Ceramics: Rationale for material selection

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Abstract
All imaginable types of materials and techniques, from very conservative ceramic restorations to very complex restorations of either metal or high-strength crystalline ceramics veneered with porcelain, have been introduced and tried with varying levels of success. There is considerable misinformation, and a general lack of published rational treatment planning guidelines about when to use the ceramics available in dentistry. This article provides readers with a systematic process for treatment planning with ceramic materials. Specific guidelines are outlined for the appropriate clinical conditions for using the various ceramic materials available.

Introduction
Many types of ceramic materials and processing techniques have been introduced throughout the years. As early as 1903, Charles Land patented all-ceramic restorations, using fired porcelains for inlays, onlays and crowns. Insufficient understanding of material requirements for survival in the oral environment, poor ceramic processing techniques, and the inability of adhesive cementation led to early catastrophic failure. Since then, all imaginable varieties of materials and techniques, from very conservative ceramic restorations to very complex porcelain veneered of either metal or high-strength crystalline ceramics, have been introduced and tried with varying levels of success. The authors have previously published two detailed descriptions of, or classification systems for, ceramics used in dentistry, one based on the microstructure of the material and the second on the way in which the material is processed.

There is considerable misinformation and a general lack of rational treatment planning guidelines published regarding the use of different ceramics in dentistry. The literature is replete with various accounts of clinical success and failures of all types of dental treatments. Sadowsky published a review of the literature covering treatment considerations using aesthetic materials, for example whether to use amalgam or composite and the success rates of different treatments. No recent literature could be found presenting a thorough discussion of when to use the various ceramics, for example when feldspathic porcelains should be used, when either pressed or machined glass-ceramics are appropriate, when different types of glass-ceramics should be employed, when a high-strength all-ceramic crown system of either alumina or zirconia is ideal, and when metal ceramics are suitable.

This article provides a systematic stepwise process for treatment planning with ceramic materials and presents specific guidelines for the appropriate clinical conditions for applications of the various systems.
Treatment philosophy

A treatment philosophy based on current standards of care that consider the patient’s aesthetic requirements is a prerequisite to making any decision regarding the use of a material or technique. More importantly, this philosophy should be aimed at maintaining the long-term biological and structural health of the patient in the least destructive way.

Restorative or aesthetic dentistry should be practised as conservatively as possible. The use of adhesive technologies makes it possible to preserve as much tooth structure as feasible while satisfying the patient’s restorative needs and aesthetic desires. The philosophy today is not to remove any healthy tooth structure unless absolutely necessary. This will reduce dentists’ frustration when orthodontics would have been the ideal treatment. With restorations, clinicians should choose a material and technique that allows the most conservative treatment in order to satisfy the patient’s aesthetic, structural, and biological requirements, and that meets the mechanical requirements to provide clinical durability. Each of these requirements could be the topics of individual articles.

There are four broad categories or types of ceramic systems:

1. powder/liquid feldspathic porcelains;
2. pressed or machined glass-ceramics;
3. high-strength crystalline ceramics; and
4. metal ceramics.

Category 1

Porcelains—the most translucent—can be used the most conservatively, but are the weakest.

Category 2

Glass-ceramics can be very translucent too but require slightly thicker dimensions for workability and aesthetics than porcelains do.

Categories 3 and 4

High-strength crystalline ceramics and metal ceramics, although demonstrating progressively higher fracture resistance, are more opaque and, therefore, require additional tooth reduction and are thus a less conservative alternative.

Based on the treatment goal of being as conservative as possible, the first choice will always be porcelains, then glass-ceramics, followed by high-strength ceramics or metal ceramics. The decision will be based on satisfying all the treatment requirements, that is, if the more-conservative material meets all the treatment requirements then that is the ideal choice. The article will identify the clinical conditions in which treatment requirements dictate the use of a specific category of ceramics.

Space required for aesthetics

The first consideration is the final 3-D position of the teeth, that is, smile design. There are several resources available for smile design. The second consideration is the colour change desired from the substrate (tooth), since this will dictate the restoration thickness. In general with porcelains, a porcelain thickness of 0.2–0.3 mm is required for each shade change (A2 to A1 or 2M1 to 1M1). For example, A3 to A0 would require a veneer of 0.6–0.9 mm in thickness.

Glass-ceramics have the same space requirements as porcelain for effective shade change; however, the authors find it difficult to work with this category and produce the best aesthetic results when the material is less than 0.8 mm in thickness. High-strength all-ceramic crowns require a thickness of 1.2–1.5 mm, depending on the substrate colour, and metal ceramics need a thickness of at least 1.5 mm to create lifelike aesthetics. With that in mind, a diagnosis based on tooth position and colour change will direct treatment planning, as well as the final decision regarding tooth preparation design (i.e. total tooth structure reduction).
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and whether orthodontic treatment is required to facilitate a more conservative and aesthetic outcome.

_Clinical parameters to evaluate_

Once the 3-D smile design has been completed, colour change assessed, and adjunctive therapy finished to create an environment that will allow the least removal of healthy tooth structure, an evaluation of each tooth is needed for ascertaining which ceramic system and technique are most suitable. The evaluation of individual teeth for specific material selection involves assessing four environmental conditions in which the restoration will function.

_Substrate_

The first consideration is evaluating the substrate to which the material will be attached (Fig. 1). Is it enamel? How much of the bonded surface will be enamel? How much enamel is on the tooth? Is it dentine? How much of the bonded surface will be dentine? What type of dentine will the restoration be bonded to (tertiary or sclerotic dentine exhibits a very poor bond strength, and bonding to this type of dentine should be avoided when possible)? Is it a restorative material (e.g. composite, alloy)? These questions should be addressed for each tooth to be restored, since this will be a major parameter for material selection.

It is generally understood and accepted that a predictable and high bond strength is achieved when restorations are bonded to enamel, given the fact that the stiffness of enamel supports and resists the stresses placed on the materials in function. However, it is equally understood that bonding to dentine surfaces, as well as composite substrates, is less predictable given the flexibility of these substrates. The more stress placed on the bonds between dentine and composite substrates and the restoration, the more damage to the restoration and underlying tooth structure is likely to occur. Therefore, because enamel is significantly stiffer than either dentine or composite and much more predictable for bonding, it is the ideal substrate for bonded porcelain restorations.

_Flexure risk assessment_

Next is the flexure risk assessment. Each tooth and existing restorations are evaluated for signs of past overt tooth flexure. Signs of excessive tooth flexure can be excessive enamel crazing (Fig. 2), tooth and restoration wear, tooth and restoration fracture, micro-leakage at restoration margins, recession, and abfraction lesions. Often, the aetiology is multifactorial and controversial. However, if several of these conditions exist, there is an increased risk of flexure on the restorations that are placed, which may overload weaker materials. Evaluation of this possibility is also based on the amount of remaining tooth structure. The more intact the enamel is, the less potential there is for flexure.

The amount of tooth preparation can directly affect tooth flexure and stress concentration. There is much potential subjectivity in any observational assessment of clinical conditions; however, an assessment of flexure potential for each tooth to be restored is needed. A subjective assignment of low, medium, or high risk for flexure is based on the evaluated parameters, as outlined below:

Low risk for clinical situations in which there is low wear; minimal to no fractures or lesions in the mouth; and the patient’s oral condition is reasonably healthy.

Medium risk when signs of occlusal trauma are present; mild to moderate gingival recession exists, along with inflammation; bonding mostly to enamel is still possible; and there are no excessive fractures.

High risk when there is evidence of occlusal trauma from parafunction; more than 50 % of dentine exposure exists; there is significant loss of enamel due to wear of 50 % or more; and porcelain must be built up by more than 2 mm.
Excessive shear and tensile stress risk assessment

The third parameter is the risk (or amount) of ongoing shear and tensile stresses that the restoration will undergo, since the prognosis is more guarded for specific materials. All types of ceramics (especially porcelains) are weak in tensile and shear stresses. Ceramic materials perform best under compressive stress. If the stresses can be controlled, then weaker ceramics can be used, for example bonded porcelain to the tooth. The same parameters are evaluated, similar to flexure risk, for example deep overbites and potentially large areas where the ceramic would be cantilevered (Fig. 3).

If a high-stress field is anticipated, stronger and tougher ceramics are needed; if porcelain is used as the aesthetic material, the restoration design should be engineered with such support (usually a high-strength core system) that it will redirect shear and tensile stress patterns to compression. In order to achieve that, the substructure should reinforce the veneering porcelain by utilising the reinforced-porcelain system technique, which is generally accepted in the literature as a metal–ceramic concept. The practitioner can assess and categorise low, medium, or high risk for tensile and shear stresses based on the parameters and symptoms mentioned above.

Bond/seal maintenance risk assessment

The fourth parameter is the risk of losing the bond or seal of the restoration to the tooth over time. Glass-matrix materials, which consist of the weaker powder/liquid porcelains, and the tougher pressed or machined glass-ceramics, require maintenance of the bond and seal for clinical durability. Owing to the nature of the glass-matrix materials and the absence of a core material, the veneering porcelains are much more susceptible to fracture under mechanical stresses and, therefore, a good bond in combination with a stiffer tooth substructure (e.g. enamel) is essential for reinforcing the restoration. If the bond and seal cannot be maintained, then high-strength ceramics or metal ceramics are the most suitable, since these materials can be placed using conventional cementation techniques.

Clinical situations in which the risk of bond failure is higher are:
- moisture control problems;
- higher shear and tensile stresses on bonded interfaces;
- variable bonding interfaces (e.g. different types of dentine);
- material and technique selection of bonding agents (i.e. as dictated by such clinical situations as inability to achieve proper isolation for moisture control to enable use of adhesive technology); and
- the experience of the operator (Fig. 4).

An assignment of low, medium, or high risk for bond and seal failure is based on the evaluated parameters.

Category 1: Powder/liquid porcelains

Guidelines

Bonded pure-porcelain restorations are ideal as the most-conservative choice but are the weakest material and require specific clinical parameters to be successful. Many good materials and techniques are available for bonded porcelain (e.g. Creation, Jensen Dental; Ceramco 3, DENTSPLY; EX-3, Noritake). However, VITA VM 13 (VITA Zahnfabrik) is recommended by the authors when 3D-Master shades are taken, and Vintage Halo (SHOFU) when classic shades are taken.

When following clinical parameters and guidelines at the University of California, Los Angeles’s Center for Esthetic Dentistry (UCLA Center for Esthetic Dentistry), these materials have been used with similar success rates compared with porcelain fused to metal (i.e. less than a 1% fracture rate if all parameters are followed, unpublished data; Figs. 5 & 6).
Aesthetic factors

Space requirements for shade change: 0.2–0.3 mm is required for each shade change.

Environmental factors

1. Substrate condition: There is 50% or more remaining enamel on the tooth, 50% or more of the bonded substrate is enamel, 70% or more of the margin is in enamel. It is important to note that these percentages are subjective assessments based on an overall evaluation of all parameters affecting the teeth to be restored and which may influence material selection. If bonding to some dentine substrate, the dentine should be mostly unaffected and superficial, since sclerotic dentine exhibits a very poor bond strength.

2. Flexure risk assessment: There is a higher risk and a more guarded prognosis when bonding to dentine. Owing to dentine's flexible nature, it is recommended that restorations with low fracture resistance materials be avoided and, therefore, the presence of a higher percentage (i.e. at least 70%) in high-stress areas such as the margins) of enamel is recommended when restoring using powder/liquid (Category 1) materials. By increasing the presence of enamel, the prognosis is improved and, depending on the dentine/enamel ratio, the risk can be assessed as low to moderate.

3. Tensile and shear stress risk assessment: There is a low to low/moderate risk. Large areas of unsupported porcelain, deep overbite or overlap of teeth, bonding to more-flexible substrates (e.g. dentine and composite), bruxing, and more distally placed restorations increase the risk of exposure to shear and tensile stresses.

4. Bond/seal maintenance risk assessment: There is an absolute low risk of bond/seal failure.

Summary

Porcelains are generally indicated for anterior teeth. Occasional bicuspid use and rare molar use would be acceptable only with all parameters at the least-risk level.

Category 1 materials are ideal in cases with significant enamel on the tooth, and generally with low flexure and stress risk assessment. These materials require long-term bond maintenance for success.

Category 2: Glass-based pressed or machinable materials

Guidelines

Glass-ceramic pressable materials, for example IPS Empress (Ivoclar Vivadent) and Authentic (Jenson) and the higher-strength IPS e.max materials (Ivoclar Vivadent), can be used in any of the same clinical situations as Category 1 materials. Machinable versions of glass-ceramic material, for example VITABLOCS Mark II (VITA Zahnfabrik), IPS Empress CAD (Ivoclar Vivadent), and IPS e.max CAD, can be used interchangeably with the pressed versions. Monolithic IPS e.max, owing to its high strength and fracture toughness, has shown promise as a full-contour, full-crown alternative, even on molars.14

Glass-ceramics can also be used in clinical situations when higher risk factors are involved. Other than certain risk factors (see below) that would limit their use, these materials can be difficult to use when there is less than 0.8 mm in thickness, except at marginal areas. They can gradually thin to a margin of approximately 0.3 mm.

All things being equal, if the restoration is still a Category 1 clinical situation and there is more than 0.8 mm of working space, glass-ceramics should be considered owing to their increased strength and toughness, and the presence of sufficient room to achieve the desired aesthetics.
Aesthetic factors

Space requirements for workability and shade change: A minimum working thickness of 0.8 mm and 0.2–0.3 mm for each shade change is required.

Environmental factors

1. Substrate condition: There is less than 50 % of the enamel on the tooth, less than 50 % of the bonded substrate is enamel, and 30 % or more of the margin is in dentine.

2. Flexure risk assessment: The risk is medium for Empress, VITABLOCS Mark II and Authentic-type glass-ceramics, and layered IPS e.max. In cases in which flexure risk is medium to high (and full-crown preparation is not desirable), the authors have found in their clinical trials that monolithic IPS e.max has been 100 % successful for as long as 30 months in service. All glass-ceramic restorations, including IPS e.max, were adhesively bonded in their samples.

3. Tensile and shear stress risk assessment: The risk is medium for Empress, VITABLOCS Mark II and Authentic-type glass-ceramics, and layered IPS e.max. It is medium to high for bonded monolithic IPS e.max.

4. Bond/seal maintenance risk assessment: There is a low risk of bond/seal failure for Empress, VITABLOCS Mark II and Authentic-type glass-ceramics, and layered IPS e.max. It is medium for monolithic IPS e.max.

Category 3: High-strength crystalline ceramics

Guidelines

Mostly (e.g. VITA In-Ceram, VITA Zahnfabrik) all-crystalline materials are used for core systems to replace metal that would then be veneered with porcelain. Alumina-based systems, for example In-Ceram and NobelProcera (Nobel Biocare), were first on the market but are now generally being replaced with zirconia systems. Alumina systems have shown to be very clinically successful for single units, with a slightly increased risk in the molar region. They can be recommended for any single-unit anterior or bicuspid crown (Figs. 13 & 14).

The authors have observed a slight increase in failure with conventional cements. For example, after using alumina restorations for many years at the UCLA Center for Esthetic Dentistry, the authors observed that at between eight and ten years, the failure rate doubled to approximately 2 %, with those failures being core fractures necessitating replacement (unpublished data). Their suggestion for alumina-core restorations is either a resin-modified glass ionomer luting cement (e.g. RelyX, 3M ESPE) or a resin cement. For zirconia-core systems (e.g. LAVA, 3M ESPE), the authors have not experienced core fracture but have seen problems with chipping of porcelain.

White and McLaren found that a special slow-cool thermal cycle minimises the stress in the porcelain and at the porcelain/zirconia interface. Clinically, since the authors of this current article have been using the altered firing schedules, their replacement rate for chipping has been reduced by less than 1 %. 

Presssed or machined glass-ceramic materials, such as Empress, VITABLOCS Mark II and Authentic, are indicated for thicker veneers, anterior crowns, and posterior inlay and onlays (Figs. 7 & 8) in which medium or less flexure, and shear and tensile stress risk is documented (Figs. 9 & 10). Also, they are only indicated in clinical situations in which long-term bond and seal can be maintained. IPS e.max (Figs. 11 & 12), which is a different type of glass-ceramic that has higher toughness, is also indicated for the same clinical situations as the other glass-ceramics, but can be extended for single-teeth use in higher-stress situations (as in molar crowns). This is provided it is used in a full-contour monolithic form and cemented with a resin cement.
**Aesthetic factors**

Space requirements for workability and maximum aesthetics: A minimum working thickness of 1.2 mm is required, and 1.5 mm is ideal if masking.

**Environmental factors**

1. Substrate condition: Substrate is not critical, since a high-strength core supports veneering material.
2. Flexure risk assessment: The risk is high or below. For high-risk situations, core design and structural support for porcelain become more critical.
3. Tensile and shear stress risk assessment: The risk is high or below. Note that for high-risk situations, core design and structural support for porcelain become more critical. Preparations should allow for a 0.5 mm core plus 1 mm of porcelain to ensure the best aesthetic results. Additionally, there should not be more than 2 mm of unsupported occlusal or incisal porcelain; the restoration core should be built out to support marginal ridges. For higher-risk molar regions, it is better to use zirconia cores rather than alumina cores, provided the current firing parameters are followed. Full-contour zirconia restorations (e.g. BruxZir, Glidewell Laboratories) have been recommended for high-risk molar situations. Failure of these restorations is not likely to be an issue; some preliminary concern involves wear of the opposing dentition with full-contour zirconia. No clinical data could be found to confirm or refute this. Clinically, only full-contour zirconia against full-contour zirconia in the molar region should be considered when no other clinical option is viable.
4. Bond/seal maintenance risk assessment: If the risk of obtaining or losing the bond or seal is high, then zirconia is the ideal all-ceramic to use.

**Summary**

A high-strength ceramic (specifically zirconia) is indicated when significant tooth structure is missing, unfavourable risk for flexure and stress distribution is present, and it is impossible to maintain bond and seal (e.g. most full-crown situations with subgingival margins; Figs. 15 & 16).

**Category 4: Metal ceramics**

**Guidelines**

For almost half a century, metal ceramics have been the standard for aesthetic full-crown restorations. Generally, they have the same indications as Category 3 zirconia-based restorations. With metal ceramics, manufacturers have eliminated the complications throughout the years; these materials do not have the same thermal firing sensitivity as zirconia does. However, anterior teeth metal ceramics need to be approximately 0.3 mm thicker to have the same aesthetics as properly designed zirconial/porcelain crowns. When porcelain-fused-to-metal restorations are indicated, the CAPTEK (Precious Chemicals USA) system has been the material of choice at the UCLA Center for Esthetic Dentistry owing to its superior aesthetic properties.

**Aesthetic factors**

1. Space requirements for workability: 1.5–1.7 mm is required for maximum aesthetics.
2. Substrate condition: The substrate is not as critical, since the metal core supports the veneering material.
3. Flexure risk assessment: The risk is high or below. For high-risk situations, core design and structural support for porcelain become more critical.
4. Tensile and shear stress risk assessment: The risk is high or below. For high-risk situations, core design and structural support for porcelain become more critical.
5. Bond/seal maintenance risk assessment: If the risk of obtaining or losing the bond or seal is high, then metal ceramics are an ideal choice for a full-crown restoration.

**Summary**

Metal ceramics are indicated in all full-crown situations, esp. when all risk factors are high (Fig. 17).

**Conclusion**

This article has presented a systematic process of clinical evaluation and rationale for material selection. The most important point is that the most-conservative restoration should be done if the clinical criteria are met; for example, a full-coverage crown or deep-cut glass-ceramic restoration should not be performed when a more conservative porcelain restoration is indicated.

**Editorial note:** A complete list of references is available from the publisher.

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