Prospective Clinical Trial of a New Press-over Crown System

Kathryn L. Conard, DDS

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Approved by:
Lyndon F. Cooper, DDS, PhD
Carol Haggerty, DDS, MPH
Thomas Ziemiecki, DDS, MS
ABSTRACT
Kathryn L. Conard, DDS
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Under the direction of Lyndon F. Cooper, DDS, PhD

Porcelain-fused-to-metal (PFM) and all-ceramic alternatives to metal alloy crowns are preferred in esthetically-oriented communities. When strength is of concern, the PFM crown is an accepted historical reference. Pressed-on-metal (POM) crowns are PFM restorations produced by an alternative method. Their advantages include durability, reduced abrasion, reduced porosity, and pragmatic advantages in mass production. Strong, predictable, wear-resistant, well-fitting, esthetic POM crowns may offer significant advantages over conventional PFMs.

This study’s aim was to evaluate two-year crown survivability. It required six clinical visits. Evaluation was planned at six, 12 and 24 months after crown cementation using CDA and USPHS quality evaluations. Follow-up evaluations continue for this IRB-approved study, but POM technology has been favorable with few adverse events. Results are 36 patients treated with 40 crowns with good to very good esthetics, veneer porcelain with reproducible quality, lacking surface porosity at the metal-ceramic interface, no voids and acceptable to satisfactory marginal adaptation.
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LIST OF ABBREVIATIONS

CAD-CAM: Computer-aided design, computer-aided manufacture
CDA: California Dental Association
IPS: Ivoclar porcelain system
PFM: Porcelain-fused-to-metal
POM: Pressed-on-metal
R: Romeo rating
S: Sierra rating
SCA: restoration rating
SCR: marginal discrepancy rating
SOCO: over contoured rating
SU CO: under contoured rating
TOC: Total occlusal convergence
UNC: University of North Carolina
USPHS: United States Public Health Service
1 INTRODUCTION
The prescription of single crowns occurs over 40x10^6 times annually in the United States\(^1\). The clinician’s decision to place a crown is largely based on desire to replace missing tooth structure, protect and reinforce or esthetically enhance existing tooth structure. Many clinical and practical factors influence the clinician’s decision regarding the type of crown prescribed. This is an important pre-operative decision because it influences the preparation of the recipient tooth. Occlusion, tooth position in the arch, location of the final crown margin, esthetics, periodontal condition, structural integrity, and vitality of the tooth to be restored all factor into this decision.

In early 2000s, 65% of crowns fabricated in a 6-month period were metal-ceramic crowns with only 23% being all-ceramic restorations. Metal-ceramic crowns have a proven record over decades of use\(^2\). Metal-ceramic crowns have been around for 35 years\(^3\). When teeth require restoration that cannot support existing enamel or prevent tooth fracture, an onlay or a veneer crown is recommended. When esthetics is a principle concern, such as for anterior teeth, veneer crowns with esthetic qualities are mandated. An ideal veneer crown would fulfill several requirements including a) marginal integrity consistent with peri-coronal tissue health, b) goodness of fit to complement resistance and retention form, c) biocompatibility of materials, d) durability and strength, e) non-abrasive to opposing teeth, and f) esthetic qualities matching healthy enamel. Ideally, a veneer crown would perfectly replace enamel optically and recapitulate the cemento-enamal junction in its marginal integrity and recapitulate the dentino-enamel junction in its goodness of fit. The relatively
long history (Table 1) of veneer crowns suggests that technological advances have focused on all of these different features of an ideal veneer crown, but have yet to result in an ideal replacement for dental enamel.

1.1 History

The preparation of teeth for veneer crowns by rotary instrumentation is among the oldest techniques in restorative dentistry. There are many ways to fabricate dental crowns. Early crowns were cast of gold. Later restorations were veneered with tooth colored acrylic resins or cemented porcelain facings to enhance esthetics. The introduction of the porcelain-fused-to-metal (PFM) crowns opened an era of widely available technology for esthetic crown construction. PFM and all-ceramic alternatives to metal alloy crowns are preferred for tooth restoration and replacement in esthetically oriented communities. When strength is of concern, the PFM crown is an accepted historical reference. Continual developments including porcelain margin techniques and layering porcelains further enhanced this technology to a currently accepted esthetic technique for tooth restoration.

Different techniques have been used since the 1950s to fabricate collarless metal-ceramic crowns. At first, a metal substructure was cast around a platinum foil matrix. With a later method refractory dies were developed so that the porcelain could be fired directly to the die without the foil. Some techniques were created to apply the platinum foil matrix to the cast substructure to apply porcelain. Later the use of platinum foil was eliminated and the condensed porcelain lifted directly off the die. Feldspathic porcelains were an adaptation of a European formulation containing clay, quartz, and feldspar. The European formulation was a great improvement over Chinese porcelains of the 1720s. The developments by Europeans of high firing temperatures and replacing lime (CaO₂) with
feldspar as a flux brought improvement. Improving color and translucency came with formulations by Elias Wildman in 1838 to development of vacuum firing in 1949. In 1885, an innovative use of a metal-ceramic crown system came with development of platinum post crowns. Land, in 1886, used a burnished platinum foil substructure and a high, controlled heat gas furnace for the first fused feldspathic porcelain crowns. In the 1950s, leucite added to porcelain resulted in an increased coefficient of thermal expansion that allowed porcelain fusion to certain gold alloys for crown.

All-ceramic restorations were popularized by pressing technologies such as Dicor restorations. One example of a glass ceramic material is DICOR. This monophasic material was pressed by a lost wax technique and provided advantages inherent to ceramic crowns. The survival of Dicor crowns was examined by Malament and Socransky. The Kaplan-Meier survival analysis for these crowns in different locations and depending on the core material and the luting agent of the mouth ranged from 10 year values of 53.1% to 95.7%. These ceramic restorations displayed worse survivor functions on molars (hazard ratio 3.37). The authors utilized a proportional hazards model to illustrate the importance of tooth position, core structure and luting agent on DICOR crown survival. The data might further suggest how monophasic materials (Dicore, Empress, e.max Lithium Disilicate) might behave. Later developments included pressed leucite glass ceramic (Empress) and pressed lithium disilicate crowns. More recent developments in CAD-CAM technology have led to alumina, lithium disilicate and zirconia copings and crowns that can meet the esthetic needs and clinical quality (goodness of fit) requirements of the patient and clinician. Pressed-on-metal (POM) crowns are PFM restorations produced by an alternative method and may offer significant advantages over PFMs (Table 3).
**TABLE 1: History of veneer crown restorations**²,⁶-¹¹

<table>
<thead>
<tr>
<th>Year</th>
<th>Contribution</th>
<th>Contributor</th>
</tr>
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<tbody>
<tr>
<td>1720s</td>
<td>Europeans manufactured translucent porcelains (Feldspar)</td>
<td></td>
</tr>
<tr>
<td>1808</td>
<td>Individual porcelain teeth with embedded platinum pins</td>
<td></td>
</tr>
<tr>
<td>1817</td>
<td>Introduction of individual porcelain teeth to America</td>
<td>Antoine Plantou</td>
</tr>
<tr>
<td>1837</td>
<td>Fine porcelain teeth begin manufacture</td>
<td>Claudius Ash</td>
</tr>
<tr>
<td>1838</td>
<td>Improved translucency and color of porcelain</td>
<td>Elias Wildman</td>
</tr>
<tr>
<td>1882</td>
<td>Glass fired in molds</td>
<td></td>
</tr>
<tr>
<td>1886</td>
<td>First fused feldspathic porcelain crowns</td>
<td>Charles Land</td>
</tr>
<tr>
<td>18th</td>
<td>Porcelain teeth were potentials for artificial teeth</td>
<td></td>
</tr>
<tr>
<td>century</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1949</td>
<td>Vacuum firing</td>
<td></td>
</tr>
<tr>
<td>1950s</td>
<td>Add leucite to porcelain to increase coefficient of thermal expansion for fusion to alloys</td>
<td></td>
</tr>
<tr>
<td>1956</td>
<td>Fabricate crowns by fusing porcelain to gold</td>
<td>Charles Brecker</td>
</tr>
<tr>
<td>1960s</td>
<td>Development of techniques for internal coloring of crowns with fabrication</td>
<td></td>
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<tr>
<td>1962</td>
<td>Metal-ceramic systems addressed mismatch of coefficient of thermal expansion</td>
<td>Weinstein et al</td>
</tr>
<tr>
<td>1966</td>
<td>First commercial aluminous veneer porcelain (InCeram, Procera, Dicor)</td>
<td></td>
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<tr>
<td>1968</td>
<td>First fabrication of crowns with glass ceramic (leading to Dicor, Cerestore)</td>
<td>MacCulloch</td>
</tr>
<tr>
<td>1970s</td>
<td>New techniques for fabrication of metal-ceramic crowns, commercial shoulder porcelains developed</td>
<td></td>
</tr>
<tr>
<td>1976</td>
<td>1⁰ commercially viable foil-reinforced crown</td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td>Porcelain jacket crown</td>
<td>Land</td>
</tr>
<tr>
<td>1984</td>
<td>Platinum-bonded restorations, Dicor glass ceramic</td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td>Publish that metal-ceramic restoration most popular restorative combo</td>
<td></td>
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<tr>
<td>1987</td>
<td>Preformed platinum alloy copings reinforce aluminous porcelain crowns</td>
<td></td>
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<tr>
<td>1989</td>
<td>Higher strength feldspathic porcelain</td>
<td></td>
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<tr>
<td>1991</td>
<td>Empress (porcelain bonding)</td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>Fabricate all-ceramic crowns with alumina (Procera)</td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>Zirconia products became commercially available introduction of CAD-CAM</td>
<td></td>
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<tr>
<td>2008</td>
<td>e.max</td>
<td></td>
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1.2 Survival and longevity

Uncertainty remains whether evidence-based treatment decisions have been made in Prosthodontics. Biological complications for tooth-supported fixed reconstruction include caries, loss of tooth vitality, and progression of periodontal disease. The color of a metal substructure in metal-ceramic crowns makes it difficult to imitate natural esthetics of the tooth. This metal coloration can also affect the gingival color. Crown survival is defined as a crown that remains with or without modification during the time of observation. Pjetursson et al provided a review for single all-ceramic and metal-ceramic crown survival. Annual failure of all-ceramic crowns was found to be between one and two with a five-year survival rate of 93.3%. Metal-ceramic crowns had a nine-year follow-up with an annual failure rate of up to 1.5 crowns, resulting in a five-year survival rate of 95.6%. Relative failure rates for all-ceramic crowns and glass-ceramic crowns had significantly higher failure rates than metal-ceramic crowns. The highest failure rate was for glass-ceramic crowns placed on posterior teeth. Pjettersson et al report loss of tooth vitality as the most common biological complication, followed by dental caries. Five-year rates of all-ceramic crowns lost due to caries were 0.2% and 0.7% for metal-ceramic crowns. Most other literature reports caries as the most common complication for fixed restorations. Biological complications were reportedly higher for the metal-ceramic crowns than for the all-ceramic crowns. A possible explanation for metal-ceramic being higher is they have greater longevity. Ceramic fracture of metal-ceramic crowns was 0.4% after five years in this study and loss of retention is reported from other studies to be 0.7%. However, ceramic chipping at 5 years was reportedly 5.7%. This is the only technical complication that was reportedly higher for metal-ceramic crowns than for all-ceramic crowns. Cumulative failure rates for all-ceramic crowns were 6.7% and for metal-ceramic crowns 4.4% after five years.
Current clinical concerns surrounding the clinical use of PFM restorations often center on esthetic outcomes, particularly as related to opacity and the marginal interface. The average life span of a PFM restoration is 10 years\textsuperscript{13}. When compared to veneer gold restoration with a survival rate of approximately 90\% at 10 years, a relative need for improvement is suggested\textsuperscript{14}. Additionally, the changing dental laboratory technician work force may challenge obtaining high quality PFM ceramics from the majority of dental laboratories. To overcome the realities and perceived limitations of PFM crowns, all-ceramic alternatives have emerged during the past two decades.

1.3 Materials

The history of crown manufacture in dentistry helps to inform us of the current clinical dilemma: esthetics or function. Dental metals are not pure, but rather mixes that are fused above a melting point of each element, resulting in alloys held by metallic bonds. Wax is burnt out of the mold and the mold is expanded for the metal application. Gradual temperature increase should occur over one hour to avoid investment material cracking. Overheating can cause changes in physical properties that result in brittleness or contamination of the casting. There are inherent errors in the lost wax technique. The process of heating and cooling of an alloy within a mold results in formation of grains and expansion or contraction of the cast object. This affects both the dimensional and physical properties of the object\textsuperscript{15}. Gold casting is dependent on multiple steps and various pieces of equipment. It is sensitive to minor changes and is dependent on the knowledge and technique of the technician. The use of metal castings as substrates for porcelain-fused-to-metal crowns requires careful preparation.
Porcelain has increasingly been used for dental restorations, primarily for esthetic reasons. It has relatively poor tensile strength, but reinforcement with an underlying metal substructure improves this weakness. Important properties of glass include low ductility, not conducting heat or electricity, high tensile and compressive strength, and low shear strength.\(^1\)

Strength, fracture toughness, and resistance to cracking are properties to consider with ceramics. Strength is dependent on testing rather than an inherent property of the ceramic itself. Strength is a measure of the influence of water, fracture toughness, and distribution of failure flaws, often a result of processing rather than of the material itself. A problem when considering strength is it is usually considered for individual materials and not the entire restoration, if made of different materials. Fracture toughness is more an inherent property and useful when comparing ceramics. Fracture toughness is a measure of how easy a ceramic will fail with growth of a crack started in an existing flaw.\(^9\)

Porcelain has been used for intraoral restorations for years due to its compatibility with soft tissues and for its improved esthetics. The composition has changed over the years to improve its quality. Dental porcelain is made by mixing materials and firing. It is primarily made of feldspar, kaolin, and quartz. Feldspar is a double silicate of aluminum and potassium. It fuses at normal porcelain firing temperatures to create a matrix that binds the small crystals of kaolin and quartz. This gives porcelain its vitreous and translucent properties when fired. Feldspar can also be a flux and glaze to the surface. Fluxes are additions to increase mixture fluidity and eliminate impurities. The quantity affects the fusing point of the porcelain. Sodium and potassium carbonates, borax, and glass are some other materials that may serve as a flux in dental porcelain. Kaolin comes from
decomposition of feldspathic minerals and is a hydrated aluminum silicate. Porcelain opacity increases with increased kaolin. Quartz gives stiffness and hardness during and after firing of the porcelain. Aluminum oxide is also a component in dental porcelain. Also known as alumina, it is very hard and chemically bonds with the porcelain. This hardness helps inhibit crack propagation. Tin, nickel, cobalt, titanium, chromium, iron, gold oxides, or metallic gold and platinum may be used to pigment the porcelain.\(^16\)

There are three main groups of dental ceramics: materials that are mostly glassy, particle-filled glasses, and polycrystalline ceramics. Ceramics with greater esthetics are mostly glassy and those that are higher strength substructures are mostly crystalline. Glassy ceramics best mimic optical properties of enamel and dentin. It is amorphous and does not have form. Dental ceramic glasses are derivatives of feldspar and based on silica and alumina, grouping them into aluminosilicate glasses. Feldspar-based glasses resist crystallization, or devitrification. When fired, they have wide firing ranges that allow them to resist slumping if temperatures get too high, and they are biocompatible.\(^9\)

For particle-filled glasses, filler particles are added to the glass composition. This allows improvement in the mechanical properties and allows control of optical effects that include opalescence, color, and opacity. Crystalline is usually the filler of choice but particles of a higher melting glass may also be used. The first used in dental ceramics was leucite. It is added to porcelains of metal-ceramic restorations to alter its thermal and mechanical behavior so that the porcelain could be applied to a metal substructure since it has a higher coefficient of thermal expansion compared to feldspathic glasses. Therefore, the porcelain behavior will be sensitive to minor alterations in its composition. Leucite also provides some translucency to the porcelain and etches quickly to allow for micromechanical
bonding with resin cements. Analysis has shown that multiple firings of dental porcelains alters the leucite content; some increasing and some decreasing. Multiple firings and slow cooling can promote immediate and delayed cracking of porcelain. This may influence porcelain cracking during laboratory procedures of crown fabrication. Once-fired porcelains can be stronger than those with multiple firings\(^8\). Porcelains that have leucite fillers added for strength include pressable and traditional powder porcelains. Glass ceramics are a type of particle-filled glasses, in which the fillers are grown inside the glass after forming the object by precipitation with heat treatment. These include ingots for pressing into molds. A recent glass-ceramic is commercialization of crystalline lithium disilicate\(^9\).

Polycrystalline ceramics are a tougher and stronger ceramic that does not contain glassy components. Regular arrays of densely-packed atoms make them more difficult to crack than glasses with irregular networks. However, these ceramics are more difficult to form into shapes, like prostheses, and tend to be more opaque than glassy ceramics. With their strength, polycrystalline ceramics may serve as substructures for veneered glassy ceramics\(^9\).

Acceptable crown manufacture techniques should provide benefits. Meeting desires and demands for both strength and esthetics can cause a challenge in selecting a restorative material. Traditional choices for metal-ceramic crowns that have a strong core material cause the disadvantage of high value and increased opacity of the substructure, resulting in an esthetic challenge. Relying on dissimilar materials, the bonding interface and the quality of the bond has variation that is influenced by the manufacture of the restoration. Though the core is strong, veneered layering ceramic has low flexural strength and fracture toughness,
causing concern for chipping or fracture of ceramic during function. Increased edge strength results in greater marginal integrity\textsuperscript{17}.

Margin placement affects restoration and margin strength, material bulk, and fabrication accuracy. With increasing esthetic demands, crowns with facial porcelain margins are becoming more popular. This margin can be located slightly subgingival or at the gingival crest and still maintain the strength of the metal substructure\textsuperscript{18}. Elimination of the facial metal collar allows ideal contours to be obtained easier. Supragingival margins are desirable when possible for periodontal health. If restoration margins are placed subgingivally, the biological width should be respected. Kois termed this the dento-gingival complex, including the epithelial attachment, connective tissue attachment, and gingival sulcus. Margin choice should not be based on fit but rather on personal preference of the dentist, esthetics, ease, and type of metal-ceramic crown.

Margin types historically used with metal-ceramic crowns include chamfer, beveled chamfer, shoulder, and beveled shoulder. Chamfers are easy to form, distinct, readily visible, result in adequate bulk of restorative material, and rigidity and sufficient depth for development of normal axial contours. A chamfer is 120 degrees and enhances esthetics while providing biologically acceptable contours (figure 1)\textsuperscript{19}. Hamaguchi et al found no significant difference in metal margin distortion from porcelain addition with different margin types compared, Richter-Snapp et al reported that marginal fit of metal-ceramic crowns are not significantly affected after porcelain application, and Syu et al found no significant differences with axial and marginal fit of different margin types. These, and other studies, confirm that margin choice should not be based on marginal fit alone\textsuperscript{20}.
1.4 Crown Types

Currently, an exhaustive repertoire of crown fabrication techniques exist. While gold fabricated by lost wax technique methods is a robust manufacture method, it has not been industrialized. Fit of traditional feldspathic porcelain restorations is a result of change in powder to solid density change and an effect of multiple firings causing shrinkage. This problem can be reduced by fabricating restorations with pressed ceramics in a mold at high temperatures under viscous flow. This allows the only change to be during cooling and the expansion can be controlled\(^8\).

A jacket crown is a single restoration of porcelain or resin that covers the clinical crown and ends at or under the gingiva. It is indicated for fractured, carious, discolored, malaligned, or abraded teeth with favorable occlusion. Teeth that are too short to retain this restoration should have a veneered gold restoration unless the occlusion does not allow it. This restoration requires clinical skill, as well as a personalized technique with an intimate knowledge of materials and desired perfection in the laboratory. Tooth shape and contact location may not allow a jacket crown to be used. A shoulder margin is desired for these restorations. Foil matrices and firing shrinkage limits the use of porcelain jacket crowns fabricated with aluminous porcelain\(^21\). The porcelain jacket crown represents an historic
reference for all ceramic materials that represent the weakest features of ceramic restorations, including technical complexity and physical inadequacy.

Porcelain jacket crowns fail from the inside out. If the porcelain surface is interrupted, it is weakened and even occlusal adjustment may weaken the crown\textsuperscript{16}. Porcelain jackets have low tensile strength because of surface irregularities, which can make the restoration brittle and subject to fracture due to lack of ductility. Adding alumina as a filler can increase ceramic strength by filling matrix cracks, but its addition will decrease the translucency of the restoration\textsuperscript{15}. Posterior resin jacket crowns will not withstand occlusal pressures, can break adhesion of the cement and over time may split the crown. Therefore, they are not recommended for posterior restorations\textsuperscript{16}.

A veneered gold crown is a full-cast metal crown with either porcelain or acrylic resin veneered on the facial and proximal surfaces. One advantage of this over a fully veneered crown, or PFM, is greater resistance to occlusal forces that the restoration may encounter. This restoration is not a conservative one due to the amount of tooth reduction needed. This restoration requires more tooth reduction than a jacket crown. A shoulder margin preparation on the facial is the desired design. The veneered crown is indicated when a jacket crown may fracture or be abraded easily or when a metal restoration is the only restoration to be used but esthetics are an issue\textsuperscript{16}. Cast metal substructure can contribute to longer life of a veneered porcelain crown. It helps protect the porcelain from developing tensile stress at flaws in certain areas by helping to distribute the stress, as well as slow cracks that may develop in the porcelain\textsuperscript{9}.

Resin may be used for veneering a full-cast crown. It is not as esthetic as porcelain and significant failure of the veneer result is a reality. Resin’s wear resistance is less than
that of porcelain. Adequate thickness needs to be obtained to mask the underlying metal substructure. If used properly, resin can remain color-stable for some time. Over time, with loads, even light loads, resin will alter its shape and undergo elastic deformation with stresses that may not cause permanent changes. The resin will not bond directly to the metal, so it must rely on a mechanical bond. Acrylic has a higher coefficient of thermal expansion than gold, introducing space between the acrylic and gold. Resin also has a low resistance to abrasion, which can cause faster wear of the restoration. Resin form is less of an art than porcelain application, making it easier for laboratory technicians to obtain an acceptable result.

The advancement of dental technology accelerated with successful fusing of porcelain to dental gold alloys resulted in widespread adoption of the PFM crown. The creation of a metal coping by lost wax technique requires multiple steps to create a life-like veneer that reproduces many aspects of human enamel. The process is highly dependent on the success of the porcelain to gold-alloy bond.

The porcelain to gold-alloy bond is a combination of compressive, chemical, mechanical, and Van der Waals forces. Primary and secondary bonds are present. Primary bonds are chemical, or ionic forces, and secondary bonds that are physical, Van der Waals forces. The metal-ceramic bond of POM crowns is based on adhesion, which includes mechanical, chemical, and intermolecular forces. Etching of crystalline leucite that leaves microscopic crypts is the most common way dental micromechanical bonds are created in crowns. Mechanically, the ceramic integrates into depressions on the metal surface. The ceramic has compressive strain due to the coefficient of thermal expansion being lower than the alloy, resulting in increased bond strength. Oxygen atoms in the metal & ceramic layer
initiate the chemical bond. Chemical bonding is thought to be necessary to obtain bond strengths needed for clinical dentistry. This chemical bond of metal-ceramic restorations includes an intermediate oxide layer at the interface. Van der Waals forces provide the intermolecular forces, but are weaker forces than the mechanical and chemical forces. Applying opaquer during casting, the surface tension is broken and a better bond is created between metal and ceramic during firing.

Dental porcelains are usually subjected to multiple firings during crown fabrication. Known as “fritting,” chemical reactions and temperatures can be controlled and shrinkage reduced. Multiple phases of physical change occur during the firing cycle of crown fabrication. The first stage is the biscuit stage and little shrinkage occurs in this phase. Because contamination can easily occur in this phase, it is often skipped and the porcelain is brought to a low maturity. Maturity/vitrification occurs next and may be divided into multiple phases. Then glaze, followed by coalescence, which is an overglazed, rounded form of the porcelain. Color, translucency, and sheen can be seen when maturity occurs, as well as shrinkage having taken place. If porcelain has low-glaze, it is just beyond maturity and water sorption may occur. High glaze is also undesirable because it is close to coalescence and loss of detail, as well as abnormal sheen occurs in this state. Porcelain fabrication and fusing can result in the introduction of such variation due to the detail involved in the processes.

Recent advances in dental laboratory technology involve procedural approaches to enhance the reproducibility of esthetic veneer crown fabrication, both with regard to integrity of the alloy – porcelain bond and the esthetic quality of the ultimate PFM crown. Some approaches involve automation by CAD / CAM technology. Other procedural enhancements have involved the alternative application of porcelain to the metal substrate using the
pressing or molding of molten porcelains onto the metal core within a preformed mold of the crown.

Pressable lithium disilicate is fabricated by a bulk casting method that is a unique production. It involves glass technology that is a continuous manufacturing process involving melting, cooling, simultaneous nucleation of two different crystals and growth of crystals being constantly optimized to avoid defect formation\textsuperscript{17}. The lost-wax technique is used for POM fabrication. Metal is waxed to shape and function, invested, and burned out. The POM ingot is pressed into a mold, divested, and characterized. There is less waste with this fabrication method than with others since fully anatomic crowns for different patients can be pressed in one press cycle. Little time and technical effort are needed to fabricate these crowns, relative to other metal-ceramic crowns. They do not need cutback and there is no need for ceramic layering. In-line POM allows laboratory work to be streamlined, is reproducible, and allows consistent quality for fabrication\textsuperscript{23}.

POM ceramic used was Ivoclar Vivadent, Inc. IPS e.max lithium disilicate glass ceramic. It has optimum esthetics with great optical properties and can be used with conventional or adhesive cementation. The ceramic has needle-like crystal structure for strength and durability. Lithium disilicate (Li\textsubscript{2}Si\textsubscript{2}O\textsubscript{5}) is about 70\% volume needle-like lithium disilicate crystals (3um x 6um long) crystallized in a glassy matrix (figure 2), which results in high flexural strength and fracture toughness. The e.max Press ingots are made of leucite and alkali aluminosilicate glass\textsuperscript{23}. The IPS e.max lithium disilicate has a composition of quartz, lithium dioxide, phosphor oxide, alumina, potassium oxide, and other components. The combination of powders produce a glass melt until the proper viscosity is achieved, then allowing it to be poured into a separable steel mold of the desired shade. The melt is cooled
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until a temperature is reached where no deformations occur. This process allows for quality control. A highly thermal shock-resistant glass ceramic with low thermal expansion is produced due to the composition and is processed using the lost-wax hot pressing techniques\textsuperscript{17}.

Figure 2: Lithium disilicate crystals\textsuperscript{23}

1.5 Preparation guidelines

For easy processing and predictable outcome, given unique physical properties of lithium disilicate crowns, there are a few "keys to success". For the restoration design, to ensure strength and esthetics, the dimensions should be obtained in the wax-up of the crown to include 1.5 millimeters of occlusal and circular material thickness. With the wax-up and finishing, care should be taken to obtain the greatest detail in the wax, providing precise contours and contact, leaving minimal finishing due to the material's hardness\textsuperscript{17}. Clinical and practical factors influencing crown manufacture include a) occlusion, b) preparation reduction of the tooth, c) material thickness, d) material properties. Crowns have ideal preparation criteria that consider fit, contour, color, and durability. Mechanically, biologically, and esthetically sound preparations are desired. Total occlusal convergence (TOC) of the prepared tooth to resist dislodgement laterally should be 10-22 degrees. Occluso-cervically, the minimal dimension of incisors and premolars should be three millimeters and molars should be four millimeters. Without these dimensions, auxiliary resistance features, such as boxes and grooves, are needed. Adequate resistance may be obtained with an occluso-cervical/facio-lingual ratio of at least 0.4 millimeters for all teeth.
When viewed from the occlusal, circumferential morphology that reserves the proximal line angles can help to resist dislodgement. Forces that most need to resist dislodgement are facio-lingual during mastication and parafunction. The amount of tooth reduction needed is based on tooth position and alignment in the arch, occlusion, esthetics, periodontal condition, tooth shape, and crown type. Periodontal health can affect crown placement, but crown placement can also affect periodontal health\textsuperscript{20}.

![Figure 3: Preparation Guidelines\textsuperscript{17}](image)

Preparation guidelines for POM crowns follow the usual guidelines for metal-ceramics. A shoulder or chamfer is possible for margin design. If a conventional cementation protocol is selected, the crown margins should be in metal. If an adhesive protocol is desired, then a ceramic margin is possible. For POM, in areas of metal, a minimum of 0.3 millimeters should be allowed and a minimum of 0.8 millimeters for areas of ceramic. The margin width should be one millimeter wide. If a shoulder is prepared, it should be circular. If a chamfer margin preparation is used, it should be 10-30 degrees in angulation with an occlusal reduction of two millimeters\textsuperscript{23}. Collarless metal-ceramic crowns are desired due to increased esthetic demands coupled with strength of the metal substructure. Fabrication of an all-porcelain facial margin can give a clinically acceptable adaptation of the metal margin\textsuperscript{23}. For the metal framework of the POM crowns, the cusp
support should be designed to allow even ceramic thickness, allowing the force to be transmitted to the framework rather than the ceramic.

Crown contours and marginal placement can impact the periodontal condition of the affected tooth. If there is inadequate contour of the prosthetic crown, undercontoured is more desirable than overcontoured\(^25\). Crown thickness is needed to obtain proper crown anatomy, as well as occlusion and crown color. Color matching can be a challenging task in dentistry. With increasing esthetic demands from patients, color is a part of success of a restoration\(^26\). Different fabrication techniques produce porcelain margins with significant color differences. Human eye detection of color depends on spectral distribution, size, shape, structure, and surroundings of the color stimulus, and the state of the observer’s vision and experiences. This is a subjection evaluation and varies among clinicians and patients\(^26\). At least 50% of observers can visually notice a color change of one degree or greater. Perceived tooth color is affected by shape, size, and location of a restoration because of intrinsic color gradation of a restoration\(^26\). Shoulder porcelain margins present the greatest deviation in color. This could be due to the difference in particle size and optical properties between types of porcelain applied\(^27\). Masking metal substructure with opaque porcelain results in less esthetic restorations and may be a result of inadequate tooth reduction\(^21\). PFM have greater esthetics than cast metal restorations, but due to the metal substructure, there is a lack of light transmission. All-ceramic crowns allow improvement of esthetics, but their fit is lacking.

Positive properties of ceramics include esthetics, strength, goodness of fit, biocompatibility, and wear. Chemicals can affect ceramics by increasing their abrasiveness on opposing dentition, increasing plaque retention, creating surface flaws resulting in weaker structure, and increasing susceptibility of the ceramic to further chemical attack.
Abrasiveness and longevity of ceramics makes practitioners hesitant to use them in certain situations. Enamel against enamel and porcelain against enamel or porcelain have higher wear rates than opposing acrylic or gold. Lithium disilicate is strong, esthetic, biocompatible, has wear compatibility, ease of use, and cementation options.

Structural needs require stronger materials causing the clinician to select restorations with less esthetic ceramics veneered onto copings or frameworks. Clinical longevity of the restoration is an important measure of outcome. There is a lack of guidelines for quantitative esthetic analysis, so this is a criterion that is dependent on subjective evaluation by the dentist, laboratory technician, and the patient.

### 1.6 POM

The POM ceramic is homogeneous and monolithic, making it free of pores. Pressable lithium disilicate has superior strength; two times that of other non-layering ceramics, a monolithic strength that sets it apart from other restorations for posterior full-coverage restorations at 400 MPa flexural strength. Strength and fatigue testing of lithium disilicate pressable materials show that monolithic lithium disilicate allows significant durability for the final crown. Regardless of in vitro testing, lithium disilicate is superior to other crown materials, such as leucite glass ceramic, metal-ceramic, and zirconia.

Advantages of pressable lithium disilicate include greater edge strength than traditional glass ceramics, resulting in thinner finishing without chipping. It can be pressed to thin dimensions due to low viscosity, allowing a less aggressive preparation. Finally, greater translucency allows for the "chameleon effect". This effect is created when light that enters a metal glass ceramic crown becomes selectively filtered by the colorants that
shade the porcelain and scatter, allowing light reflected from other teeth and restorative materials to be absorbed\textsuperscript{29}.

Materials with greater translucency may give better esthetics due to less reflection and optic effects in the gingival third of the restoration can help influence this improvement in esthetics\textsuperscript{6}. An observer’s perceived color match are influenced by optical properties of surface character and translucency, as well as lighting\textsuperscript{26}. Opalescence, translucency, and light diffusion resemble a natural tooth. Having a facial porcelain margin helps improves esthetics eliminating the metal margin display on the facial, but also providing a more natural optic effect with more natural light transmission in the gingival third of the crown.

Laboratory testing has shown the reduced metal coping to be as strong in compressive loading as full-length copings\textsuperscript{9}. Historically, the metal-ceramic crown has not been as esthetic as the all-ceramic option\textsuperscript{19}. Improvements in materials have continued to be made for metal-ceramic crowns. In 1956, Brecker reported that improvements in cervical esthetics could happen with elimination of the metal collar on the facial, allowing a collarless metal-ceramic crown\textsuperscript{7}.

The esthetic capabilities of lithium disilicate allows diverse uses of the material for veneers, inlays and onlays, partial/anterior/posterior crowns, and fixed partial dentures. It is available in four translucencies with nanostructure controlling opacity. Greater opacity is created by light scatter at interfaces between crystals and glass matrix. If the crystal and glass matrix refractive index is similar, very high translucency can be obtained. Altering opacity does not affect the strength and modulus\textsuperscript{8}. Metal-ceramics have made it difficult to keep value while increasing chroma, but metal glass ceramics allow esthetic improvements of hue and chroma due to their translucency\textsuperscript{24}. Most glass ceramics are given their color by
external surface staining with shade porcelain. If this layer is too thin or abrasive materials, such as dental prophy paste or daily fluoride gels are applied, the color may be lost\textsuperscript{8}.

Lithium disilicate is more biocompatible and less cytotoxic than some other frequently used dental restorative materials, such as composite. For example, e.max Press is considered to be non-cytotoxic and meets guideline requirements. There are no recognized risks to patients with the use of dental ceramics\textsuperscript{3}.

Ceramic can be abrasive and wear opposing dentition. Compatibility and resistance to wear are critical in selecting material. Microstructural elements (grains, filler particles, and pores) of ceramic, as well as the fracture toughness and hardness can influence the wear. Size, shape, and character of abrasive features on the ceramic surface determine the wear of enamel and are a function of the fracture toughness of the ceramic. Enamel wear is progressive and related to physical, microstructural, and surface characteristics of the ceramic crown\textsuperscript{24}. It is thought that glass ceramics and feldspathic ceramics can be kinder to opposing dentition that previously thought. All-ceramic restorations have low tensile strength, relatively low fracture toughness, and are abrasive to opposing enamel\textsuperscript{23}. Lithium disilicate wear on opposing tooth structure was very low, when tested, compared to either tested materials, indicating it is kind to opposing dentition. In vitro and clinically, lithium disilicate’s wear on opposing enamel is less than many ceramics used. Lithium disilicate is reportedly comparable to enamel-to-enamel wear\textsuperscript{23}. 

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Figure 4: Comparison of enamel wear
Table 2: Comparison of Esthetic Crown Alternatives

<table>
<thead>
<tr>
<th>Material</th>
<th>Survival</th>
<th>Marginal Integrity</th>
<th>Esthetics</th>
<th>Biologic Response</th>
<th>Patient Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFM</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Porcelain (Dicor)</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All-ceramic</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Relative advantages and disadvantages of POM and PFM crowns

<table>
<thead>
<tr>
<th></th>
<th>POM</th>
<th>PFM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong substructure</td>
<td>Advantage</td>
<td>Advantage</td>
</tr>
<tr>
<td>Fracture susceptibility</td>
<td>Advantage</td>
<td>Disadvantage</td>
</tr>
<tr>
<td>Durable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictable</td>
<td>Advantage</td>
<td></td>
</tr>
<tr>
<td>&gt; Esthetics than metal</td>
<td>Advantage</td>
<td>Advantage</td>
</tr>
<tr>
<td>&gt; Esthetics than all-ceramic</td>
<td>Disadvantage</td>
<td>Disadvantage</td>
</tr>
<tr>
<td>Opacity</td>
<td></td>
<td>Disadvantage</td>
</tr>
<tr>
<td>Fabrication procedures</td>
<td>Advantage</td>
<td>Disadvantage</td>
</tr>
<tr>
<td>Amount of porosity</td>
<td>Advantage</td>
<td>Disadvantage</td>
</tr>
<tr>
<td>Control of marginal integrity</td>
<td>Advantage</td>
<td>Disadvantage</td>
</tr>
<tr>
<td>Amount of tooth preparation</td>
<td>Advantage</td>
<td>Disadvantage</td>
</tr>
<tr>
<td>Abrasive to opposing dentition</td>
<td>Advantage</td>
<td>Disadvantage</td>
</tr>
</tbody>
</table>

POM crowns provide the clinician some options for the method of cementation. For POM, adhesive or conventional cementation can be used\textsuperscript{23}. If an adhesive cementation protocol is used, a resin cement, such as Multilink © is recommended. For the conventional protocol, a glass ionomer is suggested\textsuperscript{23}. Clinical studies show no differences in survival or failure of lithium disilicate with adhesive or conventional cementation options.
1.7 Aim of study

Is POM a viable option? The aim of this project was to investigate survival of an alternative to conventional PFM restorations, namely crowns fabricated by POM technology, over an initial two-year period, as well as evaluate clinical measures of crown quality, marginal integrity and peri-coronal tissue responses. We hypothesized that the 12-24 month survival rate of POM crowns will not differ among premolar and molar crowns.
2 MATERIAL AND METHOD

1.1 Patient Selection

Individuals 18-75 years of age and in need of a single crown were recruited from the University of North Carolina (UNC) Dental Faculty Practice and Graduate Prosthodontics clinic. Inclusion and exclusion criteria (Table 4) were evaluated when patients were screened. Thirty-six patients were enrolled for placement of 40 crowns: 19 molars, 20 premolars, and one canine crown.
1.2 Inclusion and exclusion criteria

Table 4: Inclusion and Exclusion Criteria for Patients

<table>
<thead>
<tr>
<th>Inclusion</th>
<th>Exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Written Informed Consent</td>
<td>Untreated rampant caries</td>
</tr>
<tr>
<td>18-75 years of age</td>
<td>Untreated periodontal disease</td>
</tr>
<tr>
<td>≥ 20 teeth</td>
<td>Absence of opposing dentition</td>
</tr>
<tr>
<td>Stable intra-occlusal contacts</td>
<td>Known bruxer</td>
</tr>
<tr>
<td>Need full-coverage crown(s)</td>
<td>Absence of a proximal contact tooth</td>
</tr>
<tr>
<td>Good physical &amp; mental health</td>
<td>Known pregnancy at inclusion</td>
</tr>
<tr>
<td>Willing to return for recalls</td>
<td>Alcohol or drug abuse</td>
</tr>
<tr>
<td>Contra-lateral tooth present</td>
<td>Local or systemic condition that prevents use of local anesthetic</td>
</tr>
<tr>
<td>Mesial or distal tooth contact</td>
<td>Known allergy to restorative materials used in study</td>
</tr>
<tr>
<td></td>
<td>Study tooth to serve as RPD abutment</td>
</tr>
<tr>
<td></td>
<td>Unlikely compliance with study procedures, according to investigators</td>
</tr>
<tr>
<td></td>
<td>Unable or unwilling to return for follow-ups</td>
</tr>
<tr>
<td></td>
<td>Unrealistic expectation of patient</td>
</tr>
</tbody>
</table>

This study was designed as a single cohort prospective investigation with a two-year follow-up investigation. The treatment period included diagnosis and treatment planning, crown preparation, final impression, and provisionalization, crown try-in and crown delivery with follow-up visits planned to take place at six, 12, and 24 months. Six scheduled visits were planned.

1.3 Treatment

1.3.1 Evaluation and planning (Visit 1):

The screening procedure included a clinical and radiographical assessment. Individuals providing informed consent were enrolled and planned for treatment. Evaluation and planning followed the guidelines described in Prosthodontic textbooks. This visit involved a) complete dental examination and dental history, b) making of impressions for study casts, and c) recording of inter-occlusal registrations where required.
1.3.2 Tooth preparation, impression and provisionalization visit (Visit 2):

1.3.2.1 Pre-operative measurements

The gingival index and plaque index were to be measured at the tooth being treated and the contra-lateral tooth of the arch in question. Pre-operative photographs were made of the entire tooth treated including the mesial and distal adjacent tooth from the buccal, lingual and occlusal orientations. A buccal photograph of the pre-operative condition in maximum intercusptation position was also made.

1.3.2.2 Tooth Preparation

The patient was anesthetized. The tooth to be crowned was prepared using a deep chamfer margin design.
1.3.2.3 Final Impression

Immediately following tooth preparation, tissue retraction was performed using a standard two-cord impression technique and a full-arch impression containing the treatment tooth was made using a vinyl polysiloxane impression material. The accepted impression was delivered to the dental laboratory for fabrication of the POM crown. In addition, the laboratory was provided with a) an inter-occlusal registration, b) an opposing full arch cast, c) a tooth shade prescription and d) a completed dental prescription.

Operative photographs were made of the entire tooth treated included the mesial and distal adjacent tooth from the buccal, lingual and occlusal orientations. A buccal photograph of the pre-operative condition in maximum intercuspation position was also taken.

1.3.2.4 Provisional crown fabrication

Provisional crowns were fabricated using bisacryl resin carried to the prepared tooth using a polymeric matrix. The polished provisional crown was cemented with provisional cement and excess removed.

1.3.3 Crown delivery (Visit 3)

1.3.3.1 Try-in and Cementation:

Cementation of the crown was performed after evaluation of the clinical situation. The gingival index and plaque index were measured at the treated tooth and the contra-lateral tooth of the arch in question. Photographs of the post-operative provisional crown were made of the entire tooth treated including the mesial and distal adjacent tooth from the buccal, lingual and occlusal orientations. A buccal photograph of the post-operative provisional crown condition in maximum intercuspation position was also taken.
Final polishing of porcelain was performed using magnification and Dialite polishing points.

Any crown requiring major adjustment will be returned for modification by the laboratory technician.

The final crown was cemented using resin-based Multilink© cement and the residual cement carefully removed. A final bitewing radiograph was taken to confirm seating of the crown, check cement removal and record bone levels.

1.3.4 Follow-up (6 months to 24 months)

The gingival index and plaque index measurements at the tooth being treated and the contra-lateral tooth of the arch in question were planned. Photographs of the post-operative provisional crown taken of the entire tooth treated including the mesial and distal adjacent tooth from the buccal, lingual and occlusal orientations. A facial photograph of the post-operative provisional crown condition in maximum intercuspation position were taken.
In addition to the photography, CDA and USPHS quality scores of restorations and measurement of gingival and plaque indices at six, 12 and 24 months, follow-up bitewing radiographs were taken at 24 month follow up visit to re-evaluate the interproximal fit of the crown and to record bone levels.

Patients could be discontinued from study treatment and assessments at any time. A patient could be withdrawn from the study voluntarily, for non-compliance, if they were incorrectly enrolled, or they were lost to follow-up. Incorrectly enrolled patients, were not withdrawn from follow-up visits, but will be excluded from the efficacy analysis.
3 RESULTS

Table 5: Crown fracture at 1 year

<table>
<thead>
<tr>
<th></th>
<th>Number Teeth</th>
<th>Fracture</th>
<th>Endodontic Fracture</th>
<th>Total Fracture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Premolars</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Molars</td>
<td>19</td>
<td>3</td>
<td>1 (#30)</td>
<td>15.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(#14, 18, 30)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td>3</td>
<td>1 (#30)</td>
<td>10%</td>
</tr>
</tbody>
</table>

One-year results show four fractures out of our 40 placed crowns for patients that returned for recall. All of these fractures have been on molar crowns, one of which had a post-cementation endodontic access prepared through it. This shows a 10% total fracture rate at one year for the POM crowns with a rate of 15.7% on POM molar crowns.

Table 6: CDA Ratings Recorded

<table>
<thead>
<tr>
<th>CDA Score</th>
<th>Number Crowns</th>
<th>Percentage *</th>
</tr>
</thead>
<tbody>
<tr>
<td>SU CO</td>
<td>1</td>
<td>2.5</td>
</tr>
<tr>
<td>S</td>
<td>3</td>
<td>7.5</td>
</tr>
<tr>
<td>SO CO</td>
<td>3</td>
<td>7.5</td>
</tr>
<tr>
<td>SCR</td>
<td>3</td>
<td>7.5</td>
</tr>
<tr>
<td>SCA</td>
<td>1</td>
<td>2.5</td>
</tr>
<tr>
<td>R</td>
<td>36</td>
<td>90</td>
</tr>
</tbody>
</table>

*Greater than 100% total; multiple scores for a single crown

Periodontal findings revealed some tissues showed improvement after crown placement. Others showed stability. One crown, or 2.5% of the crowns in this study, were rated SU CO, meaning a restoration that was slightly under contoured. Three crowns, 7.5%, in this study were rated S, SO CO, and SCR. S is for Sierra, which is the range of
acceptability. These were restorations that were of acceptable quality but had one or more features that deviate from ideal. SOCO is a restoration that was slightly over contoured. SCR was rated for a restoration with evidence of slight marginal discrepancy, but no evidence of decay. Repair could be made or was unnecessary. One crown, or 2.5%, was rated SCA. This indicates that a more conservative restoration could be placed, but a crown was acceptable. R for Romeo was the rating provided to 36 of the crowns in this study, for 90% of the crowns. It is the range of excellence, indicating that the restoration was of satisfactory quality and expected to protect tooth and surrounding tissues.

<table>
<thead>
<tr>
<th>Site</th>
<th>Debond/Fracture</th>
<th>Symptoms</th>
<th>Reimpress for crown fit</th>
<th>Crown remake</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>debond</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>pain</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>Hypersensitive/ache</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Veneer fracture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Veneer fracture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Veneer fracture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>Cold sensitivity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Three crowns were remade due to acceptability of fit; two of them prior to cementation, one after radiographic evaluation at delivery. Two of the patients that reported symptomatic found relief with time and further occlusal evaluation. One of the patients received root canal treatment for pulpitis that alleviated the symptoms reported.
Figure 5: Distribution of crowns provided in the UNC POM study:
4 DISCUSSION

Research of ceramics has focused on refining metal-ceramic systems for over 30 years. This has resulted in better alloys, porcelains, and porcelain-metal bonding. In the 1980s, better esthetics could be obtained by a ‘shrink-free’ all-ceramic crown system and crowns that are of castable glass ceramic, as well as innovative processing, and renewed interest of all-ceramics.

POM technology is a change from traditional metal-ceramic techniques of incremental and lateral segmentation build-up. It is a simplification of the PFM crowns. POM provides esthetics that comes from the pressable ceramics with the strength of the metal in PFM. This combination eliminates the need for bulky metal restorations with unsupported porcelain. Posterior restorations need resistance to stress that is predictable and today, patients want the esthetics that porcelains can provide\textsuperscript{30}. The hot-pressed porcelain technique of POM restorations uses a waxed restoration that can be processed into porcelain, giving detail that was previously available mostly with metal and acrylic resin restorations. It is a simple and accurate process that avoids distorted margins in individual restorations\textsuperscript{31}.

Ceramics have several problems to overcome, including flow of the ceramic, metal-porcelain compatibility, and technical complications. When a ceramic is fired, it is heated until the glass becomes soft enough to flow. It is at this temperature that the particles become one, but the viscosity will decrease. This joining of particles will create porosities where the particles do not contact. With continued firing, the voids become rounded during sintering, or continued firing, increasing the ceramic strength. As firing continues, voids rise
to the surface. Glass flow helps eliminate pores but too much can cause slumping of the ceramic. Leucite filler has helped to decrease the slumping seen with earlier ceramics, but does not entirely eliminate it. Therefore, fired ceramics maintain porosity 10-30% porosity, which weaken the ceramic.

Another problem that metal-ceramic restorations encounter is the compatibility of the metal and ceramic. For an acceptable restoration, the metal and ceramic must be chemically, mechanically, and thermally compatible. Application of porcelain can distort the metal substructure due to lack of compatibility between the two materials, a problem of thermo-mechanical compatibility. The porcelain and metal alloy should have similar fusing temperatures and coefficients of thermal expansion. Leucite has again helped to reduce this problem, but the multiple steps required for stacking porcelain for PFM restorations still leaves this as an unsolved problem. Chemical compatibility will result in resistance to thermal and functional stresses. Multiple bond types play a role in bonding these two structures together, but a chemical bond is reportedly the most important. Application of an opaque layer to the metal substructure facilitates this bonding by creating a metal-oxide layer. Mechanical interlocking also helps with bonding porcelain to metal but roughness of the surface may decrease bonding. Contamination of the surfaces can result in failure of the porcelain-metal bond.

Technical problems are encountered with porcelain dental restorations. Though not as high as all-ceramic crowns, metal-ceramic crowns do encounter porcelain chipping and fracture\textsuperscript{11}. Loss of retention of the restoration is another technical problem of crowns. Marginal discoloration is a problem of metal-ceramic restorations, but is one of esthetic concern and has been a decreasing concern with all-porcelain facial margins.
Porcelain restorations do still have problems and research continues to try to overcome these problems. Intraoral ceramic break-down is often due to mechanical forces, chemicals, or a combination\(^6\). A complication develops secondarily during a primary disease or condition and may indicate clinical failure, but not usually. Most problems with crowns are biological. The five most common complications for single crowns are need for endodontic treatment (0-11\%), porcelain fracture (2.7-6\%), loss of retention (1-23\%), periodontal disease (0.6\%), and caries (0-2.7\%)\(^{31}\). Most clinical trials select patients who are not at high caries risk and thus reports are low for most restorative investigations. Typically, the recurrent caries level in clinical trials is less than 3\%\(^{33}\).

### 4.1 Failure

A failure curve represents a wide range of actual results related to different factors. It is just the average performance for a pool of restorations. An important factor influencing the curve is the clinical judgment involved in deciding when to replace a restoration. For esthetic restorations including crowns, the failure of the veneer with display of metal might be more motivating than recurrent caries, wear, loss of attachment, gingival recession or periodontitis. Crowns are typically retained until they debond (cement failure), there is gross caries or endodontic failure. Late failure of retained teeth may occur due to coronal leakage, and periodontal disease. This trial has not had the opportunity to evaluate late failure yet. Early failures may represent major flaws in the process, the design, or fundamental material defect. Failure in clinical trials is often a combination of causes or events\(^{32}\). Complications rarely cause prosthesis loss, but rather may require additional intervention\(^{34}\).
4.1.1 Veneer fracture

Anterior crowns have lower fracture rates than posterior crowns. However, chipping of an anterior crown may be as detrimental as fracture of posterior ceramic because it may warrant replacement of a restoration that may not have been deemed necessary for a posterior restoration due to esthetic concerns of anterior teeth. Posterior all-ceramic crowns have greater failure rates than metal-ceramic crowns. In posterior crowns, the lowest failure rates are for crowns with high fracture toughness and high-strength alumina & alumina-like materials. Other factors that affect fracture rate of crowns include bruxism, if the space is a bound or unbound edentulous space, if the tooth is treated with post and core or has natural dentin support, fabrication or technical error introduced into the crown, and material selection. The first all-ceramic crowns were esthetic, but prone to fracture. Bulk failure and porcelain cracking affect 5-10% of single metal-ceramic crowns at six years. After three years, IPS e.max Press crowns have reportedly shown a low failure rate. It is possible that the crystal shape in this ceramic impedes crack propagation and subsequent fracture. An in vitro study showed fracture resistance on molars that is comparable to unprepared teeth. The reported resistance to crack formation suggests that this ceramic is more reliable for restorations in posterior stress-bearing areas.

Our study found at one-year follow-up three crowns that present with ceramic fracture and one with ceramic chipping, resulting in 10% fracture or chipping of the placed crowns. Merriam-Webster defines fracture as a break, or to cause disorder or to go beyond its limits, while chipping is defined a cutting or breaking a small piece or fragment of something, such as a tooth or crown. One crown in our study had a post-cementation endodontic access prepared excessively in the occlusal surface and it is believed that the
actual access preparation is what fractured the porcelain of this particular crown, based on clinical evaluation. One of the fractured crowns fractured to the metal substructure, indicating a laboratory fabrication error. Since these crowns have double opaque layering applied to the metal substructure prior to pressing of the lithium disilicate ingot, contamination may have occurred that caused debonding of the veneering ceramic. The other two crown fractures occurred in the same patient; one maxillary and one mandibular. The maxillary fracture was an interproximal porcelain fracture and may indicated unsupported porcelain. The mandibular crown in the patient was an altered fabrication design due to occlusal clearance limitations. This crown had a cast occlusal surface with POM veneering on the facial only. This ceramic fracture may indicate a design flaw of this material. All of these fractures occurred between the six-month and one-year follow-up visits. All fractures were with molar crowns, resulting in a one-year molar fracture rate of 15.7%. Location may be contributory. However, the indicated fractures have other factors that may have contributed to the ceramic chipping and fracture and does not seem to be a weakness of the pressable ceramic at this time.

4.1.2 Endodontic

Treating a tooth pulpally may allow retention of the restoration and remaining tooth structure, as well as surrounding structures. Available evidence indicates that endodontic treatment has high long-term survival rates for teeth that are sound periodontally with pulpal and/or periapical pathosis.\textsuperscript{34}

4.1.3 Marginal

Precise fit is needed to preserve the integrity of teeth. To maintain this fit over time, specific and stable properties are needed for certain materials. Material choice is affected by
access and size of the restorative space. A material is effective if it withstands strong and repetitive forces of mastication, sudden temperature changes, acid, moisture, bacterial and enzyme behavior. When combining materials, changes in properties of individual materials results\(^\text{15}\). An advantage of POM is a metal substrate can be adapted to the space.

Metal collars decrease the esthetics of metal-porcelain restorations, so facial ceramic margins address this concern. Accuracy of this margin can be compromised with sintering shrinkage of the porcelain during firing. Marginal discrepancies can also occur due to multiple applications of porcelain resulting in spheroiding of the porcelain. Not only is accuracy affected, but this is time-consuming for the technician to try to correct. Fabrication of PFM margins is more technique-sensitive than pressed ceramics. Laboratory technicians report that they can produce a pressed restoration quicker and easier than they can using the feldspathic technique. The porcelain be affected, but distortion of the metal substructure can also occur with metal-ceramic crown fabrication, affecting the fit. This can occur at many different stages of fabrication. The spheroiding and sintering problems may be avoided with pressed ceramics using the lost-wax technique. This method achieves marginal accuracy within acceptable limits. In a study of marginal fit, three times as many metal-ceramic restorations of feldspathic porcelain were rejected than POM for being clinically unacceptable. The trend showed that there was less variation and better fit among the pressed crowns than the feldspathic crowns\(^\text{35}\).

Marginal fit is the most important criteria that dentists use to evaluate clinical acceptability of cast restorations. Perfection cannot be achieved for marginal adaptation, though no discrepancy is desirable. Close marginal adaptation of restorations influences the long-term prognosis of the tooth and restoration. Marginal gaps allow cement solubility and
may result in caries. Margins are also a prime niche for plaque that can cause caries, periodontal break-down, and possible failure of the restoration. One of the main advantages of the POM technique is that margins of high fidelity may be reproducibly fabricated with few additional technical steps. The generalized process of porcelain application by molding has proven to produce good marginal integrity\textsuperscript{34}. Importantly, multiple studies have found metal-ceramic crowns to have more consistent fitting crowns than cast gold crowns. The fit of the gold crowns fell within the upper range of acceptability, making them more likely to fall outside of that limit of 120 microns or less of acceptable marginal opening. An explorer can be, and often is used for detection a marginal defect, but is often dependent on orientation and path of the explorer. This study confirmed the goodness of fit of PFM crowns, in this case produced using the POM methodology.

4.1.4 Evaluation measures

There is not a standardized method for evaluating crown margins nor is there agreement on the parameters or where to measure\textsuperscript{25}. Where to measure a crown margin for fit is arbitrary in most studies\textsuperscript{7}. Measures of marginal adaptation include direct view, cross-sectional, impression technique, and explorer and visual exam. Some of these techniques require destroying the crown. Due to hydrodynamic intracoronial pressures that occur during cementation of crowns, measurement techniques that do not involve cementation of the crown do not correctly reflect marginal adaptation. Consistency of measurement location is more important than where it is actually measured\textsuperscript{13}.

Despite all the energy invested into laboratory testing, there are no tests that are truly predictive of long-term clinical performance. Bayne stated that there are five categories of variables influence clinical outcomes\textsuperscript{33}. They include operator factors,
design factors, material factors, intraoral location factors and patient factors. It must be recognized that the operator factors, design factors and material factors converge at the point of crown manufacture. Any methodological improvement in the production of a dental crown that can reduce variability in the operator (dentist or technician), design or material or improve the operator, design or material influences could enhance clinical therapy. Clinical performance of a dental prosthesis can be objectively performed by direct analysis using the United States Public Health Service (USPHS) guidelines (Appendix A). They are a system of steps for clinical evaluation that provides a) intraoral events that should be measured in a clinical trial, b) gives ranking to important clinical changes, and c) allows for calibration of trial evaluators.

Prior to 1964, clinical dental research was inadequately organized and researchers were not sure what to measure or how to report it because a direct system of oral evaluation of restorations had not yet been developed. Today, it is widely accepted that subjective judgment must include five major parameters: color match, marginal discoloration & integrity, anatomic form, and dental caries. The scale was phonetically codified from best to worst as alfa, bravo, charlie, and delta. The assessment is based on direct intra-oral observation and is used to determine acceptability or failure of a restoration. The risk assessment is left to the clinician and therefore, there is not a way to group findings across categories. Changes between scale ratings are not necessarily equal. Interest in additional parameters led to expansion of the categories to include occlusion, post-operative sensitivity, fracture, and retention.

Multiple factors affect the clinical outcome of a restoration. They include: operator, design, material, intraoral location, and patient. Operator factors are skill, not judgment,
differences between dentists. Design factors include operator judgment for appropriate clinical parameters for the material of choice. Material factors involve laboratory properties. Intra-oral factors include variations in intra-oral conditions where the restoration will be located, such as stress and saliva. Patient factors include environmental effects, such as behavior and genetics. Operator is the most important factor and can account for 50% of overall risk, with the restorative material itself contributing the least risk.  

4.1.5 Clinical relevance

Clinical information that is available on pressable ceramics is limited. This material proves promising for posterior metal-ceramic restorations, but long-term data is needed. A limitation of this study is the lack of formal data on patient satisfaction. Operator variability could have affected the findings of this study, as multiple operators were investigators, yet one investigator performed evaluations. A small team of technicians, one with each specialty of waxing, metal finishing, opaquing, contour, glazing, and quality control, handled all restorations in the laboratory for this study. The trial size is small. Size and expense of a trial can be disadvantages; so many small trials can be conducted for risk analysis. Thirty-three percent of patients did not return for at least one follow-up in the one-year follow-up time period, accounting for 32.5% of crown evaluations for either the six-month and/or one-year evaluations, yet we remain optimistic. Data collection has occurred for a short time. Two years may be too short to gain information on survival and complication rates for these single crowns. Limited data is published to-date on this material. Further follow-up is warranted.
4.1.6 Future Direction

The information obtained from this and other studies on POM technology may prove useful for future direction in the improvement of dental ceramics. Improvements or elimination of the opaquing layer(s) and how to do so effectively may be of value. CAD-CAM integration may be a further step in the technology that is worth investigating. Can the metal substructure and then the ceramic be milled and integrated together? Pressable ceramics are esthetic and reportedly strong. Can additional material improvements happen? A good clinical evaluation of crown technology has yet to be established and may prove useful, especially if dentistry is to provide treatment of evidence-based dentistry.
5 CONCLUSION

Within the limits of this study…

1. IPS pressable ceramic is a more esthetic metal-ceramic restoration than traditional PFM.

2. IPS pressable ceramic can still fracture.

3. Pressable metal-ceramic restorations have good marginal adaptation.
APPENDIX A: USPHS Criteria for Restorations

Direct Clinical Evaluation Criteria

A. Color-Matching Ability:
   - **Alpha**-no mismatch in color, shade or translucency
   - **Bravo**-mismatch in color, shade, translucency within normal range.
   - **Charlie**-mismatch between restoration and adjacent tooth structure outside of the normal range.

B. Marginal Integrity (Marginal Adaptation):
   - **Alpha**-no evidence of a crevice along the margin into which an explorer will penetrate
   - **Bravo**-visible evidence of marginal crevice without exposure of base or dentin
   - **Charlie**-visible evidence of marginal crevice with dentin or base exposed and mobile or fractured restorations

C. Anatomic Form (Wear):
   - **Alpha**-restoration normally contoured and continuous with existing anatomic form.
   - **Bravo**-restoration under contoured and discontinuous with existing anatomic form
   - **Charlie**-restoration under contoured and discontinuous with existing anatomic form so as to expose dentin or base.

D. Cavosurface marginal discoloration (Interfacial Staining):
   - **Alpha**-no discoloration anywhere on the margin between restoration and tooth structure
   - **Bravo**-marginal discoloration without penetration in a pulpal direction
   - **Charlie**-marginal discoloration with penetration in a pulpal direction

E. Axial Contour:
   - **Alpha**-axial contour continuous with existing tooth form with normal proximal embrasures
   - **Bravo**-slightly under contoured; axial surface, proximal line angles flattened, composite low, not continuous with enamel
   - **Bravo**-slightly over contoured; axial surface full, proximal line angles over accentuated, composite high, not continuous with enamel
   - **Charlie**-moderately under contoured or over contoured
   - **Delta**-decidedly under contoured or over contoured

F. Proximal Contact:
   - **Alpha**-contact tight (closed) on visual inspection; "snap" floss resistance to pass through
   - **Bravo**-contact visually present; little if any resistance to floss pass through
   - **Charlie**-contact visually open
   - **NA**-non applicable
G. Secondary Caries:
   **Alpha**-no evidence of caries contiguous with the margin of the restoration
   **Bravo**-caries contiguous with the margin of the restoration

H. Postoperative Sensitivity:
   **Alpha**-no postoperative thermal or pressure sensitivity
   **Bravo**-postoperative thermal or pressure sensitivity
APPENDIX B: Crown quality evaluation rating system (CDA)\textsuperscript{38}

<table>
<thead>
<tr>
<th>Rating</th>
<th>Operational explanation</th>
<th>Code</th>
<th>Indications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satisfactory</td>
<td>Restoration is of satisfactory quality and is expected to protect tooth and surrounding tissues.</td>
<td></td>
<td>Crown or fixed partial prosthesis is optimal restoration of choice. (Refer to General Guidelines.)</td>
</tr>
<tr>
<td>R: Range of excellence Romeo Code R Call: Romeo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S: Range of acceptability Sierra Code: S Call: Sierra</td>
<td>Restoration is of acceptable quality but exhibits one or more features that deviate from ideal.</td>
<td>SCA</td>
<td>More conservative restoration could be placed, but crown or FPD is acceptable.</td>
</tr>
<tr>
<td>T: Replace or correct for prevention Tango Code: T Call: Tango</td>
<td>Restoration is not of acceptable quality.</td>
<td>TNI</td>
<td>No clear indication for crown or FPD.</td>
</tr>
<tr>
<td>V: Replace statim Victor Code: V Call: Victor</td>
<td>Future damage to tooth or its surrounding tissue is likely to occur.</td>
<td>TDM</td>
<td>Restorations may cause damage or adversely affect prognosis for tooth or teeth.</td>
</tr>
<tr>
<td></td>
<td>Restoration is not of acceptable quality.</td>
<td>TPR</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Damage to tooth or its surrounding tissues is now occurring.</td>
<td>VOT</td>
<td>Crowns are made without consideration of other treatment possibilities. Or, special conditions that require reevaluation are not discovered or taken into consideration.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VCND</td>
<td></td>
</tr>
</tbody>
</table>
### APPENDIX C: Crown quality evaluation criteria and abbreviations (CDA)\(^8\)

<table>
<thead>
<tr>
<th>Code</th>
<th>Surface and color</th>
<th>Code</th>
<th>Anatomic form</th>
<th>Code</th>
<th>Margin integrity</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRO</td>
<td>Surface of restoration is slightly rough or pitted; can be polished.</td>
<td>SOCO</td>
<td>Restoration overcontoured slightly.</td>
<td>SCR</td>
<td>Visible evidence of slight marginal discrepancy with no evidence of decay; repair can be made or is unnecessary.</td>
</tr>
<tr>
<td>SMM</td>
<td>Slight mismatch between shade of restorations(s) and adjacent tooth or teeth.*</td>
<td>SUCO</td>
<td>Restoration slightly undercontoured.</td>
<td>SCIS</td>
<td>Discoloration on margin between restoration and tooth structure.*</td>
</tr>
<tr>
<td>SOH</td>
<td>Occlusion is not totally functional.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMR</td>
<td>Marginal ridges slightly undercontoured.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCO</td>
<td>Contact slightly open.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SFA</td>
<td>Facial flattening is present.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLG</td>
<td>Lingual flattening is present.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAF</td>
<td>Anatomic form of pontic may cause food retention; no irritation of soft tissue.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCI</td>
<td>Surface grossly irregular, not related to anatomy and not subject to correction.</td>
<td>TUCO</td>
<td>Restorations grossly undercontoured.</td>
<td>TFAM</td>
<td>Faulty margins that cannot be properly repaired.</td>
</tr>
<tr>
<td>IMM</td>
<td>Mismatch between restoration(s) and adjacent tooth or teeth outside normal range of color, shade, or translucency.*</td>
<td>TUCO</td>
<td>Restorations grossly overcontoured.</td>
<td>TPEN</td>
<td>Penetrating discoloration along margin of restoration in pulp direction.*</td>
</tr>
<tr>
<td>TET</td>
<td>Occlusion affected.</td>
<td></td>
<td></td>
<td>TCEM</td>
<td>Retained excess cement.</td>
</tr>
<tr>
<td>TCO</td>
<td>Contact is faulty.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOV</td>
<td>There is marginal overhang.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAF</td>
<td>Anatomic form of pontic likely to result in food retention, causing irritation to soft tissue or caries in abutments.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VSF</td>
<td>Surface is fractured.</td>
<td>VTO</td>
<td>Traumatic occlusion.</td>
<td>VMO</td>
<td>Mobile restoration.</td>
</tr>
<tr>
<td>VGP</td>
<td>There are gross porosities in crown material.</td>
<td>VUO</td>
<td>Gross underocclusion or restoration.</td>
<td>VFR</td>
<td>Fractured restoration.</td>
</tr>
<tr>
<td>VSD</td>
<td>Shade in gross disharmony with adjacent teeth.*</td>
<td>VPN</td>
<td>Restoration causes unremitting pain in tooth or adjacent tissue.</td>
<td>VCAR</td>
<td>Caries continuous with margin of restoration.</td>
</tr>
<tr>
<td>VDM</td>
<td>Damage is now occurring to tooth, soft tissue, or supporting bone.</td>
<td>VTF</td>
<td>Tooth structure is fractured.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Criteria apply to anterior teeth.
REFERENCES


17. Ivoclar IPS e.max lithium disilicate brochure. 2009. USA


