Lessons Learned in the Use of Different All-Ceramic

Restorations Over 26 Years: Survival and Involved Clinical Risk

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Abstract: The fundamental objective of dental treatment is the continued health and longevity of the dentition. While advances in material formulations and clinical techniques promise to benefit patient care, various confounding variables (ie, preparation design, patient gender) affect the outcome of a dental restoration. These factors can be difficult to simulate in a laboratory setting when one is attempting to accurately mimic the clinical environment. This article presents a synopsis of the authors’ prospective clinical study of three physically different all-ceramic restorations in order to examine the interactions of several clinical and demographic variables affecting the restorations long-term survival.

Key Words: all-ceramic, fracture, survival, Kaplan-Meier, monolithic
Dental professionals have to consider a multitude of diagnostic and restorative factors when treating their patients. These considerations include the continued health and longevity of the dentition, the patient’s esthetic expectations, the specific functional requirements of the patient, and the restorative material required to address the aforementioned. When ceramics are the restorative option of choice, the selected material has to provide specific esthetic and physical properties that positively influence the intended treatment goal and its potential for success in a given patient.

Ceramic Material Requirements

A variety of all-ceramic materials (eg, IPS Empress, Ivoclar Vivadent, Amherst, NY; InCeram, Vident, Brea, CA; Procera, Nobel Biocare, Yorba Linda, CA) are currently available in the dental market, and each must satisfy certain requirements prior to use in restorative cases:

- Accurate margins
- Favorable biologic response
- Translucency/opacity (ie, color)
- Material properties (strength, toughness, and damage resistance)

Accurate Margins

The physical and optical properties of contemporary dental ceramics—and their respective laboratory fabrication sequences—have been improved from earlier generations of ceramic materials. Nevertheless, their long-term survival in
prosthetic restorations depends on the ability of the attending clinicians to achieve accurate margins during the placement of the definitive restoration, or the result is ultimately predisposed to failure from material fracture, chipping or marginal caries.

Thirty years ago, accurate margins could be predictability achieved with gold restorations, the standard of care to which all-ceramic restorations are inevitably measured. Gold restorations continue to demonstrate long-term excellent clinical performance in part due to their intimate margins.

Favorable Biological Response

As with gold restorations, most ceramic materials are dense, hard materials that exhibit a positive biological response—that is, they resist the adverse effects associated with colonization by microorganisms of the intraoral environment. In the author’s clinical experience, minimal plaque or pellicle adheres to highly glazed ceramic materials 2. These findings, while beyond the context of this discussion, are congruent with an additional concern of researchers who have described the importance of preventing the types of microleakage in dental restorations observed in composite resin materials 3. In addition the all-ceramic materials exhibit minimal to no physical degradation that might adversely affect hard and soft tissues.
Translucency/Opacity

Color, shade, and esthetics are also critical factors for the dental restoration. High-strength materials are often crystalline or biphasic in nature resulting in altered coloration and opacity. This requires veneering porcelain to mask this strong core material and each portion of the resulting bilayer exhibits different properties and behaviors. Application of layering or veneering material to achieve a suitable shade match—is a challenge for even skilled technicians.

Material Properties - Strength

The bilayer nature of the high-strength all-ceramic complete coverage restoration (crown) is similar in some respects to a natural tooth. The veneered porcelain/ceramic core behaves much like the enamel layer of the tooth, which is physically bonded to the “organic” dentin layer. This is significant to the long-term function of prosthetic restorations, as cracks generally initiate at the cementation layer (high tensile stress surface) of the crown (whether it is fabricated as layers or as a ceramic monolith like IPS Empress)\(^4\). Once a crack initiates, it propagates unnoticed until catastrophic failure occurs.

Clinicians should understand the comparative physical properties, especially strength, toughness, and damage resistance of ceramic restorative materials, before prescribing that material for the care of their patients. In the dental profession, it is commonly held that a ceramic material with greater measured physical properties will have a significantly increased long-term survival of a
dental restoration fabricated of that specific material. In truth, this is not always the case. Materials that are strong in their pristine, polished state may be exceptionally vulnerable to damage from fabrication and/or fatigue that result from normal occlusal function. Strength is a necessary, but not sufficient condition for clinical survival. Investigators have used various commendable methods to measure “strength factors,” yet without accounting for toughness and damage resistance, particularly slow crack growth, the tests may provide little indication of how “strong” the material is in a clinical environment.

Furthermore, it can be challenging for practitioners to determine which of the existing laboratory tests best replicates clinical performance and thus apply such knowledge. For example, publications throughout the dental industry bear witness to manufacturers’ strength data as an indication of long-term performance, yet the value of this information depends to a significant extent on the type of fracture test (e.g., Hertzian, bar, rod) they have withstood. These tests provide interesting results with regard to ceramic materials, thicknesses, and related data, but learned information regarding the involved forces cannot be reliably transferred to daily practice. Ultimately, any ceramic material is at its strongest before it is placed intraorally, where it withstands wear, crack propagation, tortional forces, microbiological invasion, continued fatigue, and ultimately, accumulated damage.

*Fractography and Accumulated Damage*
A more accurate measure of a ceramic material’s strength may be derived from the application of fractography\(^4\). Due to the procedures involved in their fabrication, ceramic materials exhibit certain flaws, porosities, and fault lines within the materials themselves. Although fractography once referred exclusively to the origin of cracks and the manner by which they propagated, the term has been applied more recently to the study of damage to the properties of polycrystalline ceramics. Different types of ceramic materials exhibit different types of cracks when exposed to loading or grinding forces, and dental professionals continue to examine these characteristics in order to seek effective methods of creating an improved ceramic restoration. At present, many fracture theories abound, but none is necessarily related to the long-term survival of ceramic materials.

Contact fatigue, determined from appropriately configured test conditions, might be useful in guiding decisions about ranking of materials, although largely inconclusive in this regard. In this test, whether single-cycled Static Loading or multicyced Dynamic Loading, a spherical load is placed on a ceramic disk until the material breaks. These tests and other related models do not accurately depict the fracture of a ceramic material and, consequently, its prognosis for long-term survival. To understand the deformation of a ceramic material as it relates to clinical success, one must study crack propagation and fatigue in an aqueous salivary environment. It is critical to examine how a given ceramic material accumulates damage and what this accumulated damage does to the crystalline form of the final product.
Thus, investigators have acknowledged that ceramic strength is time-sensitive, and that these materials are continuously affected by stress corrosion in both static and dynamic fatigue (chemically assisted crack growth). They are exposed to multiple forces and will show a notable reduction in stress/strain behavior within the oral environment. After some period of function, the cumulative effect of these deformation forces with existing cracks and flaws in the ceramic restoration will result in fracture (ie, fail) requiring replacement/retreatment.

**Long-Term Clinical Monitoring of Empress, In-Ceram and Dicor Restorations**

For over two decades, one of the authors (KAM) recorded data and clinically assessed, on an almost daily basis, measured clinical variables and the relation of these variables to the survival\(^7\)-\(^9\) of all-ceramic restorations functioning in the oral environment. By definition, these variables included risk groups that differed by background factors and clinical factors that could have influenced the outcome. Each restoration was delivered at a single practice site in the conventional manner, followed during maintenance visits, and upon fracture, was considered to be a failure. (In limited instances, the restorations were replaced for reasons other than failure and were noted accordingly). Beginning in March 1983 and ending in February 2008 (Table 1) a host of variables was recorded for each of 476 patients with 1,914 IPS Empress restorations, 414 patients with
1,454 Dicor restorations (Dentsply International, York PA and Corning Glass Works, Corning, NY), and 137 patients with 324 In-Ceram restorations (Vident, Brea, CA).

The IPS Empress all-ceramic material (Ivoclar Vivadent, Inc., Amherst, NY) was developed in association with Arnold Wohlwend and Peter Scharer\textsuperscript{10,11} of the University of Zurich. A leucite-reinforced glass-ceramic, IPS Empress consists of nucleation agents and is manufactured through the controlled crystallization of minute leucite crystals found in the glassy matrix through the use of nucleation agents\textsuperscript{12}. As a monolithic ceramic, this material can be pressed to full or partial contour and colored appropriately; it can also be layered with a corresponding IPS Empress veneering ceramic powder which is then sintered for an optimal color match. In this respect, it handles to some appreciable extent as a feldspathic porcelain. IPS Empress as a silicate-based ceramic is amenable to acid etching (AE) and can then be luted to teeth with a composite resin cement system. Numerous authors have described the esthetic potential of this material, and various researchers have attested to its physical properties and long-term survival\textsuperscript{13,14}.

Dicor glass ceramic material (Denstply International, York, PA) was developed by Peter Adair and David Grossman at Corning Glass Works\textsuperscript{15-16} in 1978. After working out details for clinical applications\textsuperscript{17,18}, the material was released to the dental community in 1982. Dicor was a fluorine-containing tetrasilicic glass-ceramic in the Pyroceram family of glass-ceramics. Restorations were made using the lost wax technique. The casting must be
cerammed to develop internal mica based crystals to create glass-ceramic form. Dicor was a dense well-researched dental material that could be used as a monolithic ceramic with surface metallic oxide colorants or used as a bilayer ceramic where it was used as a core with feldspathic ceramic applied as a veneering material. Dicor was first developed to be luted to teeth with zinc phosphate or glass ionomer (GIC) luting agents. One of the authors (KAM) along with the two developers created a 10% ammonium bifluoride etchant to both clean and etch the surface to allow composite resin luting. Clinical investigations have examined the many variables that might affect the long-term survival of Dicor complete coverage restorations. Improved physical and clinical performance was described when Dicor was acid etched. Other studies examined the effect of breaking strength of Dicor related to gender, tooth position, thickness, margin design and the type of luting agent. Studies have related the fracture resistance of Dicor crowns to crown length and the effect of varying the elastic moduli of the underlying supporting structure. The effect that flaws in Dicor or luting agent spaces had on fracture potential and tensile strength were tested as well as the effects of physiologic aging, abrasiveness, wear and surface roughness.

In-Ceram glass ceramic material (Vita, Bad Sackingen, Germany) was developed by Michael Sadoun and originally described as a slip-cast aluminum oxide ceramic. It initially consists of a densely packed slurry (80-82 wt%) of pure aluminum oxide and then fired at 1120°C for 3 hours on a refractory die. A lanthanum glass is infiltrated into the porous coping and fired again to 1100°C for
4 hours producing a coping without shrinkage yet having high mechanical strength properties (In-Ceram alumina is equivalent to 99.9% pure aluminum oxide). The infiltrated In-Ceram coping is dense, homogeneous and of high strength. This opaque coping is veneered with a feldspathic porcelain creating a bilayer ceramic restoration. The In-Ceram restoration cannot be acid etched and like all all-ceramic materials must never be sand blasted to minimize surface cracks and to maintain its physical strength. This ceramic can be luted with either classic or composite resin luting agents. Clinical investigations have examined the long-term survival in the mouth.

**Lessons Learned from Analysis of Clinical Monitoring**

The development of three all-ceramic restorative materials with differing formulations and physical properties along with the long-term monitoring of survival of these restorations in large number of patients over an extended period of time provided an opportunity to compare the relative survival of the restorative materials themselves and identify important clinical and demographic variables that affecting survival. The findings are presented as Kaplan Meier survivor functions since these are intuitively understood and give a reader an opportunity to determine the probability of survival of a given type of restoration at different points in time. Significance of differences between different survivor functions were determined by the log rank test and are presented in each Figure. Survivor functions comparing the survival of the complete coverage restorations
for each of the three all-ceramic materials evaluated are shown in Figure 1. This “gross” examination across all teeth indicates that the survival of AE IPS Empress (Empress) was statistically significantly better than AE Dicor (Dicor). This suggests that differences in their physical properties such as aging effects of the different all-ceramic materials may play a role in clinical survival.

It was also clear that overall these all-ceramic material restorations had a better long-term survival when luted to single rooted teeth as compared to molar teeth (Fig.2). Dicor and In-Ceram restorations luted to single rooted teeth (incisors, canines and premolars) exhibited statistically significantly better survival than restorations of the same materials luted to molar teeth. There was no statistically significant difference between survival of Empress restorations luted to single rooted or molar teeth. However the number of molar restorations for this material was limited. The lesson learned in this analysis was that all-ceramic restorations, particularly Dicor and In-Ceram, placed on molar teeth are more likely to exhibit fracture or significant chipping than when placed on single rooted teeth, However the use of Empress on molars may diminish such differences.

Composite resin luting materials were developed to improve the retention, resistance and stress distribution qualities compared to either zinc phosphate or glass ionomer luting agents. Dicor restorations luted with composite resin luting agents exhibited statistically significantly better survival than similar restorations luted with zinc phosphate or glass ionomer luting agents. In the present study, when restorations luted with composite resin were compared, the restorations on
single rooted teeth exhibited excellent survival, better than those luted on molar teeth (Fig 3).

Another factor that appeared to influence the survival of In-Ceram and Dicor complete coverage restorations was the gender of the subject (Fig.4). Dicor and In-Ceram restorations placed in the oral cavity of males showed a poorer survival than restorations placed in females. This may have been due at least in part to greater masticatory forces in males. However survival of Empress was virtually identical in males and females. It may be surmised that the properties of Empress that minimized differences in survival of restorations placed on single rooted or molar teeth were similar to those that minimized differences in survival in males and females. Unfortunately, these properties cannot as yet be defined.

The nature of the surface to which a restoration is luted (core) also influences the survival of the three all-ceramic complete coverage restorations (Fig.5). This is particularly noticeable for Dicor and In-Ceram. When luted to dentin the restorations exhibited a poorer survival than when luted to gold or ceramic. The survival of Empress restorations did not differ appreciably when placed on dentin, gold or ceramic.

The above data were evaluated using univariate analysis. Since different “predictor” variables often act as surrogates in data analysis and may interact, it was of interest to determine whether factors found to be statistically significant in a univariate analysis would remain significant after adjusting for other variables in a multivariate model. Table 2a presents statistically significant variables in the
Cox Proportional Hazards model when analyzing the Dicor complete coverage data. Molar (vs. All else), Dentin Core (vs. Gold core), Male (vs. Female) and GIC luting agent (vs. Resin) increased the probability of restoration failure after adjusting for the other variables in the model. Two variables were significantly associated with In-Ceram failure after adjusting for other variables in the model. These were Molar (vs. All else) and Male (vs. Female). None of the variables were statistically significantly associated with Empress failure in the Cox Proportional Hazards model (data not shown).

The most positive lesson to be learned from the long-term clinical monitoring of the three physically different all-ceramic material complete coverage restorations was that the restorations when placed on single rooted teeth luted with composite resin luting agents exhibited excellent survival for at least 10 years. It was found that certain clinical and demographic factors increased risk of failure for both Dicor and In-Ceram and to a lesser extent Empress restorations. These included placement in males, on molar teeth, on dentin cores and luted with zinc phosphate or glass ionomer luting agents. Of interest was the finding that certain factors expected to influence restoration survival did not do so. These included thickness of the restoration, length of restoration axial walls and margin design (data not shown).

The above data indicate that all-ceramic restorative materials, particularly monolithic ceramics, have made a positive entrance into the options that dental practitioners can provide to their patient. With a careful blending of the skills and knowledge of the material scientist, clinical investigators and industry it seems
likely that improved formulations and carefully designed clinical procedures will lead to long-term survival of functional, biologically acceptable and esthetically pleasing dental ceramic restorations.

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Bibliography


Figure Legends

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Figure 1. Kaplan Meir survivor functions of Empress, Dicor and In-Ceram complete coverage restorations. The shaded areas in the right set of panels indicate the 95% confidence intervals. There was a significant difference between the survivor functions of the Empress and Dicor complete coverage restorations using the log rank test.

Figure 2. Kaplan Meier survivor functions and 95% confidence intervals for Empress, Dicor and In-Ceram complete coverage restorations on molar and “single-rooted” teeth. Significance of difference between survivor functions was determined using the log rank test.

Figure 3. Kaplan Meier survivor functions and 95% confidence intervals of Empress, Dicor and In-Ceram complete coverage restorations on “single-rooted” (left panels) and molar teeth (right panels) cemented with composite resin luting agents.

Figure 4. Kaplan-Meier survivor functions and 95% confidence intervals of Empress, Dicor and In-Ceram complete coverage restorations in males and females. Significance of difference between survivor functions was determined using the log rank test.
Figure 5. Kaplan Meier survivor functions and 95% confidence intervals of Empress, Dicor and In-Ceram complete coverage restorations luted to dentin, gold, and ceramic core structures. Significance of difference between survivor functions was determined using the log rank test.