Curriculum Vitae

Name: Naif Ghazi Sinada

Contact Information: naif.sinada@gmail.com

Degree and Date to be Conferred: M.S., 2017

Collegiate Institutions Attended:

2014-2017: University of Maryland School of Dentistry – M.S. 2017

2013-2014: Brookdale University Hospital & Medical Center – GPR Certificate 2014

2009-2013: Midwestern University College of Dental Medicine – D.M.D 2013

2007-2009: University of Iowa College of Public Health – M.P.H. 2009

Community & Behavioral Health

2002-2007: University of Iowa College of Liberal Arts and Sciences – B.A. 2007

Biology

Minor: Chemistry, International Studies

Professional Publications:

1. Sinada N. All-on-4® Treatment Concept in a Severely Resorbed Jaw Using Narrow-Platform Implants: A Case Report. *Compend Contin Educ Dent.* 2017;38: e9-e12.

2. Atkinson MBJ, Mariappan SVS, Bučar D-K, et al. Crystal engineering rescues a solution organic synthesis in a cocrystallization that confirms the configuration of a molecular ladder. *Proc Natl Acad Sci U S A*. 2011;108: p. 10974-10979.

3. Atkinson MB, Bucar DK, Sokolov AN, Friscić T, Robinson CN, Bilal MY, Sinada NG, Chevannes A, MacGillivray LR. General application of mechanochemistry to templated solid-statereactivity: rapid and solvent-free access to crystalline supermolecules. *Chem Commun (Camb)*. 2008; p. 44:5713-5..

Community Activities or Special Awards:

Midwestern University Esthetic Dentistry Club – Founder, 2009

Outstanding Leadership Award – 2009-2010

Class Council – *President* – Midwestern University – 2009-2010

Class Council – *Suite Senator* – Midwestern University – 2009-2010

Student Government – *Council Member* – Midwestern University – 2010-2013

American Public Health Association – *Student Member at Large* – November 2007

Abstract

Title of Thesis: The Effect of CAMBRA Agents on Fracture Strength of Lithium Disilicate Crowns

Naif Sinada, Masters of Science, 2017

Thesis Directed by: Radi Masri, DDS, PhD, Associate Professor, School of Dentistry Division of Prosthodontics

Purpose: The purpose of this study is to examine the effects of commonly used CAMBRA agents (Prevident and chlorhexidine) on the fracture strength of three commonly utilized lithium disilicate ceramics: pressed (Press), milled (CAD), milled and veneered with fluorapatite (CAD/CERAM).

Methods and Materials: Forty-eight rectangular specimens in each group of Press, CAD, and CAD/CERAM were fabricated. Twelve specimens from each group were immersed in the assigned control solutions (water, 6% alcohol) and anticaries solutions (Prevident, chlorhexidine) in an airtight plastic container. For the simulation of 2 years use the samples were soaked in chlorhexidine for 3 hours, Prevident, 6% alcohol and distilled water for 12 hours. A Universal Testing Machine was used to apply load-to-fracture using progressive load values until complete fracture was observed. Statistical analysis was completed using a one-way ANOVA followed by Tukey's HSD test. A p value $\leq .05$ was considered significant.

Results: The results demonstrated that the fracture strength of samples soaked in Prevident were significantly lower. Water, 6% alcohol, and chlorhexidine had no effect on the fracture strength of the ceramics. In addition, there was no significant difference

between the means of the fracture strengths of the different ceramic materials of all solutions. There was also no significant interaction between the three different ceramics and the four different soaking solutions.

Conclusion: Within the limitations of this study, it can be concluded that Prevident can change the fracture strength of lithium disilicate ceramics when used for a period of 2 years. Prolonged use of chlorhexidine, on the other hand, appears to have no significant effect on the fracture strength of lithium disilicate. Therefore, caution should be used with prolonged use of Prevident in patients that have lithium disilicate restorations, regardless of how they were manufactured.

The Effect of CAMBRA Agents on Fracture Strength of Lithium Disilicate Crowns

by
Naif Sinada

Thesis submitted to the faculty of the Graduate School of the
University of Maryland in partial fulfillment
of the requirements for the degree of
Master of Science
2017

Table of Contents

List of Tables

List of Figures

Introduction

CAMBRA

a. What is CAMBRA and What Are CAMBRA Agents?

i. Definition

Although the incidence of dental caries in the US has exhibited trends of drastic decrease dating back to the 1970s, current prevalence estimates of the disease demonstrate that it is still a significant public health concern.[1] The most recent National Health and Nutrition Examination Survey (1999-2004) conducted by the NIH estimated that 92% of adults 20 to 64 have had dental caries in their permanent teeth. Public health interventions have historically ranged from preventive community-based measures (e.g. community fluoridation programs), to intrapersonal health education intervention efforts. This is only to be expected given the complexity of risk factors that influence the persistence and propagation of dental decay.

Multiple risk factors are to be considered when examining the multi-factorial nature of dental caries; the 3 main factors being diet, microflora, and the susceptible tooth surface.[2] In order to aid the clinician through the management of dental caries, the California Dental Association established a set of guidelines based on an individual's caries risk assessment—giving rise to Caries Management By Risk Assessment (CAMBRA).[3] In this work, Featherstone et al. described a balance between pathological factors (e.g. acidogenic bacteria, dietary carbohydrates) and protective factors (e.g. antibacterials, salivary fluoride) that can either prevent or reverse dental caries through a process of remineralization. This presence, or lack thereof, of a "caries balance" between demineralization and remineralization is the foundation of what drives the CAMBRA concept in that the clinician may create an environment whereby a shift in balance in favor of caries management exists.

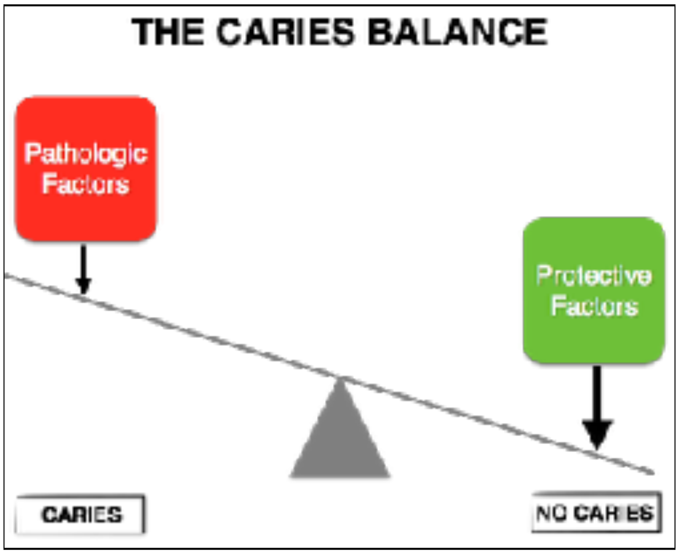

Figure 1: The Caries Balance

The caries balance between pathological and protective factors is depicted above as being in favor of the development of caries. By objectively outlining these pathological and protective factors, Featherstone et al. were able to consequently develop a caries risk assessment guide.[4] In doing so, they classified individuals as being at low, moderate, high, and extremely high caries risk. The placement of individuals in each category is based on: (1) disease indicators, (2) risk factors, (3) and protective factors.

(1) *Disease indicators*: These are clinical signs that indicate that dental caries is present, or has been present recently. This includes the presence of visible cavities, the presence of white spots on enamel surfaces, the presence of interproximal caries/radiographic radiolucencies, and the restoration of caries

within the last 3 years. The existence of any of the above listed indicators results in the placement of the patient into a high-risk category.[4] Albeit descriptive, these indicators are merely clinical observations that indicate the presence of disease, not the cause or source of the disease.

(2) *Risk factors*: These are biological determinants of a patient's caries risk. The nine risk factors that were outlined are as follows: visible heavy plaque on teeth, frequent snacks of sugars/cooked starch between meals (>3 times/day), deep pits/fissures, recreational drug use, inadequate salivary flow (<0.5ml/min), exposed tooth roots, the presence of orthodontic appliances, medium or high streptococci mutans and lactobacilli counts, and saliva reducing factors (e.g. medications, head/neck radiation, and systemic factors such as Sjögren's syndrome). In the absence of disease indicators, the sum of these risk factors determines the risk of the patient.

(3) *Protective Factors*: These can be therapeutic or biological in nature, provided that they favor shifting the caries balance away from caries development. The eleven protective factors that were outlined are as follows: the use of fluoride toothpaste once daily, the use of fluoride toothpaste at least twice daily, the use of fluoride gel/rinse daily, the use of 5000ppm fluoride toothpaste daily, the application of fluoride varnish within the last 6 months, the application of in-office topical fluoride within the last 6 months, the use of xylitol gum/candies 4 times daily for the last 6 months, the use of calcium/phosphate paste

in the last 6 months, salivary flow that is visibly adequate or >1ml/min by test, and living/working/attending school in a community with fluoridated water.

As part of this risk assessment, Featherstone et al. advocated for bacterial (ATP) tests for all patients as a baseline measure. Once such data is collected, the summation of risk factors, in light of protective factors, allow the clinician to assess caries risk as low, moderate, high, or extremely high. It is necessary that this caries risk assignment be accompanied with both a restorative treatment plan, as well as a caries management plan that includes home care, office preventive treatments, and recall visits whereby a reassessment of the patient's caries risk occurs.

By considering this outlined risk assessment in treatment planning, the clinician is then able to treat the individual appropriately according to their risk category, rather than just limiting all patient treatment to caries excavation. For example, patients with one or more frank cavities tend to have moderate to high levels of an intraoral bacterial load. Therefore, placing restorations in a patient with frank cavities does not necessarily reduce the patient's overall bacterial load. By using CAMBRA principles, the clinician can supplement caries excavation with salivary flow tests and bacterial cultures to assess the efficacy of treatment—aiding in the total reduction of the existing bacterial load.[5]

ii. CAMBRA agents

In addition to the eleven previously listed protective factors, Featherstone has classified protective factors into three main groups: (1) Salivary components and flow, (2) Fluoride, Calcium, and Phosphate, and (3) Antibacterials from extrinsic sources.

(1) *Salivary components and flow*: The natural protective ability of saliva is attributed to numerous important components that affect intraoral pH levels[6]—namely calcium, phosphate, and fluoride.[7,8] Saliva contains proteins that keep calcium in solution and maintain a level of supersaturation[9], as well as buffers (e.g. phosphate) that help neutralize intraoral acids.[10]

(2) *Fluoride, Calcium, and Phosphate*: The presence of fluoride in saliva inhibits demineralization by absorbing the fluoride from solution onto tooth surfaces.[7] In the remineralization process, fluoride speeds up remineralization by combining with calcium and phosphate in saliva to build new mineral surfaces on crystal surfaces of teeth. The new minerals built on existing crystal surfaces are both less soluble and more acid resistant than they were previously. Therefore, these effects are primarily topical in nature in that their plaque inhibition function works via the deposition of new enhanced surfaces. While benefits of systemic fluoride therapy are minimal, therapeutic levels of fluoride are easily achieved with over the counter fluoride rinses (0.05% NaF), in-office applied fluoride gel (>5000ppm F), high concentration fluoride toothpaste (1.1% NaF dentifrice), fluoride varnish, and fluoridated water.[11,12]

(3) *Antibacterials from extrinsic sources*: Acid-producing bacteria can begin intraoral colonization even before teeth erupt.[13] Therefore, antibacterial agents can both aid in hindering the proliferation, as well as transmission of bacteria between individuals. Chlorhexidine gluconate 0.12% used as an antibacterial

agent has been shown to be effective in reducing the bacterial challenge in high-risk individuals, even in the presence of problematic compliance. Xylitol can also act in an antibacterial capacity by altering the way that bacteria adhere to tooth surfaces; thus, inhibiting bacterial transfer between individuals.[14] It can be administrated in multiple forms including chewing gum, mints, toothpastes, oral rinses, mists, and infant/toddler wipes. Because acidogenic bacteria are unable to process xylitol as an energy source, it can also inhibit future recolonization of bacteria.

iii. Indications for use of different CAMBRA agents

Jenson et al. expanded on previous CAMBRA research, in collaboration with Featherstone, by providing comprehensive clinical protocols for CAMBRA, stating: “in addition to a comprehensive restorative treatment plan, each patient should have a comprehensive caries management treatment plan.”[5] The basis of this statement lies in the idea that assigning patients into different risk assignment levels does indeed make a difference in the management of patients across risk groups.[5,15] In addition to dictating what diagnostic procedures are indicated across different risk levels, these clinical protocols also outline specific risk factor management procedures (Figure 2). For example, moderate-risk patients should not only require more frequent bitewing radiographs (when compared to low-risk patients), but they should also be considered for (1) additional fluoride therapy (e.g. 0.05% NaF daily rinse) in order to aid tipping the caries balance toward arresting the progression of caries, (2) as well as daily xylitol gum/

candies that act as retardants for cariogenic bacteria, because they are not able to feed on xylitol.[16] Extreme-risk patients, on the other hand, must be managed more aggressively than all the other risk levels. This would include adjunct therapeutic regimens such as (1) antimicrobial therapy (e.g. 0.12% Chlorhexidine gluconate) to aid in combating the infectious pathogens that cause dental caries[17], (2) buffering rinses to replace the natural cleansing/buffering ability of saliva, and (3) calcium/phosphate pastes designed to replace salivary components that aid in the remineralization of tooth structure.[18]

iv. Protocols for use of different CAMBRA agents

Specific protocols outlined by Jenson et al. are to be applied only after a thorough risk assessment of each patient. After placing the individual into their appropriate risk category, the following protocols for the use of different CAMBRA agents may be applied:

(1) *Low Caries Risk*: These patients should be advised to use over the counter (OTC) fluoride toothpastes for brushing twice daily, as well as caries recall examinations every 6-12 months.

(2) *Moderate Caries Risk*: These patients should be advised to use OTC fluoride toothpastes for brushing twice daily, in addition to 0.05% NaF daily rinse. These patients should also be seen every 4-6 months for caries recall examinations.

(3) *High Caries Risk*: These patients should be advised to use 1.1% NaF toothpastes for twice daily brushing, 10mL of 0.12% chlorhexidine gluconate

once daily for one week every month for a period of one year, and 6-10 grams of Xylitol gum/candies. These patients should also be seen every 3-4 months for caries recall examinations.

(4) *Extreme Caries Risk*: These patients should be advised to use 1.1% NaF toothpastes for twice daily brushing, OTC 0.05% NaF daily rinse, and fluoride varnish application every 3 months. Due to these patients' severe hyposalivation, they should also be advised to use 10mL of 0.12% chlorhexidine gluconate once daily for one week every month for a period of one year, 6-10 grams of Xylitol gum/candies, calcium/phosphate paste twice daily, and baking soda rinses 4 times daily. These patients should also be seen every 3 months for caries recall examinations.

CAMBRA Clinical Guidelines for Patients Age 6 and Older								
Risk Level	Frequency of Radiographs	Frequency of Caries Recall Exams	Saliva Test	Antibacterial s Chlorhexidine Xylitol	Fluoride	pH Control	Calcium Phosphate Topical Supplements	Sealants (Resin-based or Glass Ionomer)
Low Risk	Bitewing radiographs every 24-36 months	Every 6-12 months to reevaluate caries risk	May be done as a baseline reference for new patients	Per saliva test if done	OTC fluoride-containing toothpaste 2x/day. Optional: NaF varnish if excessive root exposure/ sensitivity	Not required	Not required	Optional or as per ICDAS sealant protocol
Moderate Risk	Bitewing radiographs every 18-24 months	Every 4-6 months to reevaluate caries risk	If suspicion of high bacterial challenge & assess efficacy and patient cooperation	Per saliva test if done. Xylitol 6-10g/day gum or candies. Two tabs of gum or two candies 4x daily	OTC fluoride-containing toothpaste 2x/day. NaF rinse daily	Not required	Not required	As per ICDAS sealant protocol
High Risk	Bitewing radiographs every 6-18 months or until no cavitated lesions are evident	Every 3-4 months to reevaluate caries risk and apply fluoride varnish	Saliva flow test and bacterial culture initially and at every recall	CHX 0.12% 10mL rinse for 1 min/daily for 1 week/month. Xylitol 6-10g/day gum or candies. Two tabs of gum or two candies 4x daily	1.1% NaF toothpaste 2x/day instead of regular fluoride-toothpaste	Not required	Optional: apply calcium/phosphate paste several times/day	As per ICDAS sealant protocol
Extreme Risk	Bitewing radiographs every 6 months or until no cavitated lesions are evident	Every 3 months to reevaluate caries risk and apply fluoride varnish	Saliva flow test initially and bacterial culture initially and at every recall	CHX 0.12% 10mL rinse for 1 min/daily for 1 week/month. Xylitol 6-10g/day gum or candies. Two tabs of gum or two candies 4x daily	1.1% NaF toothpaste 2x/day instead of regular fluoride-toothpaste and OTC 0.05% NaF rinse when mouth feels dry, after snacking, and after meals	Acid-neutralizing rinses (PRN)	Required: apply calcium/phosphate paste 2x/day	As per ICDAS sealant protocol

Figure 2: Table of CAMBRA guidelines to aid in the treatment of patients across different risk categories, as outlined by Jenson et al.[5]

Types of Lithium Disilicate Ceramics

The above outlined protocols, in conjunction with a comprehensive restorative treatment plan, aid clinicians in their existing arsenal of treating patients across the low to extreme caries risk levels. It is important to consider that the patients receiving this treatment rarely have mouths void of existing dental restorations. Indeed, it is conceivable that high caries risk patients present to the clinician with the presence of multiple restorative materials such as porcelain, gold, and titanium. It has been noted that some of the agents listed above may have negative effects on the inherent properties of dental porcelains.[19] Therefore, it becomes important to understand the different types of porcelains that are to be discussed in this study, and their relevant properties.

Dental porcelains are defined as non-metallic inorganic materials that are made by heating raw minerals at high temperatures.[20] They can be classified by their firing temperature[21], the processing technique,[20] or their microstructure (i.e. the amount and type of crystalline phase and glass composition).

When classifying porcelains based on their microstructure, ceramics can be defined based on their composition of glass-to-crystalline ratios. While there are infinite possibilities of glass-crystalline ratios that can be identified, four main categories are outlined:[20]

(1) *Composition Category 1*: glass-based systems (mainly silica)

(2) *Composition Category 2*: glass-based systems (mainly silica) with fillers that are usually crystalline (e.g. lithium disilicate, leucite).

(3) *Composition Category 3*: crystalline-based systems with glass fillers (e.g. alumina)

(4) *Composition Category 4*: polycrystalline solids (alumina and zirconia)

Composition category 2 ceramics (glass-based systems with fillers) contain the highest range of variation with regard to glass-crystalline ratios—so much so that this category can be classified into subcategories. Subcategory 2.1 includes materials that have been traditionally called "feldspathic porcelains" composed of low-moderate leucite-containing feldspathic glass. Subcategory 2.2 includes high-leucite containing glass that contains a glassy-phase based on aluminosilicate glass. Subcategory 2.3 includes "lithium-disilicate" glass ceramic (IPS e.max® by Ivoclar Vivadent) where the aluminosilicate glass phase has lithium oxide.

In addition to including lithium oxide, lithium disilicate based ceramics include quartz, phosphor oxide, alumina, potassium oxide, and other components.[22] This composition yields favorable properties for the dental clinician and can be achieved using various processing techniques. Namely, lost-wax hot pressing techniques, CAD/CAM system machining techniques, and milled lithium disilicate veneered with fluorapatite (CAD/CERAM).

i. Pressed Ceramics

Pressed lithium disilicate porcelains are manufactured using the well-established lost-wax technique, otherwise known as high-temperature injection molding. Heat-pressing ceramics have some inherent advantages in that this process helps avoid large pores and allows for a greater dispersion of the crystalline phase within the glassy matrix.[23]

This process first involves the creation of a wax-pattern (on a die) that is sprued, invested, and burned out. After the selection of an appropriate ceramic ingot, the casting ring is placed into a furnace where the ingot is heated to a liquid state. The liquid state is then "pressed" into the burned out pattern, creating the final restoration. After appropriate cooling is achieved, the ceramic can be prepared for intraoral delivery.

ii. CAD/CAM Ceramics

CAD/CAM technologies offer the clinician the specific advantage of being able to deliver ceramic restorations in a single patient visit. Ceramics developed using this technique are generally fabricated using two main techniques: (1) in-office chairside single-visit techniques, and (2) integrated chairside-laboratory CAD/CAM techniques.[20]

(1) *In-office chairside single-visit techniques*: Using this system, the clinician uses an intraoral scanner to transfer information to a computer that generates a digital impression. The clinician then creates a digital proposition of the restoration with ideal contours, contact, and occlusion. The proposed restorations are milled from blocks of ceramics of different shades and sizes.

(2) *Integrated chairside-laboratory CAD/CAM techniques*: This procedure generally involves the same above outlined milling procedures, but with a main difference in workflow. After tooth preparation, the clinician either (a) fabricates a traditional impression that the laboratory scans into the computer, or (b) intraorally scans the preparation and sends the data to the laboratory. In the latter case, the laboratory follows the same procedures as above outlined.

The CAD/CAM fabricated lithium disilicate restorations come out of the milling machines with a ceramic sprue that needs to be removed prior to intraoral delivery. Proximal contacts, occlusion, and flash may need to be adjusted prior to deeming the restoration adequate for cementation. The final restoration can then be cemented using appropriate cementation protocols.

iii. CAD/CERAM Ceramics

This technique involves the same milling protocols as above outlined. The main difference is that the milled restorations are not milled to final desired contours. Instead, ceramic copings are first milled then veneered with fluorapatite (IPS e.max® Ceram by Ivoclar Vivadent). This has a specific advantage in that it offers the clinician greater control with regard to the characterization, translucency, and final shade of the restoration.

<u>Relevant Properties of Ceramics That Could Affect Restoration Longevity</u>

While dental porcelains have clear esthetic advantages, inherent disadvantages in their properties have limited their historical use in dentistry. Factors that have limited initial widespread adoption in dentistry include: (1) material strength, (2) surface roughness, and (3) fracture resistance.

a. Material Strength

The first documented all-ceramic crown, the porcelain jacket crown, was used for many decades in dentistry as an esthetic alternative to existing restorative materials; with the main limitation being its tendency to fracture.[24] As the demand for more esthetic options increased, porcelains were developed using methods that improved strength and clinical performance.[25] These methods included (1) crystalline reinforcement, (2) chemical strengthening, and (3) thermal tempering in order to overcome fabrication defects and surface cracks. Fabrication defects mainly occur during the processing of ceramics and consist of inclusions/voids that are generated during the sintering process.[26] Surface cracks, on the other hand, generally occur when machining or grinding ceramics. Crystalline reinforcement of dental ceramics involves the introduction of crystalline phase components into the ceramic matrix. When compared to traditional feldspathic porcelains, heat-pressed porcelains with leucite-reinforcement in the crystalline phase have been shown to have significantly higher flexural strength and fracture toughness values.[27] Borom et al has shown that reinforcement of lithium disilicate within the glassy matrix also has similar strengthening capacities via tangential compressive stresses that occur between lithium disilicate crystals and glassy matrix, leading to crack deflection.[28] These lithium disilicate glass-ceramics have been shown to have strength values that are more than twice that of leucite-reinforced ceramics.[29] Heat-pressed lithium disilicate glass-ceramics (IPS Empress® Eris by Ivoclar Vivadent) and hard-machined & crystallized lithium disilicate ceramics (IPS e.max® CAD by Ivoclar Vivadent) have strength values of 306±29MPa and 262±88MPa, respectively.[30] These are both significantly higher when compared to strength values of 106±17MPa of heat-pressed leucite glass-ceramics (IPS Empress® by Ivoclar Vivadent).[29,31]

Chemical strengthening is another method that is used to strengthen dental ceramics. It is based on an ion exchange that occurs below the strain point of the ceramic. This exchange of small alkali ions for larger alkali ions has been traditionally limited to use with feldspathic porcelains. It has recently been shown, however, that lithium disilicate glass-ceramics can also undergo this ion exchange process.[32] These chemically strengthened materials showed a 25% increase in strength by placing them in potassium nitrate. This is thought to be the result of the formation of a compressive layer on the surface of the ceramics. Any load applied to this ceramic must first overcome the newly created compression layer, leading to an increase in fracture resistance.

Compressive stresses created via chemical strengthening can also be created with a process known as thermal tempering. This is achieved by rapid cooling of the dental ceramic when it is near its softening temperature. This cooling process leads to the generation of compressive stress in the glass surface.

b. Surface Roughness

Surface roughness, usually measured by means of stylus analyzers, has been shown to be a have a range of effects on the properties of dental ceramics. Adjustments to dental ceramic surfaces are commonplace in order to achieve proper occlusion, contacts, or characterization. These adjustments can alter the surface roughness in a way that can affect such things as a restoration's tendency for bacterial adhesion[33], or even decrease its flexural strength.[34]

Kantorski et al. evaluated how the surface roughness of porcelains and composites can affect the adherence of *Streptococcus Mutans* onto their samples.[33] They studied four samples: two kinds of resin composites, feldspathic porcelain, and leucite-reinforced glass-ceramic. They found that the surface roughness of composites were similar. The surface roughness of the composites also had no significant effect on bacterial adherence between the two composites. However, the surface roughness of the leucite-reinforced feldspathic ceramic was higher and presented higher bacterial adherence when compared to the microparticulate feldspathic ceramic.

De Jager et al. studied the effects that surface roughness had on porcelain strengths.[35] They studied the influence of finishing procedures on the biaxial flexural strength of four commercial porcelains: two porcelains that are mainly used in metal-ceramic restorations (Flexo Ceram Dentine, Vita VM K68), and two that are used for veneering and inlays (Duceram LFC Dentine, and Cerinate BODY). They found that, with the exception of one ceramic (Flexo Ceram Dentine), the smoother the surface of the sample, the stronger it was. De Jager et al. showed that the surface roughness of porcelain has an inverse correlation with flexural strength, and concluded that the surface roughness determined the strength of the ceramic.

c. Fracture Resistance

Fracture resistance of dental porcelains are influenced by a multitude of factors, including the geometry of the prosthesis, size of flaws within the prosthesis, and the location of flaws within the prosthesis. Fracture toughness of ceramics is described as the ability of a material containing a crack to resist crack propagation, and can be determined from the stress intensity factor (K_{Ic}) at which cracks within the material begin to grow. Fracture resistance of dental ceramics can also be measured by determining the load (N) magnitude that causes the ceramics to fracture.[36]

Sundh and Sjögren studied the fracture resistance of all-ceramic bridges using this particular method.[36] They evaluated the fracture resistance of yttria-stabilized zirconia blanks (Vita YZ) and magnesia partially stabilized zirconia blanks (Denzir-M) under three different conditions. The first samples were left untreated and examined as they were supplied from the manufacturer. The second samples were subjected to heat treatment (in a way similar to veneering). The third samples were veneered with a feldspar-based ceramic. They found no significant difference between the loads necessary to fracture heat-treated and veneered Denzir-M samples. They did note, however, that the fracture strength of the Vita YZ specimen increased significantly after veneering with a feldspar-based ceramic.

Tinschert et al. used this method of studying fracture resistance to study differences between lithium disilicate-based, alumina-based, and zirconia-based fixed partial dentures.[37] They evaluated 3-unit FPDs made via: (1) CAD/CAM techniques (In-Ceram Alumina, In-Ceram Zirconia, and DC-Zirkon) and subsequently layered with feldspathic porcelain, and (2) waxing/heat-pressing techniques (IPS Empress 2 core veneered with fluorapatite glass ceramic, and IPS Empress full-contour restorations made without veneering porcelain). The FPDs were fabricated, cemented on master models, and subjected to loading on a universal testing machine (Zwick) that subjects the specimen to increasing load values. They showed that the lowest failure loads occurred in FPDs made of IPS Empress and In-Ceram Alumina (<1000N), and the highest failure loads occurred in FPDs made of DC-Zirkon (>2000N). They also showed that veneered FPDs were always associated with higher failure load values, when compared to pure substructures without veneering porcelain. These results not only indicate that veneering ceramics can improve fracture resistance but they also indicate that the veneered FPDs studied gain their high strength from the core materials used.[37]

Effects of CAMBRA Agents on Different Ceramic Properties

While CAMBRA agents have been proven advantageous in the treatment of patients across the caries risk spectrum, these agents have not only been shown to have varying effects on different ceramic properties, but they've also been shown to have effects on dentinal surfaces that are subject to resin cement bonding.

a. Bond Strength

Shafiei and Memarpour evaluated the effect of chlorhexidine on the bond strengths of three different resin cements to dentin (Panavia F2.0, Variolink II, and RelyX Unicem).[38] Shear bond strength values (measured in MPA) showed that Variolink II had the highest strength (16.65±3.60MPa), and RelyX Unicem had the lowest strength (9.30±4.07MPa). Given this data, they showed that samples where chlorhexidine was applied showed increased shear bond strength when compared to samples without chlorhexidine. This was not consistent among the three cements—self-adhesive cements did not exhibit a significant change in long-term bond strength, when compared to self-etch and etch-and-rinse cements. Consequently, they concluded that chlorhexidine application could reduce the loss of bonding effectiveness over time in self-etch and etch-and-rinse cements. Research by Carrilho et al. has also shown that chlorhexidine can be useful in the *in vitro* preservation of dentin bond strength, when it is applied prior to bonding with Scotchbond.[39] They also showed that chlorhexidine can be useful in the *in vivo* preservation of the dentin hybrid layer.[40] Their observed preservation of dentin bond strength is based on the idea that matrix metalloproteinases (MMPs) are responsible for the degradation of the resin-dentin hybrid layer. They hypothesized that, since chlorhexidine inhibits MMPs[41], there would be a resultant preservation in dentin bond strength. Their data showed that this is true in both *in vivo* and *in vitro* environments. The effects of fluoride application on bond strengths of dental adhesives have been widely studied in orthodontic applications with contradicting results. Arhun et al. showed that a fluoride-releasing antibacterial self-etching adhesive system (Clearfil Protect Bond) exhibited greater shear bond strength of orthodontic brackets, when compared to two other self-etching adhesive systems (Adper Prompt L-Pop Self Etch Adhesive, and Transbond Plus Self-Ethic Primer).[42] Kimura et al., on the other hand, showed that fluoride varnish applications had no effect on the *in vitro* bond strength of orthodontic brackets using a self-etching primer system.[43] While such conflicting results indicate a need for further research, they demonstrate that fluoride products could conceivably have an effect on tooth surfaces subjected to bonding protocols.

b. Surface Roughness

While the effect that fluoride application on bonding to tooth surfaces has been widely debated, research on the effect of fluoride application on the surface roughness of different restorative materials is comparatively clearer. Butler et al. evaluated the effect that bleaching and fluoride solutions may have on the overall surface roughness of different kinds of dental porcelains.[19] They tested auto-glazed and polished feldspathic porcelains, low-fusing porcelains, and aluminous porcelains in 4 different solutions (1.23% acidulated phosphate fluoride, 0.4% stannous fluoride, 10% carbamide fluoride, and distilled H_2O). They showed that low-fusing porcelains were most affected by 1.23% acidulated phosphate fluoride. Aluminous and feldspathic porcelain also had an increase in surface roughness, when compared to control groups. Among all groups, however, auto-glazed porcelains were more affected by all different solutions compared to the other porcelain groups. This data not only showed that fluoride solutions have a clear effect on the surface roughness of different porcelains, but the data also indicated that consideration for the restorative material present in the patient is important prior to fluoride treatment in order to avoid negatively affecting their surface roughness.

Bolding et al. examined the effects of three different CAMBRA agents (Prevident, chlorhexidine, and ACT mouthwash) on the surface roughness of three restorative materials (porcelain, titanium, and base metal).[44] They showed no significant differences in the mean change to surface roughness between the porcelain, titanium, and base metal samples. They did, however, reveal significant differences between Prevident and chlorhexidine in the mean change in surface roughness. In particular, they showed that chlorhexidine treatment created rougher ceramic surfaces; whereas, Prevident treatment created smoother ceramic surfaces.

c. Fracture Strength

Unpublished research by Ghunaim et al. aimed to expand on Bolding et al.'s research by examining the effect of CAMBRA recommended anti-caries agents (chlorhexidine, Prevident) on the surface roughness of three lithium disilicate ceramics (pressed lithium disilicate, milled lithium disilicate, and milled lithium disilicate with veneered fluorapatite).[45] They found that treatment with chlorhexidine, Prevident, and alcohol (used as a control) increased the surface roughness of pressed lithium disilicate samples, and decreased the surface roughness of milled lithium disilicate, and milled lithium disilicate veneered with fluorapatite. While their research did not study the effects of these agents on the fracture strength of the ceramic samples, they concluded that such research would have significant clinical implications.

While current literature contains limited information on the effect of cavity disinfectants on the fracture strength of dental ceramics, Indira and Nandlal examined the effect of disinfectants (chlorhexidine, sodium hypochlorite) on the fracture resistance of primary molars that were restored with indirect composite inlays.[46] By comparing chlorhexidine and sodium hypochlorite treatment of teeth prior to the cementation of the composite inlays, they showed that the disinfectants had detrimental effects on the fracture resistance of the teeth. In particular, chlorhexidine and sodium hypochlorite groups had lower fracture resistance values, when compared to control groups. Since this study did not evaluate the fracture resistance of the restorative material, further research would be indicated to determine the effect of these agents on the materials themselves.

Although current literature contains limited information on the effect of cavity disinfectants on the fracture strength of dental ceramics, research in the field of orthodontics has examined the effects of these agents (namely, fluoride) on the mechanical properties of titanium and stainless steel orthodontic wires.[47] Walker et al. evaluated the effects of fluoride agents (acidulated fluoride, neutral fluoride) on (1) the loading and unloading mechanical properties, and (2) the surface quality of β-titanium and stainless steel.[48] They found that the use of both fluoride agents showed a decrease in the unloading mechanical properties of β-titanium and stainless steel; implying that these agents could decrease the functional unloading mechanical properties of the wires. This could have significant clinical implications, such as prolonged orthodontic treatment. They also showed that both β-titanium and stainless steel exhibited corrosive changes following exposure to the fluoride agents.

d. Prior to Bonding Lithium Disilicate Ceramics

The effects of MMPs on the long-term degradation of bond strength are well documented. These MMPs can be released from within the endogenous dentin matrix, or secreted by intraoral bacteria.[49,50] Since data has shown that chlorhexidine has inhibitory effects on these MMPs[41], the traditional use of chlorhexidine solutions as cavity disinfectants has been recently expanded.[51]

While Carrilho et al. showed that chlorhexidine is beneficial in preserving the dentin bond strength when applied prior to bonding with Scotchbond; it was unclear whether these effects were dependent on chlorhexidine concentrations or the types of adhesives used. Therefore, Breschi et al. determined the effect of 0.12% and 2% chlorhexidine on the bond strength of two adhesives (Adper Scotchbond 1XT, XP-Bond). They found that both 0.12% and 2% chlorhexidine significantly reduced the loss of bond strength on both adhesive systems. Therefore, they concluded that the pretreatment of chlorhexidine would have beneficial effects on the adhesive bond, regardless of concentrations.

Purpose

Given the limitations within the current corpus of research regarding the effect of recommended CAMBRA agents on fracture strength of ceramics, this study aims to expand on this deficiency. The purpose of this study is to examine the effects of commonly used CAMBRA agents on the fracture strength of lithium disilicate ceramics. The effect is measured by assessing the fracture strength (in MPa) of lithium disilicate ceramics that are soaked in different solutions.

There are 4 groups of solutions to be tested, two of which are recommended CAMBRA agents and two are control solutions. The CAMBRA agents tested were (1) 0.12% chlorhexidine gluconate, and (2) Prevident (0.2% neutral NaF). The control samples used for comparison were (1) samples soaked in 6% alcohol and (2) samples soaked in distilled water. (Alcohol controlled for the alcohol content in Prevident and chlorhexidine and distilled water was used as a natural control.)

Three different lithium disilicate ceramics were tested: (1) pressed lithium disilicate (IPS e.max® Press by Ivoclar Vivadent), (2) milled lithium disilicate (IPS e.max® CAD by Ivoclar Vivadent), and (3) milled lithium disilicate veneered with fluorapatite (IPS e.max® CAD veneered with IPS e.max® CERAM by Ivoclar Vivadent).

Hypotheses

a. Null Hypotheses

There is no significant difference in the four groups, the controls (6% alcohol, water), and the soaking solutions (Prevident, chlorhexidine) in terms of change in fracture strength.

There is no significant difference between the three lithium disilicate ceramics (e.max® Press, e.max® CAD, e.max® CAD veneered with e.max® CERAM) after exposure to different soaking treatments (Prevident, chlorhexidine, 6% alcohol, water) in terms of change in fracture strength.

There is no significant interaction between the soaking treatments (Prevident, chlorhexidine, 6% alcohol, water) and the three lithium disilicate ceramics (e.max® Press, e.max® CAD, e.max® CAD veneered with e.max® CERAM) in terms of change in fracture strength.

Materials and Methods

a. Anti-Caries Agents

Two CAMBRA recommended anti-caries agents were used in this study: (1) Chlorhexidine, and (2) Prevident. The controls used in this experiment were 6% alcohol and water. Water was selected as a natural control; whereas, 6% alcohol was used to control for the inherent alcohol content found in Prevident.

Table 1 Anti-Caries agents tested

Anti-Caries Agent	Company	City, State
Chlorhexidine	Colgate Oral Pharmaceuticals	New York, NY
Prevident	Sunstar Americas, Inc.	Chicago, IL
6% alcohol	Henry Schein	Melville, NY
Distilled water	University of Maryland, Baltimore	Baltimore, MD

b. Lithium Disilicate Ceramics

Three lithium disilicate ceramics were tested in this study: (1) pressed lithium disilicate (IPS e.max® Press by Ivoclar Vivadent), (2) milled lithium disilicate (IPS e.max® CAD by Ivoclar Vivadent), and (3) milled lithium disilicate veneered with fluorapatite (IPS e.max® CAD veneered with IPS e.max® CERAM by Ivoclar Vivadent).

Table 2 Lithium disilicate ceramics tested

Lithium Disilicate	Trade Name	Company	City, State
Pressed	IPS e.max® Press	Ivoclar Vivadent	Amherst, NY
Milled	IPS e.max® CAD	Ivoclar Vivadent	Amherst, NY
Milled, veneered with fluorapatite	IPS e.max® CERAM	Ivoclar Vivadent	Amherst, NY

c. Fabrication of Samples

The samples used in this study were the samples that were tested by Dr. Ghunaim, as outlined per the protocol developed in her study.[45] Seventy-six specimens of each group (Press, CAD, and CAD/CERAM) were fabricated using a standardized procedure to produce 2mm thick samples for all three groups of lithium disilicate ceramics.

To fabricate the Press samples, a vinylpolysiloxane putty mold was made (Coltène Lab Putty, Coltène/Whaledent Inc., Cuyahoga Falls, OH) in order to create a wax pattern with Pro-Art IPS Empress Wax beige (Figure 3). After fabrication of the wax patterns, the patterns were sprued and invested using a phosphate-bonded investment (IPS PressVest Speed) in a silicone ring (IPS Silicone Ring). Using IPS eMax® Press porcelain, the samples were pressed in a press and ceramic furnace (Ivoclar Vivadent EP5000 Press and Ceramic Furnace). The samples were subsequently divested, soaked in Invex Liquid (Ivoclar Vivadent), placed in an ultrasonic machine for 10 minutes, and air-abraded (Basic Master, Renfert USA, Saint Charles, IL). Once this process was complete, the sprue of each sample was sectioned using a sintered diamond disc (Komet, Germany).

Figure 3 Illustration of putty matrix used to fabricate wax patterns

To fabricate the CAD and CERAM samples, IPS eMax® CAD ingots were sectioned into sections of 2mm thickness using a sintered diamond disc (Komet, Germany). After polishing with sandpaper, the samples were sintered using the same furnace used to press the Press samples (Ivoclar Vivadent EP5000 Press and Ceramic Furnace). Samples assigned to CERAM groups were then veneered with the CERAM by adding one layer of IPS eMax® CERAM (Add-on) over the sectioned IPS eMax® CAD sample. They were then placed into a firing oven (Programat P700; Ivoclar Vivadent) and fired following manufacturers firing recommendations. Slow cooling was ensured upon removal by allowing the samples to first cool to room temperature.

IPS eMax® Press and IPS eMax® CERAM samples were polished using: (1) ZR™ Flash Polishers, and (2) a subsequent two-step polishing diamond paste for 30 seconds (Komet Lemgo, Germany). All three groups were glazed using Ivoclar natural glaze (Ivoclar Vivadent, Amherst, NY).

d. Immersion Procedure

The specimens were randomly divided into four groups: water, 6% alcohol, Prevident, and chlorhexidine. The specimens were then immersed in the assigned anti-caries solution in an airtight plastic container. To determine the immersion time, the manufacturer's recommendations for use were followed. In order to simulate 2 years of chlorhexidine use (at a rate of 1 minute/day for one week per month), specimens were soaked in chlorhexidine for a total of 3 hours. In order to simulate 2 years of Prevident use (at a rate of 1 minute/day), specimens were soaked in Prevident for 12 hours. In order to simulate 2 years of use of distilled water and 6% alcohol solutions (at a rate of 1 minute/day), the respective samples were soaked for 12 hours. All solutions (except for distilled water) were replaced every 30 minutes in order to replenish the active ingredients. The distilled water was not changed due to the lack of active ingredients (Figure 4).

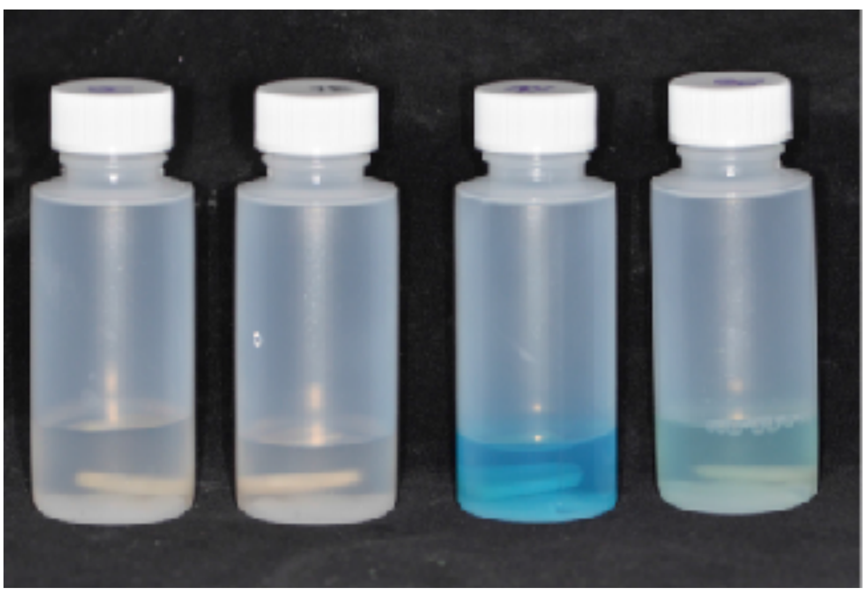

Figure 4: Samples soaking in distilled water, 6% alcohol, Prevident, and chlorhexidine, respectively.

After appropriate soaking of the ceramic specimens in respective anti-caries solutions (and controls) for the times indicated above, the specimens were subsequently rinsed with distilled water for 30 seconds, ultrasonicated, and dried. The samples were placed in an ultrasonic machine for 10 minutes, and air-abraded (Basic Master, Renfert USA, Saint Charles, IL).

Table 3: Immersion times for each solution used

Soaking Solutions	**Immersion Times (Equivalent of 2 years of intraoral use)**
Distilled water	12 hours
6% alcohol	12 hours
Prevident	12 hours
Chlorhexidine	3 hours

e. Measurement of Fracture Strength

After completing the appropriate soaking procedures for each specimen groups, rinsing the specimens in distilled water, ultrasonication, and drying the specimens; the samples were subjected to single load-to-fracture test. The specimens were mounted on a flat holder in a Universal Testing Machine and load-to-fracture was applied through a 6.25mm-radius tungsten carbide (WC) indenter to the center of each sample at a rate of 0.5mm/min in room temperature air.

Each sample was subjected to the same progressive load values until complete fracture was observed. Single load-to-fracture values were recorded for each sample, and the mean single load-to-fracture value were then calculated for each sample group (e.max® Press, e.max® CAD, e.max® CAD veneered with e.max® CERAM).

Statistical Analysis

A power analysis was performed using the results of Dr. Ghunaim's previous research for surface roughness. For testing differences between the three lithium disilicate ceramics, the power analysis showed that with an effect size of 0.37, $p \leq 0.05$, an n=108 per cell, and a one-tailed test, power was equal to 1.00. For testing differences between the four solutions, the power analysis showed that with an effect size of 0.14, $p \leq 0.05$, an n=81 per cell, and a one-tailed test, power was equal to 0.28. For the interaction, with an effect size of 0.25, power was equal to 0.82. Therefore, an n=27 was used for each cell.

Two-way ANOVA followed by Tukey's Honestly Significant Difference (HSD) test was used to test for significant differences between the three different lithium disilicate ceramic samples and the three soaking solutions, and their interaction.

Results

The effect of two CAMBRA recommended treatments (Prevident and chlorhexidine), and controls (6% alcohol and water), on the fracture strength of three lithium disilicate ceramics (Press, CAD, and CAD/CERAM) was evaluated. The ceramics were soaked in the rinses for specified times to simulate 2 years of use. After the soaking protocols were completed, the fracture strengths of the three different ceramics were assessed. The mean fracture strengths for the three lithium disilicate ceramics (Press, CAD, and CAD/CERAM) were 612.3MPa +/- 27.8MPa, 561.5MPa +/- 27.8MPa, and 564.9MPa +/- 27.8MPa, respectively (Figure 5). There was no significant difference between the means of the fracture strengths of the different ceramic materials ($F = 1.045$, $P = 0.355$) (Table 5).

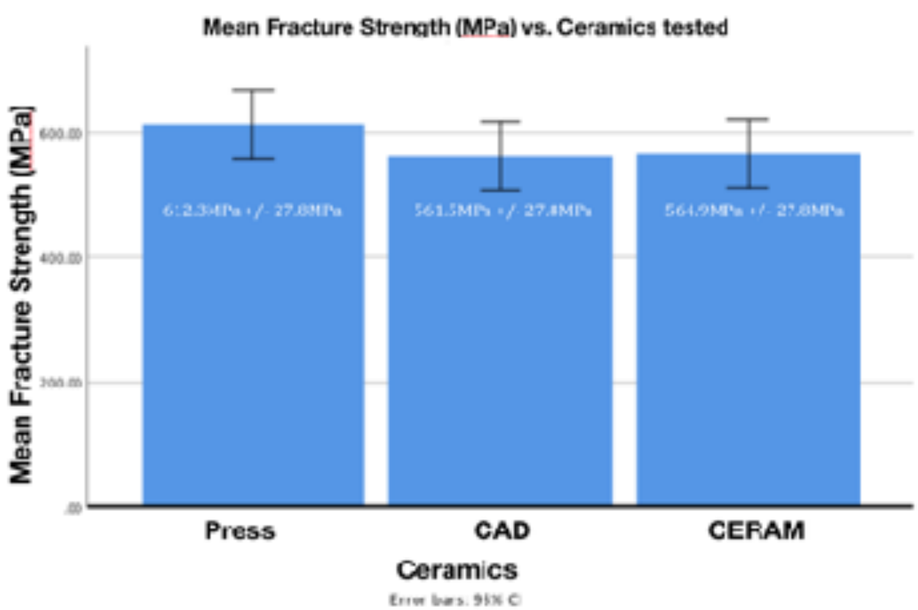

Figure 5 Mean fracture strengths of the ceramics tested

Soaking solution had a significant effect on fracture strength of the ceramics tested (F = 3.513, P = 0.017). The fracture strength of the ceramics soaked in Prevident were significantly lower, when compared to the other three solutions—with a P = 0.044. The mean fracture strength of each of the four soaking solutions (water, alcohol, chlorhexidine, and Prevident) were 651.1MPa +/- 32.1MPa, 584.8MPa +/- 32.1MPa, 578.3MPa +/- 32.1MPa, and 504.0MPa +/- 32.1MPa, respectively (Figure 6).

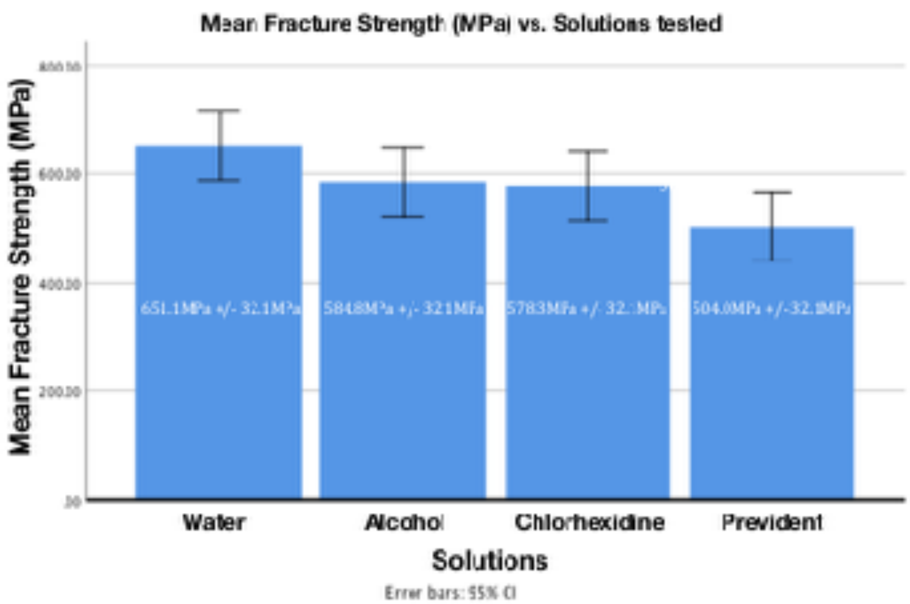

Figure 6 Mean fracture strengths of the solutions tested

Water, Six percent alcohol, and chlorhexidine had no effect on the fracture strength of the ceramics. Prevident, on the other hand, significantly decreased the fracture strength of the three different lithium disilicates (P=0.044) (Table 4).

Table 4: Tukey HSD Multiple Comparisons for Solutions Tested

Solutions Compared	Tukey HSD Q-statistic	Tukey HSD p-value	Tukey HSD inference
H_2O vs. Alcohol	2.0841	0.4573638	insignificant
H_2O vs. Chlorhexidine	2.2876	0.3729502	insignificant
H_2O vs. Prevident	4.6243	0.0073257	$p<0.01$
Alcohol vs. Chlorhexidine	0.2035	0.8999947	insignificant
Alcohol vs. Prevident	2.5403	0.2796595	insignificant
Chlorhexidine vs. Prevident	2.3368	0.3534642	insignificant

There was no significant interaction between the three different ceramics and the four different soaking solutions (F = 0.574, P = 0.751) (Figure 7).

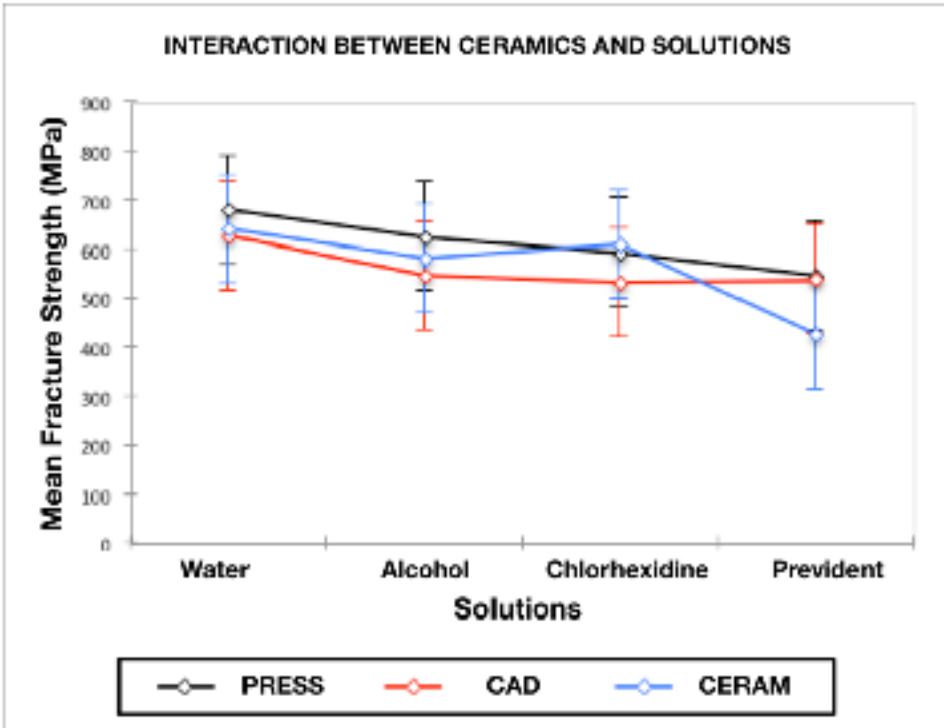

Figure 7 Interactions between the ceramics and the solutions

Discussion

One of the most important tasks in modern dentistry is caries management. Using the management protocols developed by Featherstone et al.[3], clinicians are able to address caries management by identifying specific risk levels of different patients. This enables the clinician to create individualized treatment regimens for patients. CAMBRA protocols indicate the use of several products in this caries management regimen—which includes Prevident and chlorhexidine. Although these products may have significant protective factors to the cementum and enamel against caries (since they do not affect the integrity of the dentinal complex), they may, however, affect the integrity of restorative materials commonly used in dentistry.

Research by Bolding et al[45] and Ghunaim et al. demonstrated significant changes in the surface roughness of porcelains used in dentistry when subjected to CAMBRA protocols. The present study was consequently designed to expand on the findings of this data. The clinical importance of the effects of Prevident and chlorhexidine was explored to examine how the fracture strength was also affected, if at all. Based on the results obtained in this study, the null hypotheses that there is no significant difference in the four groups, the controls (6% alcohol, water), and the soaking solutions (Prevident, chlorhexidine) in terms of change in fracture strength was rejected.

The fracture strengths of the three different ceramics were assessed. The mean fracture strengths for the three lithium disilicate ceramics (Press, CAD, and CAD/CERAM) showed no significant difference between the means of the fracture strengths of the different ceramic materials. Therefore, the null hypothesis that there is no significant difference between the three lithium disilicate ceramics (e.max® Press, e.max® CAD, e.max® CAD veneered with e.max® CERAM) after exposure to different soaking treatments (Prevident, chlorhexidine, 6% alcohol, water) in terms of change in fracture strength was accepted. This was expected since they all consist of the same restorative material.

Despite the fact that they are all lithium disilicate ceramics, differences in their fabrication methods results in differences in their crystalline microstructures. CAD consists of a fine grain lithium disilicate in a glassy matrix. Press ceramics consist of needle-like crystals that are larger and have a size range ranging from 3-6μm in length. CAD/CERAM, on the other hand, contains fluoroapatite crystals in addition to lithium disilicate bound in a glassy matrix and have a crystal size range ranging from 2-5μm. CAD/CERAM has a crystal saturation that is lower than that of both CAD or Press. In both CAD and Press, a more dense and uniform surface of the samples is inherent as a result of the fabrication technique. It could be understandably be expected, for example, that CAD would have a different fracture strength value due to the smaller crystal size. In this study, however, they all had similar fracture strengths.

In all groups, the surface produced is smooth and flat. Visual inspection of the specimens revealed no porosities in the CAD/Press groups, and minimal to no porosities were found on the CAD/Ceram surfaces. The fracture strengths found for all specimen were similar to those reported in the literature.[52,53]

Soaking solution had a significant effect on fracture strength of the ceramics tested. Water, 6% alcohol, and chlorhexidine had no effect on the fracture strength of the ceramics. Prevident, on the other hand, significantly decreased the fracture strength of the three different lithium disilicates.

It is possible that an ingredient in Prevident caused this significant difference to occur—in particular, fluoride. It remains to be seen in the literature if fluoride could have a significant effect on the ceramics tested. This would therefore be the first report to indicate a potential effect of Fluoride on the fracture strength of lithium disilicate.

There are other studies, however, that look at the relationship between fluoride and other properties of ceramics (e.g. surface roughness and bacterial adhesion). These studies looked at surface roughness of titanium abutments, ceramics and composites. Bollen et al 1997 assessed several other dental materials such as gold, resin, titanium, amalgam, and dentin. They found that 0.2µm surface roughness was the critical point below which there was no change in bacterial adhesion. In addition, they found that above this critical threshold was the point at which bacterial adhesion significantly increased. This is particularly noteworthy because they found that by increasing the surface roughness of implant abutments from 0.35µm to 0.81µm, after treatment with fluoride, the bacterial adhesion increased by 20 fold.[54] Although they reported a significant difference in the fluoride group, they did not propose a mechanism by which this occurs.

The current literature contains limited information on the effect of fluoride on the fracture strength of dental ceramics, research in the field of orthodontics has examined the effects of fluoride on the mechanical properties of titanium and stainless steel orthodontic wires.[55] Walker et al. evaluated the effects of fluoride agents (acidulated fluoride, neutral fluoride) on (1) the loading and unloading mechanical properties, and (2) the surface quality of β-titanium and stainless steel.[56] They found that the use of both fluoride agents showed a decrease in the unloading mechanical properties of β-titanium and stainless steel; implying that these agents could decrease the functional unloading mechanical properties of the wires. This could have significant clinical implications, such as prolonged orthodontic treatment. They also showed that both β-titanium and stainless steel exhibited corrosive changes following exposure to the fluoride agents. Since this study did not evaluate the fracture resistance of lithium disilicate, further research would be indicated to determine the effect of these agents on this material.

Limitations

This study did not account for other variables that the ceramic restorations would typically be subjected to in the oral environment. This can potentially affect the fracture strengths tested in vivo; like when the ceramics are subjected to forces of mastication, the oral microflora, and brushing. In this study, the specimens were soaked continuously for 12 hours to simulate 2-year use. Clinically, patients rinse with the solutions for approximately 30 seconds a day. Therefore, the continuous soaking simulated in this study does not accurately represent the cyclical clinical use by which these solutions are intended to be used. This could potentially alter the effects of the solutions on the fracture strengths of the samples examined. Studies on the dissolution of ceramics (e.g. zirconia and silicate ceramics) have shown that there is a difference in the effects of static versus flowing solution, whereby samples are subjected to soaking versus rinsing. Ceramic dissolution occurs due to the dissolution of alkali compounds and disilicate networks.[57] This dissolution is directly affected by the pH of the environment. Therefore, increasing the pH of the environment would increase the ceramic dissolution. As ceramics are soaked in static solutions, alkali compounds dissolve and the pH is consequently increased. This then increases the dissolution of the silica matrix. This cycle could indicate that continuous soaking enhances the effect of the solutions, and does not accurately mimic clinical use of the tested soaking solutions.

Clinical Implications

Within the limitations of this study, it is evident that the prescribed CAMBRA agents affect the ceramics that are used clinically. However, it was also shown that different ceramics do not behave dirrently when subjected to the same conditions. That is, fracture strength of the ceramics tested can be decreased by these rinses, such as Prevident. These changes not only induce change in fracture strength, but may also affect bacterial adhesion, fracture resistance, among other properties. Further studies are needed to demonstrate what component of these solutions is the source of the fracture strength change.

Conclusions

This study investigated the effect of CAMBRA recommended products, chlorhexidine and Prevident, on the fracture strength of the lithium disilicates: Press, CAD, and CAD/CERAM. No significant interaction was found between the solutions and the lithium disilicate ceramics. Water, Six percent alcohol, and chlorhexidine had no effect on the fracture strength of the Press, CAD, CAD/CERAM. Prevident, on the other hand, significantly decreased the fracture strength of the three different lithium disilicates. Within the limitations of this study, it can be concluded that caution should be used with prolonged use of Prevident in patients that have lithium disilicate restorations, regardless of how they were manufactured. Prolonged use of chlorhexidine, on the other hand, appears to have no significant effect on the fracture strength of lithium disilicate, regardless of how they were manufactured. Therefore, clinicians should not be concerned about prolonged use of chlorhexidine; but they should, however, be aware of the potential decrease in fracture strength of lithium disilicates with prolonged use of Prevident.

Appendix

Appendix Tables

Table 5 One-Way ANOVA Summary Table

Source	DF	Sum of squares	Mean squares	F	Sig
SOLUTION	3	390426.908	130142.30	3.513	**0.017**
MATERIAL	2	77400.895	38700.45	1.045	0.355
SOLN*MATERIAL	6	127513.993	21252.33	0.574	0.751

Table 6 Levene's Test

Levene's Test of Equality of Error Variances[a,b]

		Levene Statistic	df1	df2	Sig.
FS	Based on Mean	1.380	11	132	.189
	Based on Median	1.000	11	132	.450
	Based on Median and with adjusted df	1.000	11	104.425	.452
	Based on trimmed mean	1.285	11	132	.240

Table 7 Between-Subjects Effects Testing Table

Tests of Between-Subjects Effects

Dependent Variable: FS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	595341.795[a]	11	54121.981	1.461	.154
Intercept	48367578.539	1	48367578.539	1305.705	.000
SOLN	390426.908	3	130142.303	3.513	.017
MATERIAL	77400.895	2	38700.447	1.045	.355
SOLN * MATERIAL	127513.993	6	21252.332	.574	.751
Error	4889711.506	132	37043.269		
Total	53852631.841	144			
Corrected Total	5485053.302	143			

References

1. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Data. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [1999-2004] URL:http://www.nidcr.nih.gov/DataStatistics/FindDataByTopic/DentalCaries/DentalCariesAdults20to64.htm

2. Hunter PB. Risk factors in dental caries. *Int Dent J*. 1988;38: p. 211-7.

3. Featherstone JD, Adair SM, Anderson MH, Berkowitz RJ, Bird WF, Crall JJ, Den Besten PK, Donly KJ, Glassman P, Milgrom P, Roth JR, Snow R, Stewart RE. Caries management by risk assessment: consensus statement, April 2002. *J Calif Dent Assoc*, 2003; 31: p. 257-69.

4. Featherstone JD, Domejean-Orliaguet S, Jenson L, Wolff M, Young DA. Caries risk assessment in practice for age 6 through adult. *J Calif Dent Assoc,* 2007; 35: p. 703-7, 710-3.

5. Jenson L, Budenz AW, Featherstone JD, Ramos-Gomez FJ, Spolsky VW, Young DA. Clinical protocols for caries management by risk assessment. *J Calif Dent. Assoc.* 2007; 35: p. 714-23.

6. Mandel ID. The functions of saliva. *J Dent Res.* 1987; 66: p. 623-627.

7. Larsen MJ, Jensen AF, Madsen DM, Pearce EIF. Individual variations of pH, buffer capacity, and concentrations of calcium and phosphate in unstimulated whole saliva. *Arch Oral Biol*. 1999; 44: p. 111–117.

8. Becks H, Wainwright WW. Human saliva. XI. The effect of activation on salivary calcium and phosphorus content. *J Dent Res*. 1941; 20: p. 637–648.

9. Larsen MJ, Pearce EI. Saturation of human saliva with respect to calcium salts. *Arch Oral Biol*. 2003; 48: p. 317-22.
10. Lilienthal B. An Analysis of the Buffer Systems in Saliva. 1955; *J Dent Res.* 1955; 34: p. 516-30.
11. Lecompte EJ. Clinical application of topical fluoride products- risks, benefits, and recommendations. *J Dent Res.* 1987; 66: p. 1066-1071.
12. Lynch RJ, Navada R, Walia R. Low-levels of fluoride in plaque and saliva and their effects on the demineralisation and remineralisation of enamel; role of fluoride toothpastes. *Int Dent J.* 2004; 54: p. 304-9.
13. Wan AKL, Seow WK, Purdie DM, Bird PS, Walsh LJ, Tudehope DI. A Longitudinal Study of Streptococcus Mutans Colonization in Infants after Tooth Eruption. *J Dent Res*. 2003; 82: p. 504-8
14. Soderling E, Pienihakkinen P, Tenovuo J. Influence of maternal xylitol consumption on acquisition of mutans streptococci by infants. *J Dent Res*. 2000; 79: p. 882-887
15. Featherstone JDB, Gansky SA. A randomized clinical trial of caries management by risk assessment. *Caries Res.* 2005; 39: p. 295.
16. Lynch H, Milgrom P. Xylitol and dental caries: an overview for clinicians. *J Calif Dent Assoc.* 2003; 31: p. 205-9
17. Berkowitz RJ, Acquisition and transmission of mutans streptococci. *J Calif Dent Assoc.* 2003; 31: p. 135-8
18. Schemehorn BR, Orban JC, Wood GD, Fischer GM, Winston AE. Remineralization by fluoride enhanced with calcium and phosphate ingredients. *J Clin Dent*. 1999; 10: p. 13–16

19. Butler CJ, Masri R, Driscoll CF, Thompson GA, Runyan DA, Anthony von Fraunhofer J. Effect of fluoride and 10% carbamide peroxide on the surface roughness of low-fusing and ultra low-fusing porcelain. *J Prosthet Dent*, 2004; 92: p. 179-83.

20. Rosenblum MA, Schulman A. A review of all ceramic restorations *J Am Dent Assoc*. 1997; 128: p. 297–307

21. Phillips RW. Skinner's Science of Dental Materials, Ed 9. Philadelphia, WB Saunders Co. 1991; p. 505-527.

22. Deany IL. Recent advances in ceramics for dentistry. *Crit Rev Oral Biol Med*. 1996; 7: p. 134-143.

23. Sorensen JA, Choi C, Fanuscu MI, Mito WT. IPS Empress crown system: Three year clinical trial results. *J Calif Dent Assoc*. 1998; 26: p. 130–6

24. Land CH. A new system of restoring badly decayed teeth by means of an enamelled coating. *Independent Pract.* 1886; 7: p. 407

25. McLean JW, Hughes TW. The reinforcement of dental porcelain with ceramic oxides. *Br Dent J.* 1965; 119: p. 251-267.

26. Rosenstiel chapter 25 all-ceramic

27. Seghi, R, Sorensen, J. Relative flexural strength of six new ceramic materials. *Int J Prosthodont*. 1995; 8: p. 239–246.

28. Borom MP, Turkalo AM, Doremus RH. Strength and microstructure in lithium disilicate glass-ceramics. *J Am Ceram Soc.* 1975; 58: p. 385–391.

29. Denry I, Holloway J. Ceramics for dental applications: a review. *Materials.* 2010; 3: p. 351-368.

30. Lupu M, Giordano RA. Flexural strength of CAD/CAM ceramic framework materials. *J Dent Res*. 2007; 88: p. 224.
31. Guazzato M, Albakry M, Ringer SP, Swain MV. Strength, fracture toughness and microstructure of a selection of all-ceramic materials. Part I. Pressable and alumina glass-infiltrated ceramics. *Dent Mater*. 2004; 20: p. 441–48.
32. Fischer H, De Souza RA, Wätjen AM, Richter S, Edelhoff D, Mayer J, Martin M, Telle R. Chemical strengthening of a dental lithium disilicate glass-ceramic material. *J Biomed Mater Res A*. 2008; 87: p. 582-7.
33. Kantorski KZ, Scotti R, Valandro LF, Bottino MA, Koga-Ito CY, Jorge AO. Surface roughness and bacterial adherence to resin composites and ceramics. *Oral Health Prev Dent*. 2009; 7: p. 29-32.
34. Fischer H, Schäfer M, Marx R. Effect of surface roughness on flexural strength of veneer ceramics. *J Dent Res*. 2003 Dec; 82: p. 972-5.
35. de Jager N, Feilzer AJ. The influence of surface roughness on porcelain strength. *Dent Mater*. 2000; 16: p. 381-8.
36. Sundh A, Sjögren G. Fracture resistance of all-ceramic zirconia bridges with differing phase stabilizers and quality of sintering. *Dent Mater*. 2006; 22: p. 778-84
37. Tinschert J, Mautsch W, Augthun M, Spiekermann H. Fracture resistance of lithium disilicate-, alumina-, and zirconia-based three-unit fixed partial dentures: a laboratory study. *Int J Prosthodont.* 2001; 14: p. 231-8.
38. Shafiei F, Memarpour M. Effect of chlorhexidine application on long-term shear bond strength of resin cements to dentin. *J Prosthodont Res.* 2010; 54: p. 153-8.

39. Carrilho MRO, Carvalho RM, Goes MF, di Hipólito V, Geraldeli S, Tay FR, Pashley DH, Tjäderhane L. Chlorhexidine preserves dentin bond in vitro. *J Dent Res.* 2007; 86: p. 90–94.

40. Carrilho MRO, Geraldeli S, Tay FR, de Goes M, Carvalho RM, Tjäderhane L, Reis AF, Hebling J, Mazzoni A, Breschi L, Pashley D. In Vivo Preservation of hybrid layer by chlorhexidine. *J Dent Res.* 2007; 86: p. 529–533.

41. Gendron R, Grenier D, Sorsa T, Mayrand D. Inhibition of the activities of matrix metalloproteinases 2, 8, and 9 by chlorhexidine. *Clin Diagn Lab Immunol.* 1999; 6: p. 437–439.

42. Arhuna, N, Arman A, Sesen C, Karabulut E, Korkmaz Y, Gokalp S. Shear bond strength of orthodontic brackets with 3 self-etch adhesives. *Am J Orthod Dentofacial Orthop.* 2006; 129: p. 547-50.

43. Kimura T, Dunn WJ, Taloumis LJ. Effect of fluoride varnish on the in vitro bond strength of orthodontic brackets using a self-etching primer system. *Am J Orthod Dentofacial Orthop.* 2004; 125: p. 351-6.

44. Bolding L, Masri R, Arola D, Driscoll C, Romberg E. CAMBRA and its effect on the surface roughness of various restorative materials. *J Prosth Dent.* 2015; 114: p. 543-8.

45. Ghunaim D, Masri D, Driscoll C, Romberg E, Limkangwalmongkol, P. The effect of CAMBRA recommended anti-caries agents on surface roughness of lithium disilicate ceramics. *University of Maryland, Baltimore.* 2014. Not published. URL: http://search.proquest.com/docview/1547038858. (accessed September 9, 2014).

46. Indira MD, Nandlal BJ. Comparative evaluation of the effect of cavity disinfectants on the fracture resistance of primary molars restored with indirect composite inlays: an in vitro study. *Indian Soc Pedod Prev Dent*. 2010; 28: p. 258-63.
47. Watanabe I, Watanabe E. Surface changes induced by fluoride prophylactic agents on titanium-based orthodontic wires. *Am J Orthod Dentofacial Orthop*. 2003; 123: p. 653-6.
48. Walker MP, Ries D, Kula K, Ellis M, Fricke B. Mechanical properties and surface characterization of beta titanium and stainless steel orthodontic wire following topical fluoride treatment. *Angle Orthod*. 2007; 77: p. 342-8.
49. Mazzoni A, Pashley DH, Nishitani Y, Breschi L, Mannello F, Tjäderhane L, Toledano M, Pashley EL, Tay FR. Reactivation of inactivated endogenous proteolytic activities in phosphoric acid-etched dentine by etch-and-rinse adhesives. *Biomaterials*. 2006; 27: p. 4470-6.
50. Pashley DH, Tay FR, Yiu C, Hashimoto M, Breschi L, Carvalho RM, Ito S. Collagen degradation by host-derived enzymes during aging. *J Dent Res*. 2004; 83: p. 216-21.
51. Cunningham MP, Meiers JC. The effect of dentin disinfectants on shear bond strength of resin-modified glass-ionomer materials. *Quintessence Int*. 1997; 28: p. 545–51.
52. Bremer, F., In Vivo Biofilm formation on Different Dental Ceramics. Quintessence Int 2011;42:565-574.
53. L Alkadi, N Ruse. Fracture toughness of two lithium disilicate dental glass ceramics. *J Prosthet Dent*. 2016;116: p. 591-596.
54. Bollen, C.M., P. Lambrechts, and M. Quirynen, Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: a review of the literature. Dent Mater, 1997. 13: p. 258-69

55. Watanabe I, Watanabe E. Surface changes induced by fluoride prophylactic agents on titanium-based orthodontic wires. *Am J Orthod Dentofacial Orthop*. 2003; 123: p. 653-6.
56. Walker MP, Ries D, Kula K, Ellis M, Fricke B. Mechanical properties and surface characterization of beta titanium and stainless steel orthodontic wire following topical fluoride treatment. *Angle Orthod*. 2007; 77: p. 342-8.
57 Swain M. Impact of oral fluids on dental ceramics: What is the clinical relevance?. *Dental Materials*. 2014; 1:p. 33-42.