again and ground using silicon carbide paper through 420 grit until a final thickness of 3 mm (±30 microns) was achieved (Fig. 6). This method allowed for an addition of 1.0 mm of glaze or stain and glaze to each specimen.

Figure 6. Grinding of specimens with silicon carbide paper to achieve 3 mm thickness after stain application.

Simulated Toothbrushing

Simulated toothbrushing was performed using a multi-station brushing machine (Sabri Dental Enterprises, Fig. 7). The machine contained four arms and a reservoir that allowed brushing 8 specimens simultaneously. A soft, straight toothbrush (Oral-B #35) was used for the brush heads. The reservoirs were filled with a solution made from 150 grams of medium abrasive 70 RDA toothpaste (Colgate Total) suspended in 150 ml of distilled water (1:1 ratio). Specimens were fixed in place using custom made polymer holders and positioned so that the fiducial mark and the brush strokes were parallel with each other. Each specimen was brushed for 288 hours with a load of 200 grams at a rate of 90 strokes min^{-1} with interruptions at 72, 144, and 216 hours. Brushes and toothpaste were replaced after every 3 years of simulated brushing. Forty-eight thousand strokes in the multi-station brushing machine was determined to be equivalent to 3 years of twice daily toothbrushing for 2 minutes.[5] Specimens were rinsed with water and dried after brushing and before measurements. Each specimen was evaluated for shade changes using a spectrophotometer and surface roughness with a profilometer at baseline, and after 72, 144, 216, and 288 hours of brushing.

Figure 7. Multi-Station brushing machine.

Roughness

Surface roughness was evaluated using a profilometer (Mitutoyo Surftest SV-400, Fig. 8). The instrument was calibrated using a standard reference specimen, then set to travel at a speed of 0.10 mm s^{-1} with a range of 600 μm during testing. A Gaussian filter and the amplitude transmittance of 50% were selected. A diamond stylus (5 μm tip radius) was used under a constant measuring force of 3.9 mN. Surface roughness (R_a, R_y, and R_z) was measured 3 times by orienting the fiducial mark at the 11, 12, and 1 o'clock positions. The detector moved across the sample, and perpendicular to the direction of the toothbrushing direction. The surface analyzer was used to determine a roughness profile for each specimen.

Figure 8. Mitutoyo Surftest SV-400.

Color

Color measurements were made using a spectrophotometer (CM-700D; Konica Minolta). Measurements were acquired at baseline, and after 3, 6, 9 and 12 years of simulated toothbrushing. Samples and spectrophotometer were positioned in a customized holder which allowed repeatable positioning (Fig. 9 and 10). Measurements were performed 3 times and averaged by the software. Averages of the 3 measurements were collected and used for data analysis.

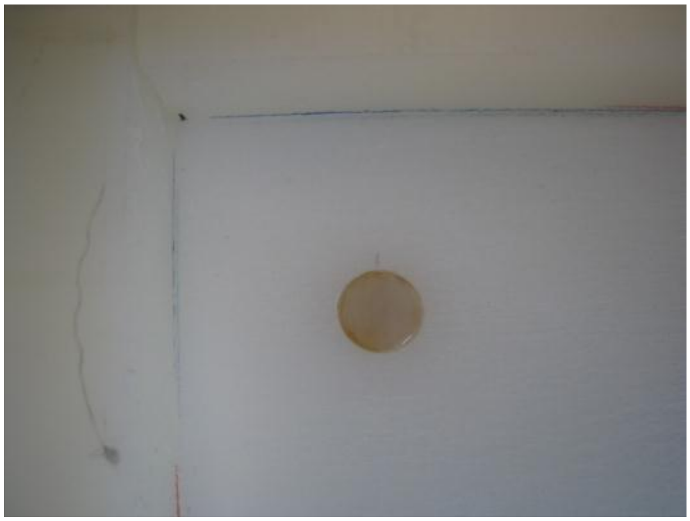

Figure 9. Custom holder for samples and spectrophotometer.

Figure 10. Spectrophotometer placement on holder.

Statistical Analysis

One examiner (L.G.) collected all 1,440 measurements. These measurements were recorded in a spreadsheet (Excel 2010, Microsoft). Analyses were made using statistical software (SPSS 21, IBM).

For both roughness and shade one factor repeated measures analysis of variance (ANOVA) was used at an alpha level of 0.05 with multiple comparisons using Tukey`s test. The repeated measures were ΔE as the dependent variable, and technique (G, SG, and T) as the factor.

CHAPTER IV

RESULTS

Empress Esthetic (EE)

Color

There was no significant shade change over time, irrespective of glaze application technique (*P*=.268) (Table 3 and 6).

Roughness

The three stain and glaze application techniques had no effect on roughness (*P*=.482). In addition, there was no significant increase in roughness over time (*P*=.141) (Table 4 and 6 and Fig. 11).

IPS e.max Press (EP)

Color

The change in color over time depended on the technique (*P*=.005). The stain then glaze (EP-SG) behaved better over time (*P*=.039) (Table 3 and 6).

Roughness

Average roughness significantly increased over time (*P*<.01). This increase did not depend significantly on technique (*P*=.709) (Table 5 and 6 and Fig. 12).

Color

Table 3. IPS Empress Esthetic and IPS e.max Press color measurements

	Baseline			3 Years				6 Years				9 Years				12 Years			
Group	L*	a*	b*	L*	a*	b*	DE	L*	a*	b*	DE	L*	a*	b*	DE	L*	a*	b*	DE
EE-G	74.84	0.41	6.5	74.89	0.38	6.5	0.14	74.88	0.4	6.55	0.2	74.95	0.4	6.54	0.16	74.97	0.4	6.55	0.16
EE-SG	70.71	4.23	11.56	70.89	4.23	11.52	0.29	70.64	4.21	11.46	0.52	70.81	4.24	11.56	0.22	70.88	4.23	11.53	0.18
EE-T	66.53	6.56	20.95	66.59	6.58	21.04	0.17	66.6	6.57	20.97	0.12	66.64	6.56	20.98	0.15	66.59	6.59	21	0.16

ΔE = Change in color compared to baseline

	Baseline			3 Years				6 Years				9 Years				12 Years			
Group	L*	a*	b*	L*	a*	b*	DE	L*	a*	b*	DE	L*	a*	b*	DE	L*	a*	b*	DE
EP-G	72.27	0.68	8.97	72.35	0.7	9.03	0.12	72.37	0.72	9.05	0.18	72.44	0.73	9.03	0.21	72.47	0.69	9.04	0.22
EP-SG	55.1	8.66	19.05	55.1	8.73	19.1	0.23	55.07	8.78	19.21	0.26	55.05	8.78	19.29	0.32	54.98	8.85	19.47	0.51
EP-T	50.78	10.92	23.04	50.73	11	23.3	0.3	50.72	11	23.33	0.35	50.61	11.15	23.79	0.82	50.67	11.13	23.64	0.66

ΔE = Change in color compared to baseline

Roughness

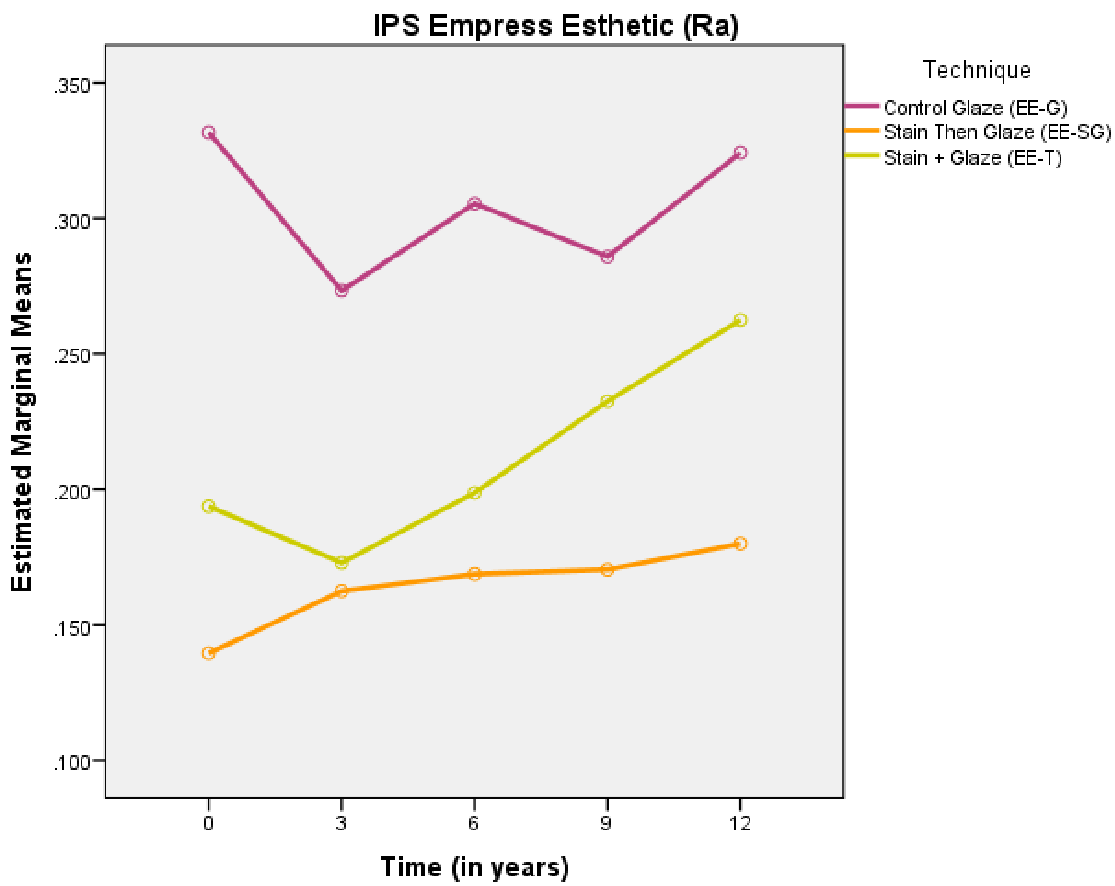

Figure 11. IPS Empress Esthetic roughness over time

Table 4. IPS Empress Esthetic roughness measurements

	Baseline			3 Years			6 Years			9 Years			12 Years		
Group	Ra	Ry	Rz	Ra	Ry	Rz	Ra	Ry	Rz	Ra	Ry	Rz	Ra	Ry	Rz
EE-G	0.33	3.28	1.3	0.27	2.36	1.05	0.31	2.9	1.21	0.29	3.05	1.14	0.32	3.07	1.22
EE-SG	0.14	1.3	0.6	0.16	1.4	0.66	0.17	1.49	0.73	0.17	1.47	0.79	0.18	1.62	0.83
EE-T	0.19	2.2	0.9	0.17	1.97	0.89	0.2	2.34	1.11	0.23	3.23	1.53	0.26	3.32	1.92

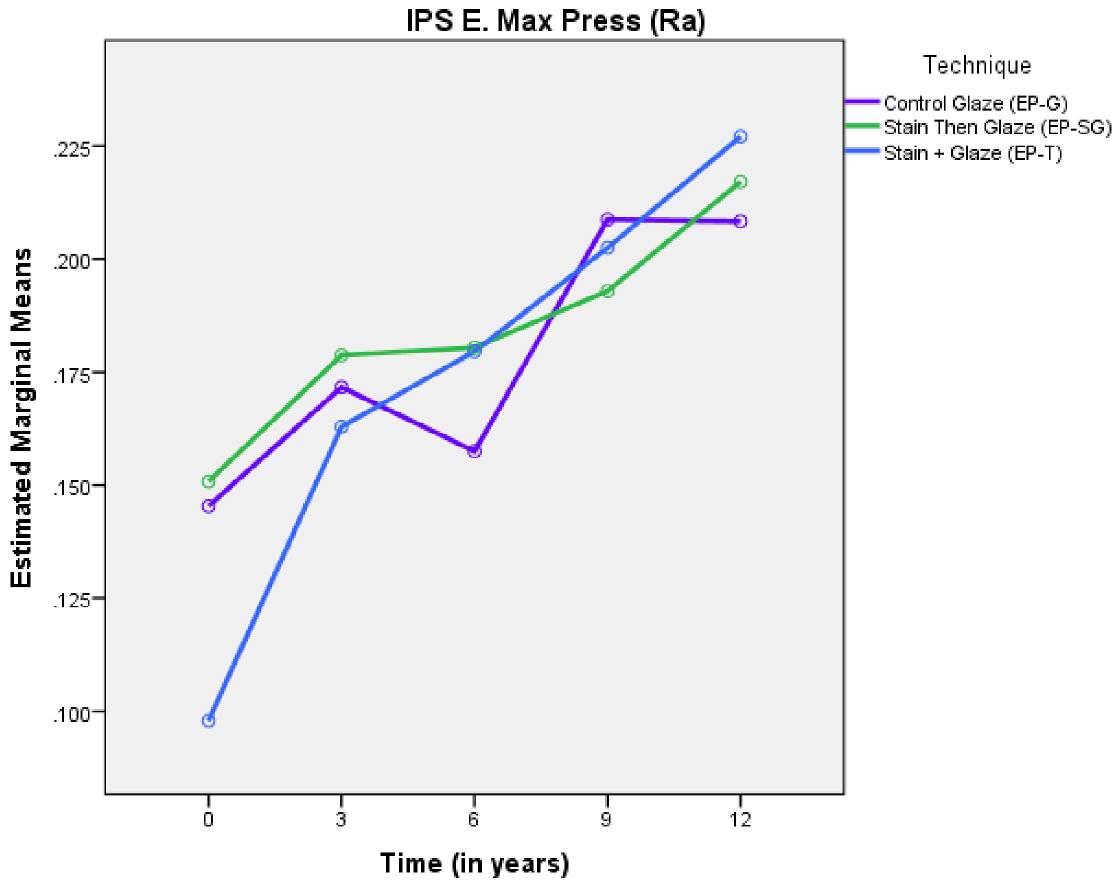

Figure 12. IPS e.max Press roughness over time

Table 5. IPS e.max Press roughness measurements

	Baseline			3 Years			6 Years			9 Years			12 Years		
Group	Ra	Ry	Rz	Ra	Ry	Rz	Ra	Ry	Rz	Ra	Ry	Rz	Ra	Ry	Rz
EP-G	0.15	2.85	1.01	0.17	2.56	1.21	0.16	2.88	1.02	0.21	3.98	1.26	0.21	3.03	1.18
EP- SG	0.15	2.31	1.06	0.18	2.41	1.09	0.18	2.31	1.09	0.19	2.75	1.17	0.22	2.75	1.42
EP-T	0.1	3.11	1.18	0.16	3.89	1.48	0.18	4.3	1.72	0.2	4.31	1.86	0.23	4.02	1.97

Table 6. One factor repeated measures analysis of variance (ANOVA) (α=.05) and Tukey HSD (α=.05)

Group	Source of variance		Shade (ΔE)	Roughness (ΔRa)
EE	Brush year		.269	.141
	Brush year x technique		.268	.482
	Technique	G Vs. SG	.078	.085
		G Vs. T	.965	.319
		SG Vs. T	.047*	.724
EP	Brush year		.000*	.000*
	Brush year x technique		.005*	.709
	Technique	G Vs. SG	.166	.989
		G Vs. T	.001*	.994
		SG Vs. T	.039*	.989

Note * indicates significant differences ($P<.05$)

CHAPTER V

DISCUSSION

This study assessed the in vitro effect toothbrushing had on color and roughness of extrinsically stained ceramic restorations. Based on the findings, two of the four null hypotheses were rejected. Only the color and surface roughness of IPS e.max Press was affected by toothbrushing.

The results of the investigation failed to reject hypothesis 1 for IPS Empress Esthetic specimens. No shade change was observed over time (P=.268). In addition, no difference was observed between techniques (P=.237). An overall ΔE of 0.16-0.18 was measured; therefore stain application technique had no effect on color preservation over time.

The results of the investigation failed to reject hypothesis 2 for IPS Empress Esthetic specimens. No changes on roughness occurred over time (P=.141). Roughness was not affected by the stain application technique (P=.482); therefore, the stain application technique in this study had no effect on roughness over time.

The results of the investigation allowed rejection of hypothesis 3 for IPS e.max samples. The stain application technique in this study was found to be statistically significant. The SG group had better results over time (P=.039).

The results resulted in the rejection of hypothesis 4 for IPS e.max specimens. Roughness was found to statistically increase over time (*P*=.01), and did not depend upon the stain application technique (*P*=.709).

Some of the factors that might influence the difference in results between the present study and similar studies might be the toothbrushing machine, load applied on samples, number of strokes, type of toothbrush, toothpaste, stain, glaze application technique, as well as, the type of stain and glaze.

Anil and Bolay[9] found a significant decrease in weight, roughness and color change of extrinsically stained feldspathic dental porcelain after an equivalent of 8.5 years of toothbrushing. It was also found that a decrease of approximately 20 microns affected the color of extrinsically stained groups. The smoothness of the surface reported by Anil and Bolay might be due to the use of a greater brushing load of 600 g, harder nylon toothbrushes and possibly high RDA toothpaste. The RDA of the toothpaste used in that study is unknown. The current study utilized 200 g of force as an average obtained from the literature[35-37] and because anything more than that has been demonstrated to be of little consequence for plaque removal.[35] The present study found no change in roughness for IPS Empress Esthetic but a significant increase with IPS e.max Press. No decrease in Ra was observed. Moreover, this study used soft straight Oral-B #35 toothbrushes and 150 grams of Colgate Total (medium abrasive 70 RDA).

Aker et al.[5] demonstrated that the use of a normal toothbrush with a common dentifrice had the ability to wear color corrective porcelain stains applied to the surface of metal-ceramic restorations over a period of 10 to 12 years, unless a protective layer of glaze was applied over the stain. That study looked at the complete removal of some portion of the stain and was assessed visually. The present study used a spectrophotometer to assess shade change (ΔE), which should correspond with loss of surface stain. No statistical change in ΔE, hence stain removal, was found for the IPS Empress Esthetic group after an equivalent of 12 years. Conversely, a statistically significant change in ΔE (stain removal) was found for the IPS e.max group. Although, the shade change was statistically significant, it was considered clinically insignificant since the ΔE values obtained where well below the 2.0 units according to the American Dental Association[9] as well as Douglas et al [26] who reported a perceptibility tolerances to be at ΔE of 2.6 while acceptability was 5.5 ΔE. In the previous studies, the complete removal of the corrective color application without glaze at a 10-12 year simulated interval may be due to the difference in material composition between the stains used for VMK-68, Ceramco, and Biobond porcelain systems and the Ivoclar Vivadent stain and glaze materials used in this study. In addition, the differences in brushing loads, toothbrush type and brushing machine might have an effect. They used a brushing load of 450 g, Pycopay No.3 toothbrush and a custom toothbrushing apparatus (Table 1).

Bativala et al.[4] found that the extrinsic stain layer was resistant to significant loss from the use of a fluoride dentifrice applied with a soft multitufted toothbrush for at least 8.5 years of simulated brushing. Furthermore, for periods up to 11.4 years, some of the stain layer remained although the surface was significantly roughened. Samples were prepared by applying stains until they were visually comparable. Samples were then sectioned in half. One half was brushed and the other half served as a control. The thickness of the stain layer of brushed and un-brushed samples were measured with a light microscope and compared. A scanning electron microscope was used for measuring roughness. However, the characterization of roughness was visually and not physically measured. The results showed in Bativala et al[4] study partially agree with the present study.

It has been reported that a patient can clinically perceive a rough surface of 0.5 microns.[43] The present study detected a maximum roughness average of 0.3 microns after 12 years of simulated toothbrushing, allowing the conclusion that although rougness was determined to be statistically significant for IPS e.max Press (EP), it is not considered clinically significant.

Each of the previously mentioned studies utilized Lund`s[10] stain application technique which consisted of placing samples all together over a white background. Stains were then added or removed until all samples appeared to be visually uniform in color. However, this technique was subjective since it relied on human visual assessment. Assessment of color using the human eye is considered inconsistent due to internal and external variables.[28] External variables such as light or internal variables such as age, fatigue, sex, color blindness, personal bias and experience play an important role in color matching.[28] The present study utilized a controlled stain and glaze application procedure that facilitated its repeatability between specimens. Samples were ground from 3 mm to

2.90 mm to allow a uniform additional layer of approximately 100 microns (±30 microns).

There are several limitations to this study. Although samples received ~100 microns of stain application, perfectly identical samples were not obtained. Samples were not found to be visually identical. Some areas were darker and other lighter, within ± 30 micron range stain thickness difference. An attempt was made to mitigate this problem by using a tool that positioned the spectrophotometer and the sample in the same relationship each time a measurement was made. Although, an attempt was made to begin the study with identically stained specimens, it was color change that was measured and statistically analyzed and not color. Secondly, the slurry and toothbrushes were replaced after every 3 years of simulated toothbrushing. This period differs from the current ADA recommendation of toothbrush replacement after 3-4 months. If the tooth brush bristles in this study lost their stiffness, this might have contributed to the minimal increase in observed surface roughness. Thirdly, no real comparisons could be made with previous studies because each study used a different porcelain, stain, and glaze system. This could explain the differences in the result due the differences in their compositions. Finally, the composition of the slurry used did not contain saliva or a synthetic saliva and did not replicate the oral environment.

CHAPTER VI

CONCLUSIONS

Within the limitations of this study, the following conclusions have been drawn:

IPS Empress Esthetic (EE)

In this study roughness and shade were not affected by toothbrushing abrasion for up to twelve years of simulated brushing irrespective of the chosen technique for stain application.

IPS e.max Press (EP)

In this study roughness and shade were significantly affected by toothbrushing abrasion for up to twelve years of simulated brushing. Moreover, shade change over time was found to be dependent on the stain and/or glaze technique. The two stage stain and glaze technique (EP-SG) was significantly more resistant to toothbrush abrasion regarding both shade and roughness. However it cannot be concluded that shade change would be clinically significant after 12 years of simulated toothbrushing.

Within the limitations of this study it can be concluded that no clinically significant shade change for both IPS Empress Esthetic and IPS e.max Press should be expected after 12 years of toothbrushing.

IPS Empress Esthetic stains and glaze were more resistant to toothbrush abrasion.

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APPENDIX A

Statistical Tables

One factor repeated measures analysis of variance (ANOVA) for IPS Empress Esthetic Roughness at 12 years.

Source	Measure		Type III Sum of Squares	df	Mean Square	F	Sig.
Time	Ra	Sphericity Assumed	.035	4	.009	1.943	.111
		Greenhouse-Geisser	.035	2.590	.013	1.943	.141
		Huynh-Feldt	.035	3.267	.011	1.943	.126
		Lower-bound	.035	1.000	.035	1.943	.178
	Ry	Sphericity Assumed	8.807	4	2.202	2.344	.061
		Greenhouse-Geisser	8.807	2.524	3.489	2.344	.093
		Huynh-Feldt	8.807	3.171	2.777	2.344	.078
		Lower-bound	8.807	1.000	8.807	2.344	.141
	Rz	Sphericity Assumed	3.171	4	.793	7.022	.000
		Greenhouse-Geisser	3.171	2.659	1.193	7.022	.001
		Huynh-Feldt	3.171	3.370	.941	7.022	.000
		Lower-bound	3.171	1.000	3.171	7.022	.015
Time * Technique	Ra	Sphericity Assumed	.032	8	.004	.914	.509
		Greenhouse-Geisser	.032	5.179	.006	.914	.482
		Huynh-Feldt	.032	6.535	.005	.914	.497
		Lower-bound	.032	2.000	.016	.914	.416
	Ry	Sphericity Assumed	7.772	8	.972	1.034	.417
		Greenhouse-Geisser	7.772	5.049	1.539	1.034	.408
		Huynh-Feldt	7.772	6.342	1.225	1.034	.413
		Lower-bound	7.772	2.000	3.886	1.034	.373
	Rz	Sphericity Assumed	3.466	8	.433	3.837	.001
		Greenhouse-Geisser	3.466	5.317	.652	3.837	.004
		Huynh-Feldt	3.466	6.740	.514	3.837	.002
		Lower-bound	3.466	2.000	1.733	3.837	.038

Error(factor1)	Ra	Sphericity Assumed	.373	84	.004		
		Greenhouse-Geisser	.373	54.383	.007		
		Huynh-Feldt	.373	68.614	.005		
		Lower-bound	.373	21.000	.018		
	Ry	Sphericity Assumed	78.917	84	.939		
		Greenhouse-Geisser	78.917	53.013	1.489		
		Huynh-Feldt	78.917	66.592	1.185		
		Lower-bound	78.917	21.000	3.758		
	Rz	Sphericity Assumed	9.485	84	.113		
		Greenhouse-Geisser	9.485	55.831	.170		
		Huynh-Feldt	9.485	70.766	.134		
		Lower-bound	9.485	21.000	.452		

Tukey HSD for IPS Empress Esthetic Roughness at 12 years.

Measure	(I) Technique	(J) Technique	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Ra	Control Glaze	Stain Then Glaze	.13983	.062013	.085	-.01647	.29614
		Stain + Glaze	.09200	.062013	.319	-.06431	.24831
	Stain Then Glaze	Control Glaze	-.13983	.062013	.085	-.29614	.01647
		Stain + Glaze	-.04783	.062013	.724	-.20414	.10847
	Stain + Glaze	Control Glaze	-.09200	.062013	.319	-.24831	.06431
		Stain Then Glaze	.04783	.062013	.724	-.10847	.20414
Ry	Control Glaze	Stain Then Glaze	1.47417*	.528762	.028	.14139	2.80695
		Stain + Glaze	.32058	.528762	.818	-1.01220	1.65336
	Stain Then Glaze	Control Glaze	-1.47417*	.528762	.028	-2.80695	-.14139
		Stain + Glaze	-1.15358	.528762	.098	-2.48636	.17920
	Stain + Glaze	Control Glaze	-.32058	.528762	.818	-1.65336	1.01220

		Stain Then Glaze	1.15358	.528762	.098	-.17920	2.48636
Rz	Control Glaze	Stain Then Glaze	.45133	.203789	.092	-.06233	.96500
		Stain + Glaze	-.09958	.203789	.877	-.61325	.41408
	Stain Then Glaze	Control Glaze	-.45133	.203789	.092	-.96500	.06233
		Stain + Glaze	-.55092*	.203789	.034	-1.06458	-.03725
	Stain + Glaze	Control Glaze	.09958	.203789	.877	-.41408	.61325
		Stain Then Glaze	.55092*	.203789	.034	.03725	1.06458

Based on observed means.

The error term is Mean Square(Error) = .166.

*. The mean difference is significant at the .05 level.

One factor repeated measures analysis of variance (ANOVA) for IPS Empress Esthetic shade at 12 years.

Measure: ΔE

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Time	Sphericity Assumed	.191	3	.064	1.345	.268
	Greenhouse-Geisser	.191	1.454	.131	1.345	.269
	Huynh-Feldt	.191	1.683	.113	1.345	.271
	Lower-bound	.191	1.000	.191	1.345	.259
Time * Technique	Sphericity Assumed	.391	6	.065	1.379	.237
	Greenhouse-Geisser	.391	2.908	.135	1.379	.268
	Huynh-Feldt	.391	3.366	.116	1.379	.264
	Lower-bound	.391	2.000	.196	1.379	.274
Error(factor1)	Sphericity Assumed	2.979	63	.047		
	Greenhouse-Geisser	2.979	30.533	.098		
	Huynh-Feldt	2.979	35.341	.084		
	Lower-bound	2.979	21.000	.142		

Tukey HSD for IPS Empress Esthetic shade at 12 years.

Measure: ΔE

(I) Technique	(J) Technique	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Control Glaze	Stain then Glaze	-.137082	.0595762	.078	-.287248	.013084
	Stain + Glaze	.015137	.0595762	.965	-.135029	.165303
Stain then Glaze	Control Glaze	.137082	.0595762	.078	-.013084	.287248
	Stain + Glaze	.152219*	.0595762	.047	.002053	.302385
Stain + Glaze	Control Glaze	-.015137	.0595762	.965	-.165303	.135029
	Stain then Glaze	-.152219*	.0595762	.047	-.302385	-.002053

Based on observed means.

The error term is Mean Square(Error) = .014.

*. The mean difference is significant at the .05 level.

One factor repeated measures analysis of variance (ANOVA) for IPS e.max Press Roughness at 12 years.

Source	Measure		Type III Sum of Squares	df	Mean Square	F	Sig.
Time	Ra	Sphericity Assumed	.105	4	.026	7.539	.000
		Greenhouse-Geisser	.105	3.187	.033	7.539	.000
		Huynh-Feldt	.105	4.000	.026	7.539	.000
		Lower-bound	.105	1.000	.105	7.539	.012
	Ry	Sphericity Assumed	11.694	4	2.924	1.477	.217
		Greenhouse-Geisser	11.694	3.302	3.541	1.477	.226
		Huynh-Feldt	11.694	4.000	2.924	1.477	.217
		Lower-bound	11.694	1.000	11.694	1.477	.238
	Rz	Sphericity Assumed	2.759	4	.690	3.132	.019
		Greenhouse-Geisser	2.759	3.076	.897	3.132	.030
		Huynh-Feldt	2.759	4.000	.690	3.132	.019

		Lower-bound	2.759	1.000	2.759	3.132	.091
Time * Technique	Ra	Sphericity Assumed	.018	8	.002	.638	.744
		Greenhouse-Geisser	.018	6.374	.003	.638	.709
		Huynh-Feldt	.018	8.000	.002	.638	.744
		Lower-bound	.018	2.000	.009	.638	.538
	Ry	Sphericity Assumed	7.014	8	.877	.443	.892
		Greenhouse-Geisser	7.014	6.605	1.062	.443	.863
		Huynh-Feldt	7.014	8.000	.877	.443	.892
		Lower-bound	7.014	2.000	3.507	.443	.648
	Rz	Sphericity Assumed	1.559	8	.195	.885	.533
		Greenhouse-Geisser	1.559	6.151	.253	.885	.513
		Huynh-Feldt	1.559	8.000	.195	.885	.533
		Lower-bound	1.559	2.000	.780	.885	.427
Error(factor1)	Ra	Sphericity Assumed	.291	84	.003		
		Greenhouse-Geisser	.291	66.928	.004		
		Huynh-Feldt	.291	84.000	.003		
		Lower-bound	.291	21.000	.014		
	Ry	Sphericity Assumed	166.312	84	1.980		
		Greenhouse-Geisser	166.312	69.351	2.398		
		Huynh-Feldt	166.312	84.000	1.980		

		Lower-bound	166.312	21.000	7.920		
	Rz	Sphericity Assumed	18.494	84	.220		
		Greenhouse-Geisser	18.494	64.589	.286		
		Huynh-Feldt	18.494	84.000	.220		
		Lower-bound	18.494	21.000	.881		

Tukey HSD for IPS e.max Press Roughness at 12 years.

Measure	(I) Technique	(J) Technique	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Ra	Control Glaze	Stain Then Glaze	-.00567	.040406	.989	-.10751	.09618
		Stain + Glaze	.00433	.040406	.994	-.09751	.10618
	Stain Then Glaze	Control Glaze	.00567	.040406	.989	-.09618	.10751
		Stain + Glaze	.01000	.040406	.967	-.09185	.11185
	Stain + Glaze	Control Glaze	-.00433	.040406	.994	-.10618	.09751
		Stain Then Glaze	-.01000	.040406	.967	-.11185	.09185
Ry	Control Glaze	Stain Then Glaze	.55625	.687401	.702	-1.17639	2.28889
		Stain + Glaze	-.86450	.687401	.434	-2.59714	.86814
	Stain Then Glaze	Control Glaze	-.55625	.687401	.702	-2.28889	1.17639
		Stain + Glaze	-1.42075	.687401	.121	-3.15339	.31189

	Stain + Glaze	Control Glaze	.86450	.687401	.434	-.86814	2.59714
		Stain Then Glaze	1.42075	.687401	.121	-.31189	3.15339
Rz	Control Glaze	Stain Then Glaze	-.02767	.268668	.994	-.70486	.64953
		Stain + Glaze	-.50433	.268668	.170	-1.18153	.17286
	Stain Then Glaze	Control Glaze	.02767	.268668	.994	-.64953	.70486
		Stain + Glaze	-.47667	.268668	.202	-1.15386	.20053
	Stain + Glaze	Control Glaze	.50433	.268668	.170	-.17286	1.18153
		Stain Then Glaze	.47667	.268668	.202	-.20053	1.15386

Based on observed means.

The error term is Mean Square(Error) = .289.

One factor repeated measures analysis of variance (ANOVA) for IPS e.max Press shade at 12 years.

Measure: ΔE

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Time	Sphericity Assumed	1.152	3	.384	12.798	.000
	Greenhouse-Geisser	1.152	2.008	.574	12.798	.000
	Huynh-Feldt	1.152	2.432	.474	12.798	.000
	Lower-bound	1.152	1.000	1.152	12.798	.002
Time* Technique	Sphericity Assumed	.772	6	.129	4.287	.001
	Greenhouse-Geisser	.772	4.015	.192	4.287	.005
	Huynh-Feldt	.772	4.864	.159	4.287	.003
	Lower-bound	.772	2.000	.386	4.287	.027
Error(Time)	Sphericity Assumed	1.890	63	.030		
	Greenhouse-Geisser	1.890	42.162	.045		
	Huynh-Feldt	1.890	51.068	.037		
	Lower-bound	1.890	21.000	.090		

Tukey HSD for IPS e.max Press shade at 12 years.

Measure: ΔE

(I) Technique	(J) Technique	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Control Glaze	Stain then Glaze	-.146646	.0775499	.166	-.342115	.048824
	Stain + Glaze	-.351311*	.0775499	.001	-.546780	-.155841
Stain then Glaze	Control Glaze	.146646	.0775499	.166	-.048824	.342115
	Stain + Glaze	-.204665*	.0775499	.039	-.400135	-.009195
Stain + Glaze	Control Glaze	.351311*	.0775499	.001	.155841	.546780
	Stain then Glaze	.204665*	.0775499	.039	.009195	.400135

Based on observed means.

The error term is Mean Square(Error) = .024.

*. The mean difference is significant at the .05 level.