Fifth
Edition

Textbook of Operative Dentistry

Including
Conservative and Restorative Dentistry

Vimal K Sikri

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CHAPTER

21

Ceramic Restorations

The use of ceramic in dentistry was first mentioned by Pierre Fauchard. The word 'ceramic' is derived from the Greek word 'Keramikos', which means 'earthen' or 'Keramos', which means 'burnt stuff'.

Ceramic is a product manufactured by the action of heat on earthen materials in which silicon and silicates predominate. Ceramics is the art of forming, i.e. modelling and processing objects made of clay or similar material. Porcelain, glass, refractories, silicon carbide, clay products (tile and terracotta) are the principal ceramic objects.

Dental ceramics are the compound of metals (aluminum, calcium, lithium, magnesium, potassium, sodium, tin, titanium, and zirconium) and non-metals (silicon, boron, fluorine, and oxygen) that may be used as a single structural component, (CAD-CAM inlay, crowns) or in layers for the fabrication of a ceramic-based prosthesis.

The wide popularity of ceramic dental restorative materials owes to their life like optical properties, biocompatibility, low thermal conductivity, coefficient of thermal expansion close to that of tooth, durability and etchability. However, two major problems associated with their use are the potential for fracture (being brittle) and the ability to cause abrasive wear of opposing tooth surfaces.

TERMINOLOGY: DEFINITIONS

The common terminologies used with ceramic restorations are:

Ceramic: Ceramic is defined as a combination of one or more metals with a non-metallic element (usually oxygen). The large atoms of oxygen serve as a matrix with smaller metal atoms tucked into the spaces between the oxygen.

Alumina core: A crystalline alumina (Al_2O_3) used as a core for ceramic veneer crowns to achieve adequate strength and opacity.

CAD-CAM ceramic: A machinable ceramic material formulated through the use of a computer-aided design and computer-aided machining process.

Castable ceramic: A ceramic, specially formulated to be cast using a lost-wax process.

Copy-milling: The process of machining a structure using a device that traces the surface pattern of a master metal or ceramic and transfers the tracings to a cutting station, where a blank is cut similar to the key-cutting procedure.

Cracking: Formation of large or minute fissures (microcracks).

Crazing: Formation of minute cracks as an immediate or delayed result of thermally induced stresses.

Leucite porcelain: A ceramic composed of a glass matrix phase and one or more crystal phases (leucite: $K_2O.\ Al_2O_3.4SiO_2$). Leucite is used to create high-expansion porcelain.

Glass-ceramic: A glassy matrix along with one or more crystal phases, produced by the controlled nucleation and growth of crystals in the glass.

Glass-infiltrated ceramic: Sintered Al_2O_3 or $MgAl_2O_4$ core with a network sealed by the capillary flow of molten glass [examples include, In-Ceram (Al_2O_3) and In-Ceram Spinell ($MgAl_2O_4$) core].

Injection-molded ceramic: A glass or other ceramic material used to form the ceramic core by heating and compressing a heated ceramic into a mold under pressure (example is IPS Empress).

Shoulder porcelain: Porcelain sintered at a lower temperature than opaque porcelain and higher than body porcelain, to produce an esthetic porcelain margin as an alternative to a metal margin on a metal–ceramic crown.

Sintering: The process of heating closely packed particles to achieve interparticle bonding and sufficient diffusion to decrease the surface area or increase the density of the structure.

Devitrification

'Vitrification' is the development of a liquid phase (reaction of melting), which on cooling provides the glassy phase, resulting in a vitreous structure. A small amount of crystallization always occurs during glass formation, although the rate of crystal growth is very low. When a glass begins to crystallize, the process is called '*devitrification*'. It may occur when the glass is held in the molten form for a long time, allowing reorganization of the molecules. This is basis of the formation of 'glass-ceramics'.

Alkalis, such as soda (Na_2O) and lime (CaO), lower the viscosity and the glass transition temperature. Devitrification is often associated with high expansion glasses (used in metal-ceramics), since the usual way of increasing the thermal expansion of a glass is by adding more alkalis, particularly soda. Once the porcelain has devitrified, it becomes difficult to form a glaze surface.

COMPOSITION

The ingredients used in different formulations of ceramics are as follows:

i. Silica

Quartz crystals (SiO_2) are used in dental porcelain as a filler and a strengthening agent. It provides high strength framework and also helps to maintain the form (shape) of the object during firing.

ii. Kaolin (White China Clay)

Kaolin increases the moldability of the porcelain and acts as a binder. It helps in maintaining the shape of the unfired porcelain during firing. At high temperature, it fuses and reacts with other ingredients to form the glassy matrix.

The main drawback of kaolin is its opaqueness.

iii. Feldspars

Feldspar is of two types: Soda feldspar and Potash feldspar. Soda feldspar decreases the fusion temperature and potash feldspar increases the viscosity of glass. The type of feldspar used can effect the coefficient of thermal expansion (mainly soda spar).

Feldspar mainly serves as:

- During firing, the feldspar fuses and forms a glassy phase that softens and flows slightly, allowing the porcelain powder particles to coalesce together.
- It has the tendency to form the crystalline mineral leucite suitable for metal bonding.

iv. Leucite

In dental porcelains, the leucite crystals are created by transforming feldspar crystals into glass and leucite crystals by a special heat treatment. When feldspar is heated at a temperature between 1150°C and 6530°C, it undergoes incongruent melting to form crystals of leucite in liquid glass. The leucite forms a refractory skeleton and the glass fills the spaces in between, providing requisite qualities to porcelain.

Leucite serves to raise the coefficient of thermal expansion (CTE) of porcelain and brings it closer to that of the metal substrate; consequently, increasing the hardness and fusion temperature.

v. Glass Formers

Glass is composed of silica (SiO_2) with oxides of sodium, potassium, calcium, barium etc., which forms the glass network.

Oxides take part in the formation of glass network; however, for dental purposes, only two glass forming oxides (silicon and boron oxides) are used to form the principal network.

vi. Glass Modifiers (Fluxes)

The elements that interfere with integrity of the glass network and alter their three-dimensional state are referred to as '*glass modifiers*'.

The main purpose of glass modifier is to lower the softening temperature of glass by reducing the amount of cross-linking between oxygen and the glass forming elements. However, higher concentration of glass modifiers may result in reduced chemical durability (resistance to attack by water, acids and alkalis). Glass modifiers, also referred to as '*fluxes*', decrease the viscosity and increase the flow. Manufacturers employ glass modifiers to produce dental porcelains with different firing temperature, such as high, medium and low fusing ceramics.

Water is an important glass modifier. The hydronium ion, H_3O^+ can replace Na^+ or other metal ions in a ceramic, that contains glass modifiers.

Alumina (Al_2O_3) and boron oxide (B_2O_3) are commonly used fluxes.

vii. Stains and Color Modifiers

Stain is a mixture of one or more pigmented metal oxides (usually composed of low fusing glass). This is dispersed in an aqueous slurry or monomer medium and applied to the restoration surface of porcelain or other specialized ceramic. It is then dried, light cured and fired to get the required characterization for the restoration. These are also called '*surface colorants*' or '*characterization porcelain*' (Fig. 21.1A, B).

Internal staining and characterization (built into porcelain, rather than applied to the surface) can produce effective results.

Fig. 21.1: Stains used to imitate markings, like enamel craze lines, calcification spots, etc.

viii. Opacifying Agents

The translucency of porcelain is not suitable to produce dentin colors, which requires greater opacity than that of enamel colors. An opacifying agent, may be titanium oxide, tin oxide and zirconium oxide, can be incorporated.

Color modifiers are used to obtain gingival effects or to highlight body colors at the same temperature as the dental porcelain (Fig. 21.2).

'Special effects' are created with the use of supplementary colors of the basic dentin porcelain, translucent or colorless porcelain and color frits.

The color pigments used in dental porcelain are summarized in Table 21.1.

ix. Fluorescence and Opalescence

'*Fluorescence*' is the absorption of radiation of a particular wavelength and its re-emission as a radiation of longer wavelength. Fluorescence adds definite contribution to the brightness and the vital appearance of a human tooth.

The agents commonly used are cerium oxide, spinel (magnesia alumina compounds) and lanthanide earths.

'*Opalescence*' is a light-scattering effect achieved with the addition of minute concentrations of oxides with high refractive index; range near the wavelength of visible light. Excessive use of opalescent agent may lead to a bluish-gray appearance of the restoration.

Fig. 21.2: Color modifiers used to obtain gingival effects or highlight body colors.

Table 21.1: Color pigments in dental porcelain

Color pigments	*Metal oxides*
Pink	Chromium or chrome-alumina
Yellow	Indium or praseodymium
Blue	Cobalt salts in the form of oxides
Green	Chromium oxide, copper oxide
Gray	Platinum gray
Lavender	Manganese oxide
Black	Iron oxide
Brown	Iron/nickel oxide

x. Glazes and Add-On Porcelain

Glazes are low fusing uncolored glass powders that are applied on the surface of a porcelain restoration. Glazes are fired at a maturing temperature, lower than that of the restoration to produce a transparent glossy layer on the surface.

Glazing serves to seal the open pores on the surface of a fired porcelain and impart an impervious smooth surface.

Add-on porcelains are generally made from materials similar to that of glaze porcelain, except for the addition of less finely ground powder of opacifying and coloring pigments. These are used sparingly for repairs, addition and also corrections of tooth contour/contact points.

xi. Alumina

Aluminum oxide (Al_2O_3), prepared from alumina trihydrate by calcination, is commonly used (The α-form of alumina is used as a fine powder in some porcelains, such as aluminous porcelain).

xii. Alternative Additives

Small quantities of alternative additives are added to porcelains during fritting. The additives are: Lithium oxide (LiO_2)—as an additional flux; magnesium oxide (MgO)—used to replace CaO; and phosphate pentoxide (P_2O_5)—added to induce opalescence.

Ceramics ingredients: Key functions

- Silica (Quartz or Flint)—filler
- Kaolin (China clay)—binder
- Feldspar—basic glass former
- Water—important glass modifier
- Fluxes—glass modifiers
- Stains and color modifiers—modify color
- Opacifying agents–highlight body color
- Fluorescent and opalescent agents—for vital appearance of teeth
- Glazes and add-on porcelain—for transparent/glossy surface
- Alumina—provides strength
- Alternative additives—improve surface appearance

CLASSIFICATION

There are several classifications of dental ceramics.

I. The conventional classification is as follows, on the basis of:
   1. *Type of glass matrix:* Leucite-reinforced porcelain, aluminous porcelain, alumina, glass-infiltrated alumina, glass-infiltrated spinell, and glass-ceramic.
   2. *Use of ceramic:* Denture teeth, metal-ceramics, veneers, inlays, crowns and anterior bridges.
   3. *Processing methods:* Sintering, casting, or machining.
   4. *Substructure material:* Glass-ceramic, CAD-CAM porcelain, sintered ceramic core.

II. Ceramics are also classified on the basis of their maturing temperature; such as:
   1. High fusing : >1300°C (not used in restorations)
   2. Medium fusing : 1101°C–1300°C
   3. Low fusing : 850°C–1100°C (taken as high fusing when used in restorations)
   4. Ultra-low fusing: <850°C (taken as low fusing in restorations)

III. Ceramics are also classified on the basis of their composition:
   1. *Esthetic ceramic:* Predominantly glass (alumino-silicate glass)
   2. *Structural ceramics:* Particle-filled glass (special silicate glasses)
   3. *Polycrystalline ceramics (no glass):* For polycrystalline ceramics, which contain no glass, the matrix is aluminum oxide or zirconium oxide, and the fillers are not particles, but modifying atoms, called 'dopants'. The polycrystalline ceramics are much tougher and stronger than glass-based ceramics. Highly esthetic ceramics are predominantly glass ceramic; those exhibiting high strength are crystalline ceramics (Table 21.2).

PROPERTIES OF PORCELAIN

The properties of porcelain are as follows:

- The compressive strength of porcelain is quite high as compared to tensile or shear strength.
- The tensile strength is low because of unavoidable surface defects and the shear strength is low because of lack of ductility in the material. Both underfiring and overfiring are deleterious to its strength. When porcelain is underfired (firing at temperatures lower than normal or for inadequate periods), the desired amount of vitrification does not occur; whereas, when overfired (firing at temperatures above normal or for longer periods), excessive vitrification occurs.
- Internal voids (voids and blebs) tend to reduce the specific gravity of porcelain.
- Porcelains are extremely hard materials and offer considerable resistance to abrasion; causes excessive wear of the opposing natural tooth structure or the restorative material.
- One major drawback with porcelain is its brittleness. (Dental ceramic is inherently fragile in tension.)
- Porcelain is translucent. (Body porcelain has a translucency of 20–35%; whereas, incisal porcelain has the highest translucency ranging from 45–50%.)
- Porcelain is relatively inert, chemically stable and corrosion resistant, which renders it highly biocompatible.
- Attain highly smooth and polished surfaces; does not allow plaque accumulation; hence, conducive to gingival health.
- The solubility of porcelain is extremely low and is probably the most resistant material to attack by oral fluids.

The physical properties of porcelain are summarized in Table 21.3.

Table 21.2: Ceramics: Composition and classification

Ceramic matrix	*Filler*	*Processing protocol (commercial name)*
1. Esthetic ceramic		
Predominantly glass: (aluminosilicate glass)		• CEREC 3 (Vitablocs Mark II)
• Feldspathic/synthetic	• Nepheline (40%) • Leucite (40–50%)	• CEREC 3 (IPS Empress) • Pressed – IPS Empress – Optec OPC
2. Structural ceramic		
Particle-filled glass (low glass content): (special silicate glasses)		• In laboratory (IPS *e.max*) • Pressed (IPS *e.max* Press)
• High lithium/lanthanum	• Lithium disilicate (70%) • Alumina (70%) • Spinel (70%) • Alumina/Zirconia (70%)	• In laboratory (In-Ceram)
3. Polycrystalline ceramic (no glass content)	DOPANT (Filler are not particles, but modifying atoms)	
• Alumina	• Magnesium (3.0%)	• In laboratory (Vita) • CAD/CAM (Procera)
• Zirconia	• Cerium/Aluminum (3.0–5.0%)	• In laboratory (IPS e.max) CAD/CAM – Zirconia – Lava – Cercon

Table 21.3: Physical properties of porcelain

Properties	*Values*
Compressive strength	50000 psi
Tensile strength	5000 psi
Shear strength	16000 psi
Elastic modulus	10×10^6 psi
Knoop hardness number	460
Coefficient of thermal expansion	12×10^{-6}/°C
Thermal conductivity	0.0050°C/cm
Thermal diffusivity	0.64 mm^2/sec
Specific gravity	2.2–2.3 gm/cm^3
Linear shrinkage (high fusing)	11.5%
Linear shrinkage (low fusing)	14.0%
Refractive Index	1.52–1.54

STRENGTHENING OF CERAMIC

The strength of porcelain is dictated by the presence of flaws. These flaws act as 'stress concentration areas'; the localized stress at a particular point leads to interatomic bonds, initiating break in a crack. As the crack propagates, the concentration of stresses continues through the material. Regarding stress concentration around flaws, tensile stresses are more damaging than the compressive stresses (tend to close the crack).

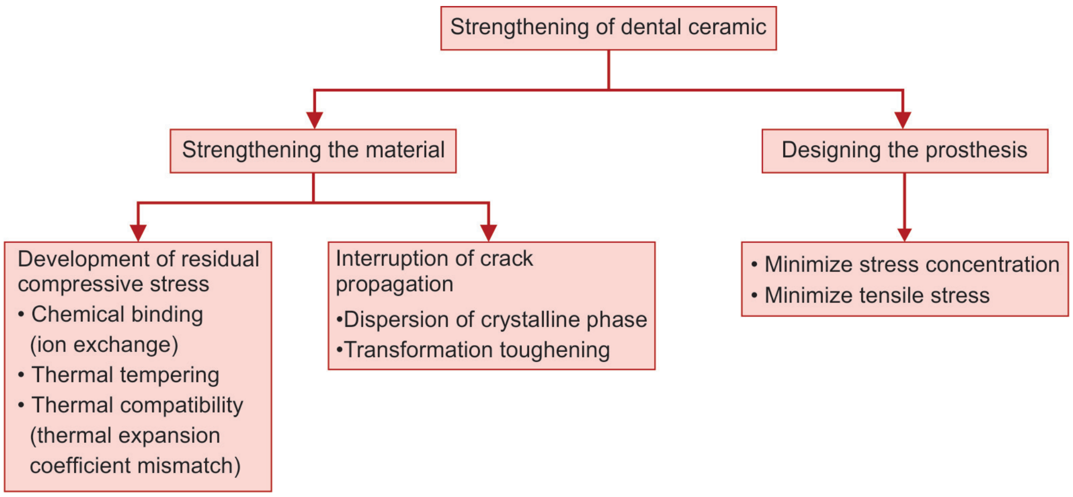
Surface flaws have higher stress concentration than do the internal flaws of similar dimensions. Microcracks, on the porcelain surface, can be a result of condensation, melting and sintering process, cooling of ceramic after maturing, high contact angle of ceramic on metal, differences in the coefficient of thermal expansion between alloy/core and veneers, grinding and abrasion, tensile stresses generated during manufacture, function, trauma, etc.

Other areas of high stress concentration are:
- Porosity, roughness and machining damage.
- Sharp line and point angles.
- Interface region of a bonded structure, where elastic modulus of the two components is quite different.
- The interface region of a bonded structure, where a large difference in the thermal coefficient exists between the two materials.
- Areas of sharp point contacts on the brittle material.
- Water produces a time dependent reduction in strength. (Water serves as a network modifier in weakening the glass.)

How to Reduce Flaws and Strengthen Ceramic

It is established that flaws are a major contributor in reducing the strength of the ceramic. The best efforts should be directed in reducing the size and number of flaws. Surface flaws can be reduced by fine

Flowchart 21.1: Strengthening of dental ceramic



polishing and glazing; however, internal flaws are difficult to manage.

The methods employed to overcome the weakness of porcelain are (Flowchart 21.1):

a. ***Strengthening the material:*** Strengthening of porcelain material involves the following mechanisms:
   i. Development of residual compressive stresses
      - Ion exchange (chemical tempering)
      - Thermal tempering
      - Thermal compatibility (thermal expansion coefficient mismatch)
   ii. Interruption of crack propagation
      - Dispersion of crystalline phase
      - Transformation toughening
b. ***Designing the prosthesis:*** The prosthesis should be designed such that direct exposure to high tensile stresses, stress concentration at sharp line angles/point angles are avoided. Full coverage of posterior teeth with conventional porcelain is contra-indicated because heavy occlusal forces can concentrate large tensile stresses on the internal surface of the crown. Tensile stresses may also develop under a porcelain crown in the anterior teeth where there is deep bite with minimal overjet. All areas of stress concentration should be minimized in the restoration. In any porcelain restoration, occlusion should include contact areas and not contact points.

CONDENSATION OF PORCELAIN

Porcelain powder is mixed with a liquid binder so that the particles are held together, and the thick creamy paste can be built to the desired shape. The process of bringing the particles closer and removing the liquid binder is known as condensation. Distilled water is commonly used as liquid binder. (Glycerine, propylene glycol, and alcohol have also been tried.) During firing, the liquid is eliminated, and the porcelain particles fill the space formerly occupied by the binder, thereby resulting in shrinkage.

The aim of condensation is to pack the particles as close as possible, in order to reduce the amount of porosity and shrinkage during firing. Two factors determine the effectiveness of condensation; one the size of the powder particles (smaller size particles are preferred to minimize voids); second, the shape of the powder particles (Round particles produce better packing as compared to angular particles). As the liquid is withdrawn, surface tension causes the powder particles to pack closely together. However, sufficient amount of liquid should be present so as to wet all the powder particles.

The methods employed for condensation are:

i. ***Vibration method:*** The paste is applied onto the platinum matrix and vibrated slowly. This brings the excess water onto the surface, which is then drawn away with a linen or clean tissue.
ii. ***Spatulation method:*** A small spatula is used to apply and smooth the wet porcelain; action bring the particles closer and the water rises to the surface, which is removed as described earlier.
iii. ***Dry brush technique:*** Dry powder is placed onto the wet surface. The excess water moves from mixture to the dry powder by capillary action and the wet particles are pulled together.
iv. ***Whipping method:*** A large soft brush is moved in a light dusting action over the wet porcelain. This brings excess water on the surface; the same brush is used to remove any coarse surface particles along with the excess water. (A combination of these methods can also be used.)

FIRING PROCEDURE

The role of firing is to sinter the powder particles to form a dense restoration. During firing, the first change is the loss of water, which was added to the powder to form a workable mass. The second change occurs with a further rise in temperature, when the particles fuse together by sintering. The third change is glazing, which occurs at temperatures of 955–1065°C. Glazing results in the formation of a glossy surface.

Porcelain restorations may be fired either by the *temperature method* or the *temperature-time method*.

Different media employed for firing are:

a. Air firing
b. Vacuum firing
c. Diffusible gas firing

a. Air Firing

The porcelain powder mixes have a certain amount of voids. When placed in air furnace, the furnace atmosphere occupies these void spaces. With the increase in temperature, the void spaces containing air assume a spherical appearance. Further, rise in temperature increases the pressure of the entrapped air and the bubbles enlarge. The surface of air-fired porcelain is generally devoid of bubbles because interstitial air near the surface can escape easily. Whenever air firing methods are employed, a very slow maturation period is preferred to allow for the maximum amount of entrapped air to escape (30°C to 50°C below the maximum firing temperature).

Porosity reduces both translucency and strength of porcelain. Translucency depends on number and size of the entrapped air bubbles. Large-sized particles have a few and larger air voids as compared to small-sized particles. Fewer bubbles, even of large size, give improved translucency. On the other hand, fine-sized particles have multiple small air bubbles, which provide opaqueness. (Porcelain powders fired in air should preferably be of coarse nature.)

b. Vacuum Firing

Vacuum firing is used to reduce porosity in porcelains. It works on the basis of removing air from the interstitial spaces before surface sealing occurs. Although the vacuum removes most of the air from interstitial spaces, some of it may be left behind. With the increase in temperature, the remaining air spaces assume a spherical appearance. When air at normal atmospheric pressure is allowed to enter the furnace, it exerts a compressive effect, compressing the internal voids to one-tenth of their original size. This results in a dense porcelain.

Following factors should be considered during vacuum firing:

- Porcelain powders must be dried slowly to eliminate the water vapours; vacuum should be applied before the placement of porcelain in the hot zone of furnace.
- Vacuum should not be applied after the porcelain has matured. Prolonged application can force the residual air bubbles to rise to the surface and cause surface blistering.
- Vacuum should be discontinued while the work is still in the hot zone of the furnace. This permits the dense skin to compress the internal voids.
- Avoid porcelains with large interstitial spaces, i.e. porcelain powders with small-sized particles are preferred.

c. Diffusible Gas Firing

In this technique, a diffusible gas, like helium, hydrogen or steam, is substituted for the ordinary furnace atmosphere. Air is driven out of the porcelain powder and replaced by the diffusible gas. With these gases, the interstitial spaces do not enlarge under the influence of increasing temperature, but decrease in size or disappear. This occurs because these gases diffuse outward through the porcelain or actually dissolve in porcelain.

Stages of Maturity during Firing

The stages of porcelain when 'sintered' or 'fired' are commonly referred to as 'bisque'.

Low bisque: The surface of porcelain is quite porous; easily absorb water-soluble dyes. Shrinkage is minimal and the fired body is weak or friable.

Medium bisque: Pores still exist on the surface of porcelain, but the flow of glass grains is increased.

Evolution of porcelain

Year (author/ manufacturer)	*Ceramic evolution*
1774 AD (de Chemant)	Porcelain denture
1810 (Fonzi)	Porcelain teeth
1880 (Herbest)	Ceramic inlays
1886 (Land)	Improved ceramic inlays
1900 (Land)	Ceramic crowns
1950–60 (various authors) (addition of alumina, leucite, etc.)	Strengthening of porcelain
1960–70 (Vita)	Commercial preparation of porcelain
1970–80 (various manufacturer)	Castable glass ceramic
1987 (Mormann)	CERAC 1
1995–2000 (Sirona)	CERAC 2,3 etc.
1995 (Vita)	In-Ceram
2005 (Ivoclar)	IPS *e.max*

As a result, any entrapped air that could not escape via the grain boundaries becomes trapped. A definite shrinkage is evident.

High bisque: The flow of glass grains is further increased, thereby completely sealing the surface and presenting a smoothness to the porcelain. The fired body is strong enough to be grinding for correction prior to final glazing.

ALL CERAMIC SYSTEMS

Porcelain is the most natural appearing synthetic replacement material for missing tooth substance. However, its esthetic appearance is compromised when it is fused to a metal substrate (due to the relatively low tensile strength and brittleness of porcelain). In an effort to improve upon the esthetics and achieving adequate strength, all ceramic system was conceived.

The term 'all-ceramic' refers to any restorative material composed exclusively of ceramic, such as feldspathic porcelain, glass-ceramic, alumina core systems and certain combination of these materials.

Advantages

- Increased translucency
- Improved fluorescence
- Greater contribution of color from the underlying tooth structure
- Inertness
- Biocompatibility
- Resistance to corrosion and wear
- Low temperature/electrical conductivity
- Esthetically pleasing

Disadvantages

- Indirect fabrication requires more time and cost
- Brittle; adequate thickness mandatory to avoid fracture
- Wear of opposing dentition
- Repair is not feasible (minor repair is carried out using composites)
- Difficulty in intraoral finishing/polishing

Indications

Where esthetics is the priority (all ceramic can mimic natural tooth appearance); indicated as inlays, crowns and laminates.

Contraindications

- Short clinical crowns/deep overbite (limited interocclusal distance)
- Heavy occlusal forces (being brittle in nature; avoided in patients with parafuctional habits)
- Where moisture control is not effective.
- Deep subgingival preparations (impression making may be difficult)

Classification

All ceramic restorations are classified according to their fabrication process, as:

a. Powder-slurry ceramic (sintered porcelain)
   i. Hi-Ceram (Alumina porcelain)
   ii. Optec HSP (Leucite-reinforced porcelain)
   iii. Duceram LFC (Hydrothermal low fusing ceramic)
b. Castable ceramic
   i. DICOR (Mica based)
   ii. DICOR plus (silicic fluoromica)
   ii. Cerapearl (hydroxyapatite based)
c. Machinable ceramic
   i. Cerec Vitablocs Mark I and Mark II
   ii. Celay Vitablocks
   iii. DICOR MGC
d. Pressable ceramic (heat pressed)
   i. IPS Empress
   ii. IPS *e.max*
   iii. Optec OPC
e. Infiltrated ceramic (slip cast)
   i. In-Ceram
      - Alumina
      - Spinell
      - Zirconia

A brief comparison of these materials is summarized in Table 21.4.

a. Powder-Slurry Ceramic (Sintered Porcelain)

i. ***Aluminous porcelain (Hi-Ceram):*** Aluminous porcelains are based on the principle of dispersion strengthening, i.e. dispersing alumina (Al_2O_3) crystals in a glass matrix. For dental purposes, single crystals of alumina are preferred over fine powdered alumina. This is to avoid excessive opacity, which occurs because of difference in the refractive indices of glassy porcelain and the alumina crystals. A bond between filler particles and the matrix and an identical coefficient of thermal expansion (CTE) of the two phases are important when using filler reinforcement in porcelain. If there is mismatch between the coefficient of thermal expansion of the two phases, it will lead to reduced elasticity and strength.

The strength and opacity of aluminous porcelain are dependent upon the size, shape and concentration of the alumina crystals. Finer the grain size, greater is the strength; but opaque due to high difference in the refractive index of the two components. Coarse grains of alumina reduce

Table 21.4: Comparison of ceramic restorative systems: Processing technology

Type of porcelain (phase)	*Flexural strength*	*Hardness*	*Inherent characteristics*
a. Powder-slurry ceramic (sintered porcelain)			
• Hi-ceram (alumina porcelain)	140 MPa	• Better than conventional porcelain	• Increased fracture resistance; prevent microcracks
• Optec HSP (leucite reinforced)	146 MPa	• Higher than conventional porcelain due to leucite content	• No core material; uniform translucency and shade throughout; • Etchable for bonding to tooth
• Duceram LFC (low fusing ceramic)	110 MPa	• Close to hardness of natural tooth	• Low fusing temperature (owing to absence of leucite) • Characterized by surface stains
b. Castable ceramic			
• DICOR (mica based)	152 MPa	• Comparable to conventional porcelain	• Less plaque accumulation as compared to other ceramic restorations
• DICOR Plus (silicic fluoromica)	160 MPa	• Dicor Plus is as hard as conventional abrasion	• Etchable core for bonding
• Cerapearl (hydroxy-apatite based)	590 MPa	• Stronger than conventional porcelain	• Surface stains may be lost due to abrasion (Dicor Plus is more stable)
c. Machinable ceramic			
• Cerec Vitablocs Mark I (tetrasilicic fluoromica)	216 MPa	• Between those of Cerec Vitablocs Mark I and Mark II	
• Cerec Vitablocs Mark II	93 MPa	• Similar to that of conventional porcelain	• Can be characterized with surface stains; however, may be lost due to abrasion.
• DICOR MGC (silicic fluoromica)	152 MPa	• Similar to that of tooth	• Wider gap between restoration and the tooth
• Celay (alumina, sanidine)	152 MPa	• Similar to that of tooth	• Etchable for bonding to tooth
d. Pressable ceramic (heat pressed)			
• IPS Empress	126 MPa initially 160–180 MPa	• Higher than conventional porcelain	• Core material is shaded and translucent • Etchable for bonding to tooth
• IPSe.max (Press), IPSe.max (CAD) (disilicate glass)	140 MPa	• Lower compressive strength than metal-ceramics	• Improved mechanical properties • Better esthetics
• Optec OPC (lithium disilicate)	165 MPa	• Higher than conventional porcelain	• Better mechanical properties and translucency • Etchable for bonding to tooth
e. Infiltrated ceramic (Slip-cast)			
• In-Ceram Alumina (alumina)	400 MPa	• Same as that of conventional porcelain	• Core material is opaque • Not etchable for bonding to tooth
• In-Ceram Spinel (magnesium oxide)	450 MPa	• Same as that of conventional porcelain	• Core material is opaque • Not etchable
• In-Ceram Zirconia (zirconia)	700 MPa	• Higher than conventional porcelain	• Opaque (poor translucency)

strength, but show increased transmission of light and are less opaque. The shape of filler particles also influences the strength. (Rounded grains are preferable over angular ones.) The concentration of alumina crystals should range from 40–50% by weight. Concentrations higher than this would prevent complete flow and wetting by the glass matrix.

Alumina crystals increase the strength by two mechanisms: one, the crystals reduce surface area of the matrix, preventing microcracks and second, the crystals increase fracture resistance in the body porcelain.

ii. ***Leucite-reinforced porcelain (Optec HSP):*** Leucite porcelain (Optec HSP) contains dispersed leucite [potassium aluminosilicate ($KAlSi_2O_6$)] crystals in a glassy matrix. The leucite-reinforced porcelains are stronger as compared to conventional porcelains. The leucite and glassy components are fused together during the baking process at 1020°C. The leucite porcelains can be used for both body and incisal portions; does not necessitate the employment of a translucent porcelain. Surface stains or pigments effectively provide the desired shade and translucency.

iii. ***Hydrothermal low fusing (Duceram LFC):*** Hydrothermal low fusing ceramic (Duceram LFC) is composed of an amorphous glass containing hydroxyl ions. The material offers greater density, higher flexural strength, greater fracture resistance and lower hardness than conventional porcelain; however, the hardness and ability to abrade the opposing natural tooth structure is reduced.

The restoration from Duceram LFC is made in two layers. The base layer is Duceram Ceramic (a leucite-containing porcelain) and the second layer (low fusing ceramic) is applied over the base layer.

Advantages

- Lack of metal or opaque substructure; good translucency.
- Moderate flexural strength; higher than conventional feldspathic porcelains.
- Can be used without special laboratory equipment.

Disadvantages

- Margin inaccuracy caused by porcelain sintering shrinkage
- Potential to fracture in posterior teeth
- Increased leucite content may cause relatively high *in vitro* wear of opposing teeth.

Uses

- Employed for inlays, onlays, crowns for low stress areas and veneers.

Advantages

- Excellent marginal fit
- Relatively high strength
- Surface hardness and occlusal wear is similar to enamel
- Can reproduce wax patterns precisely by using the lost wax technique
- Simple fabrication from waxup to casting, ceramming and coloring
- Ease of adjustment
- Excellent esthetics, resulting from natural translucency
- Inherent resistance to plaque accumulation (seven times less than on the natural tooth surfaces)

Disadvantage

- Chances of losing low fusing shade porcelains, which have been applied for good color matching.

Uses

- Used as inlays, onlays and complete crowns. Also as partial tooth coverage restorations (not indicated for fixed denture abutments with deep rests).

This material is available in a variety of shades and can be characterized with surface stains and modifiers.

b. *Castable Glass Ceramic*

i. ***DICOR (mica-based porcelain)/DICOR plus:*** A glass ceramic is a material that is formed into a desired shape and subsequently heat treated to induce partial devitrification or crystallization. DICOR, a castable ceramic, is mainly composed of SiO_2, K_2O, MgO, MgF_2, minor amounts of Al_2O_3 and ZrO_2 incorporated for durability, and a fluorescing agent for esthetics. The fluoride acts as a nucleating agent, and improves the fluidity of the molten glass.

The fabrication method for DICOR restorations uses the lost wax and centrifugal casting techniques, similar to those used for fabricating alloy castings. DICOR restorations are highly esthetic because of their translucency, which closely matches that of natural tooth enamel. The castable ceramic permits a one piece restoration made entirely of the same material, and no opaque substructure exists to impede light scattering. A 'chameleon effect' is seen with DICOR restorations in which the restoration acquires a part of the color from adjacent teeth, fillings as well as the underlying cement lute.

DICOR is chemically inert and biocompatible. The periodontal tissue reaction to DICOR is favorable. The physical properties of DICOR are summarized in Table 21.5.

Table 21.5: Physical properties of DICOR: Compared to enamel and feldspathic porcelain

Property	*Enamel*	*Feldspathic porcelain*	*DICOR*
Density, gm/cm^3	3.0	2.4	2.7
Translucency	0.48	0.27	0.56
Modulus of rupture (psi)	1500	11000	22000
Compressive strength (psi)	58000	50000	120000
Modulus of elasticity (psi × 10^6)	12.2	12.0	10.2
Microhardness	343	450	362

ii. ***Hydroxyapatite-based porcelain (Cerapearl):*** Cerapearl is composed of CaO, P_2O_5, MgO, SiO_2 and traces of other elements [CaO (45%) and P_2O_5 (15%); are essential for formation of hydroxyapatite crystals].
Cerapearl is biocompatible. The Young's modulus, tensile strength and compressive strength are higher than conventional porcelains. Cerapearl is indicated for both crowns and inlays. Another castable glass ceramic (Olympus Castable Ceramic) is improved version of Cerapearl.

The comparative mechanical properties are summarized in Table 21.6.

c. Machinable Ceramic

Machinable ceramics are supplied in the form of ceramic ingots and with the help of a machine, are fabricated into inlays/onlays and crowns. The various types of ingots used are as follows:

i. ***Cerec Vitablocs Mark I:*** This is feldspathic porcelain used with Cerec system; composition, strength and wear characteristics are similar to the feldspathic porcelain used in porcelain fused to metal restorations.

ii. ***Cerec Vitablocs Mark II:*** This is feldspathic porcelain having grain size finer than the Mark I. It exhibits less abrasive wear of the opposing tooth structure.

iii. ***Celay Vitablock:*** It is a fine feldspathic porcelain with a composition, similar to Cerec Mark II.

iv. ***DICOR MGC:*** This is a glass ceramic with fluorosilicate mica crystals in a glass matrix. Its flexural strength is higher than the castable DICOR and Cerec system.

d. Pressable Ceramic (Heat Pressed)

i. ***Reinforced glass ceramic (IPS empress, IPS e.max and Optec OPC):*** The ceramic is pre-cerammed glass reinforced with leucite, that prevents crack propagation without significantly diminishing its translucency. It is available in the form of ingots, which are heated and injected under pressure into a mold created by the lost wax technique to produce a restoration.

The material shows a lower compressive strength than metal ceramics or In-Ceram restorations.

Advantages (zirconia)

- Has the highest flexural strength amongst all ceramic systems
- Excellent fit, comparable with metal ceramics

Disadvantages (zirconia)

- Opacity of the material; hence, can be used only as a core
- Unsuitable for conventional acid etching

Uses (zirconia)

- In-Ceram zirconia is preferred for posterior crowns and bridges

Table 21.6: Comparative properties of cerapearl

Material	*Young's modulus (GPa)*	*Tensile strength (MPa)*	*Compressive strength (MPa)*	*Knoop hardness number (KHN)*	*Coefficient of thermal expansion (10^{-6}/°C)*	*Thermal conductivity (Cal cm/cm^{2}sec°C)*
Cerapearl	103	150	590	350	11.0	0.0023
Gold Alloy	95	140	400	220–240	14.4	
Enamel	80	14	390	390	11.4	0.0022
Dentin	20	70	280	70	7.0	0.0014
Porcelain	70	80	170	590	12.0	0.0024
Amalgam	58	70	360	120	25.0	0.0540
Composite resin	18	18	185	80–100	39.0	0.0026

Flexural strength is higher than DICOR and conventional porcelain.

Optec OPC shows better mechanical properties (flexural strength: 165 MPa) and translucency.

e. Infiltrated Ceramic (Slip Cast) (Table 21.7)

i. ***In-Ceram Alumina:*** Infiltrated ceramic utilizes two components: Alumina (aluminum oxide) as a core (porous substrate), and a low viscosity glass infiltrated at high temperature into this porous network. The fine grain alumina particles are mixed with water to form a slurry, referred to as a 'slip'. This slip is painted onto an absorbent refractory die and sintered at 1120°C for 10 hours to produce an opaque porous core. At this stage, the material is very fragile. In the second phase, glass infiltration material is applied onto the core and fired at 1100°C for 3–5 hours. The molten glass infiltrates into the residual pores by capillary action, and results in a dense composite structure. One disadvantage with these high alumina ceramics is their high opacity.

ii. ***In-Ceram Spinell:*** A further development in this system is the In-Ceram Spinell, which uses a spinell instead of alumina. (Spinell contains aluminum and magnesium oxide.) Because of the lower refractive index of spinell as compared to alumina, the translucency of ceramic is improved but has a comparatively lower flexural strength (twice as translucent as In-Ceram Alumina). Spinell strengthens the ceramic by deflecting the crack. Infiltrable ceramic has high flexural strength of about 450 MPa. Tensile strength is 3–4 times greater than that for the other dental ceramics. The density of these ceramics is high; hence, the traditional etching of internal surface to improve its bond to tooth structure is not effective. However, application of low fusing glazed powder on the internal surface may improve bonding.

iii. ***In-Ceram Zirconia:*** The system uses a mixture of zirconum oxide and aluminum oxide to achieve marked increase in the flexural strength (700 MPa). The combination protects the basic framework against crack propagation. However, the ceramic exhibits poor translucency.

Advantages

- Lack of metal or opaque ceramic core
- Moderate flexural strength
- Excellent fit
- Excellent esthetics

Disadvantages

- Potential to fracture in posterior areas
- Need for special equipment (pressing oven and die material)

Uses

- Used as single anterior crowns, inlays, onlays and veneers.

Newer Ceramics

i. Improved Polycrystalline Ceramics (Monolithic Zirconia)

Yttria stabilized tetragonal zirconia polycrystals (Y-TZP) was developed to overcome problems of chipping of porcelain layers over the zirconia core. However, Y-TZP has major deficiency owing to its low translucency. (Opacity of zirconia is a major problem, while placing anterior crowns; the white/opaque nature can be suitable for bleached teeth.)

The primary reason for poor performance of porcelain veneered zirconia crowns is the low thermal conductivity of zirconia core; creating stresses in the ceramic material because of large temperature gradient. (The chipping of ceramic veneer over zirconia is because of these stresses.)

The translucency of zirconia has been improved by means of microstructural modifications, viz. decrease in alumina, decrease in grain size, decrease in impurities and addition of cubic zirconia (zirconia exists in three different crystallographic forms: Cubic, tetragonal and monoclinic phase).

In general, the restoration thickness affects the translucency of the ceramics. (Lower the thickness, higher the translucency of the ceramic restoration.) Summarily, restorations made with improved

Table 21.7: Glass infiltrated ceramic (slip cast)

Physical character	*In-Ceram Alumina*	*In-Ceram Spinell*	*In-Ceram Zirconia*
Main ingredient	Alumina (lanthanum glass)	Magnesium oxide (alumina)	Zirconia (alumina)
Flexural strength (MPa)	500	450	700
Translucency	Translucent	Translucent	Opaque
Uses	Anterior crown and bridges	Inlays/onlays, anterior crowns	Posterior crowns and bridges

monolithic zirconia show low fracture rates and reasonable esthetics.

ii. *Improved Glass-Ceramics*

The conventional lithium disilicate ($Li_2Si_2O_3$) glass ceramic, used both as heat pressed (ingots) and CAD-CAM system (blocks), was modified by changing the shape of the crystals, in the name of IPS e.max.

Glass ceramic is reinforced with polycrystalline (zirconia dioxide crystals) to have better esthetic properties. The new zirconia-reinforced glass ceramic exhibits good optical properties, attain better finished/polished surface and can easily be milled in CAD-CAM (because of high amount of glass matrix). CELTRA Duo and Suprinity are the commercial preparations.

iii. *Polymer Infiltrated Ceramic Network (PICN)*

The resin is infiltrated into conventional glass ceramic to have better physical properties, especially the modulus of elasticity. (Material is considered as resin-ceramic composite; polymeric part consists of urethane dimethacrylate and triethylene glycol dimethacrylate.) Initially, glass powder is sintered followed by infiltration of monomer mixture. The commercial preparation, Enamic, showed elastic modulus values (30 GPa) close to that of dentin (20 GPa).

Other properties are in between composite and ceramic.

One major disadvantage of this material is the greater shrinkage (5.0%) as compared to the glass ceramic (1.0%). The shrinkage will result in interfacial stresses and subsequent problems because of development of gap at the interface. Due to inferior optical properties, the material is usually referred for posterior restorations.

CERAMIC RESTORATIONS

A. CERAMIC INLAYS/ONLAYS

Indications

- Cervical and proximal regions of an anterior tooth, where esthetics is the prime concern.
- Restoration will not be overloaded occlusally.
- Teeth which require strengthening/protection of remaining structure.
- No evidence of excessive attrition in relation to patient's age.
- Sufficient tooth structure is available for bonding.
- Lesions on the occlusal or proximal surfaces of posterior teeth.
- Patients who maintain good oral hygiene.

Contraindications

- Not a restoration of choice, if the tooth is grossly involved, either proximally or cervically (there must be adequate tooth structure to support the restoration).
- When access to the lesion is poor and over-cutting of tooth structure would be required; e.g. rotated teeth.
- When short teeth preclude developing adequate resistance and retention forms; e.g. heavily worn down teeth.
- Teeth with insufficient tooth substance for bonding.
- Teeth with large pulp chambers, which limit the reduction of tooth structure.
- Where posterior group function and reduced vertical dimensions apply strong lateral forces on the restoration.
- Patients with poor oral hygiene/inadequate motivation.

Advantages

- Esthetically pleasing
- Low thermal conductivity
- High tolerance of the soft tissues
- Chemically inert
- Insoluble in oral fluids
- Coefficient of thermal expansion close to that of natural tooth

Disadvantages

- Technique sensitive
- Some newer type of ceramic restorations require a special and expensive laboratory equipment.
- Restorations are brittle and can fracture; especially inadequate thickness does not resist occlusal forces.
- Hard; can abrade opposing teeth or restorations.
- Lack of perfect adaptation to cavity walls (exposes the cement line).
- Time consuming

Cavity Preparation

Porcelain inlays/onlays are mainly confined to posterior teeth (Class II inlay): Class III and Class V preparations are explained in brief for academic purposes. A thorough knowledge of stress factors is mandatory during cavity preparation for ceramic inlays. It has been established that the shear stress increases at the ceramic–tooth interface, as the occlusal contact become close to the inlay–tooth margin. (Outline is planned accordingly.) Such stresses may lead to risk of debonding and fracture of the restoration. The risk of failure of the restoration can be minimized by increasing the depth of inlay (thickness of ceramic).

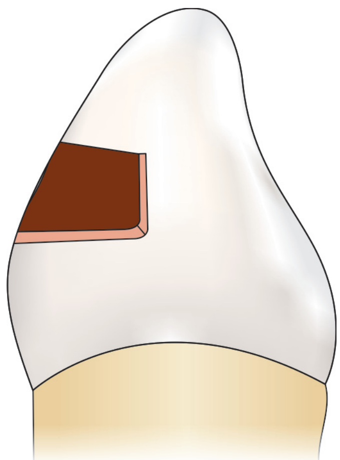


Fig. 21.3: Class III cavity—proximal view

Before cavity preparation, shade of the tooth is recorded, followed by application of the rubber dam.

Class III Cavity

i. ***Labial access:*** Access is gained from the labial side when the tooth is involved proximolabially and the lingual marginal ridge is intact and not undermined by caries. A separator (0.75 mm) is applied between two adjacent proximal surfaces. The cavity is prepared such that a labioproximal path of withdrawal is established.
   The diagrammatic cavity preparation (proximal view) is shown in Fig. 21.3.
ii. ***Lingual access:*** Lingual access is indicated on the proximal surfaces of all anterior teeth, especially when the lingual marginal ridge is weak or missing.
   The cavity preparation is followed as for inlay cavity preparation (Labiolingual path of withdrawal is established).
   The axial line angles should be rounded to avoid stress concentration. A retention groove is placed in the incisoaxial and gingivoaxial line angles, if need be. These grooves should be consistent with the labio-lingual path of withdrawal.
   A diagrammatic cavity preparation with lingual access is shown in Fig. 21.4.

Class V Cavity

Class V cavity preparation for ceramic inlay follows the basic principles of cavity preparation for esthetic inlays.

The outline form includes the area affected by caries, erosion, abrasion or existing restoration. Incisal/occlusal outline is longer than the gingival outline and both are parallel to each other mesiodistally. The mesial and distal margins follow proximal contours of the crown of the tooth.

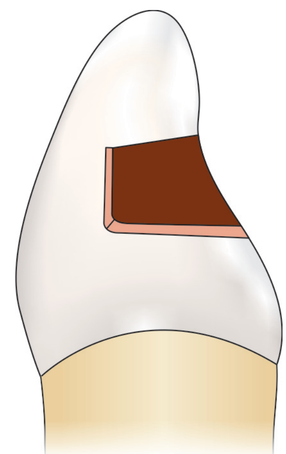


Fig. 21.4: Class III cavity—lingual access

All line angles and point angles should be rounded to avoid stress concentration prior to cementation. Retention can be improved by placing grooves on incisoaxial and gingivoaxial line angles.

A diagrammatic cavity preparation, with and without grooves, is shown in Fig. 21.5A, B.

Fig. 21.5: Class V cavity: **(A)** Without grooves; **(B)** With grooves

Class II Cavity

The basic principles of cavity preparation for cast gold inlays/onlays are followed for ceramic inlays/onlays, with minor modifications (Table 21.8 and Fig. 21.6).

In brief, the cavity preparation for a porcelain inlay is similar to that for cast metal, minus beveling and secondary flaring (Fig. 21.7).

A tapering carbide bur is used for the cavity preparation, creating divergence of the walls towards the occlusal; facilitate insertion and removal of the restoration. The occlusal divergence per wall of the cavity preparation for porcelain inlay is kept at 10–12° as compared to conventional 2–5° for cast gold restorations (The taper/occlusal convergence is slightly more than composite inlays). The main reason for excessive divergence is; ceramic being brittle, may

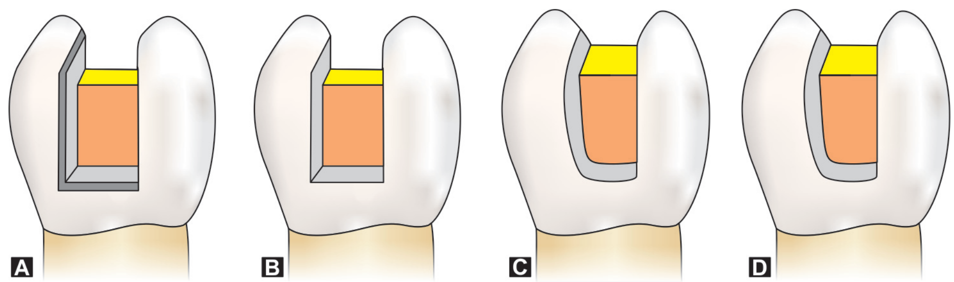


Fig. 21.6: Difference in inlay cavity preparation: **(A)** Gold inlay; **(B)** Base metal; **(C)** Composite inlay; **(D)** Ceramic inlay

Table 21.8: Difference in inlay cavity preparation

Gold	*Base metal*	*Composite*	*Ceramic*
Narrow outline	Narrow outline	Wider outline	Wider outline
Depth less	Depth less	Depth more	Depth more than composite
Short bevel at cavosurface	No bevel	No bevel	No bevel
Taper (2–6°)	Taper (2–6°)	Taper (8–10°)	Taper (10–12°)
Definite line angles	Definite line angles	Rounded line angles	Rounded line angles

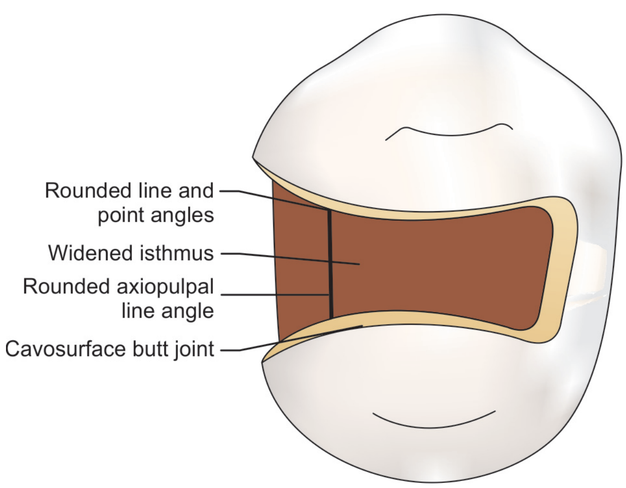


Fig. 21.7: Class II cavity preparation for a porcelain inlay

get fractured during try-in and cementation. A simple and narrow path of withdrawal is indicated during cavity preparation.

The depth of the occlusal step should be 2.0–2.5 mm for ceramic inlay (The depth is slightly more than composite inlays) (Fig. 21.8). Width of the isthmus should be minimum 1.5 mm and the axial reduction in the proximal box should be 1.5 mm (For DICOR restorations, the axial reduction can be reduced to 1.2 mm and for Optec systems even to 1.0 mm).

The tapering bur used for cavity preparation should have a rounded end to avoid sharp line angles and point angles in the preparation. No undercuts are permitted in the cavity and if present, should be blocked out using glass-ionomer cement. Pulpal floor should be smooth and flat. In case the floor is rough or deep, a glass-ionomer/composite base is recommended. In very deep preparations, a sub-base of calcium hydroxide is preferred (Fig. 21.9). All cavosurface margins should terminate in a butt joint, i.e. 90° angle. Final finishing is carried out with diamond points. All stains are removed from the walls; they may appear as black or gray lines at the margin after cementation.

Cusp capping (onlay) is needed when a cusp has fractured or is hopelessly undermined. It should also be considered when the margin of the preparation approaches 1.5 mm of the cusp tip. When capping functional cusps, a 'collar' is prepared to move the margins of the preparation away from any possible

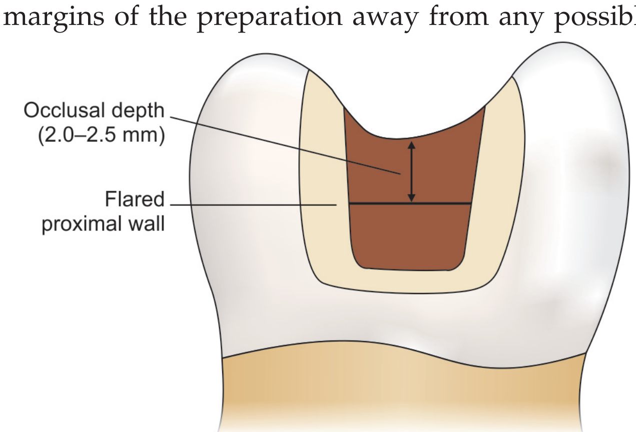


Fig. 21.8: Cavity preparation for porcelain inlay showing occlusal depth of 2.0–2.5 mm and flared proximal walls

Fig. 21.9: Cavity liner

Table 21.9: Comparative evaluation of composite and ceramic inlays

	Composite inlay	*Ceramic inlays*
Cavity design	• Medium to large • 8 to 10° taper • Minimum depth 1.5 mm • Isthmus width 2.0 mm minimum • Primary flare at proximal box walls (90–100°); margins may not be in embrasures • No cavosurface bevel • No undercuts	• Same as for composite inlays; except – More depth (2.0–2.5 mm) – More taper (10°–12°)
Laboratory procedures	• Relatively simple	• Costly, complex and time-consuming
Finishing	• Convenient	• Time consuming
Esthetics	• Good	• Excellent
Wear resistance	• Depends upon quantity and quality of fillers	• High level of wear resistance
Intraoral repair	• Possible	• Not possible (repaired by composites)
Brittleness	• Not much	• Liable to fracture during try in and cementation
Strength	• Good, as required	• High compressive strength than composite but less tensile strength
Advantages	• Controlled polymerization shrinkage • Improved mechanical properties • Reduced microleakage	• Same as for composite inlay; in addition – Marginal seal is better – Better esthetics

contact with opposing teeth. The width of the collar should be 1.0–1.5 mm. (Preparation for ceramic onlay is similar to that of metal onlays; the depth of preparation varies with the type of ceramic system.)

The ceramic inlay is comparatively evaluated with composite inlay in Table 21.9.

Fabrication of a Porcelain Inlay

Ceramic inlays are categorized into four types according to the fabrication technique:

a. Inlays fired on a platinum foil
b. Inlays fabricated on a refractory die
c. Inlays fabricated by the lost wax technique
d. Machined ceramic inlays

a. *Inlays Fired on a Platinum Foil*

The stages in the construction of a porcelain inlay include: (i) Preparation of the cavity, (ii) making a platinum matrix/mold, (iii) Porcelain build-up and firing (fusing porcelain into the matrix to restore the tooth form) (iv) glazing, (v) removing matrix from the inlay, (vi) cementing inlay into the cavity.

i. A cavity is prepared as discussed earlier.
ii. A matrix/mold is made into which the porcelain powder can be built and fused. Several materials can be used for the formation of this matrix, e.g. platinum, palladium or gold. The matrix must have a softening point above the temperature at which the porcelain fuses to ensure its stability during the making of an inlay. Platinum and palladium can be used in the fusing of any of the dental porcelains available, while gold/palladium-gold alloys, because of their lower fusing points, permit the use of low fusing porcelains only. Platinum is commonly used (foil in the thickness of 0.001"–0.0015"). The platinum is supplied in an already annealed state; however, after sometime, it becomes stiff and requires annealing. (Holding the matrix in a flame until it becomes cherry red in color and then quickly quenching it in water or alcohol.)

The matrix can be obtained in several ways:
- Direct (making it directly in the tooth cavity).
- Indirect (making an impression of the cavity and the die, then proceeding on the model).
- Indirect-direct (making the matrix on the model, and reburnishing (final shaping) it directly in the cavity).

iii. ***Porcelain build-up and firing:*** Complete cleanliness is mandatory at this stage; unclean environments can easily contaminate the porcelain with dust, plaster or any other material. The basic armamentarium includes: A clean glass slab, one camel hair brush (size 8), one or more round sable brushes (size 4 and less), mixing spatula, porcelain carver, tissue, a receptacle for distilled water and locking tweezers.

Two drops of distilled water and the porcelain powder are placed on a glass slab. The dispensed powder and water are mixed to a creamy consistency. An adequate consistency is attained when the mix tends to run on tipping the glass slab. The pointed end of a porcelain carver serves to transfer this mix to the cavity area of the matrix. Rubbing the carver across the locking pliers holding the matrix causes the mix to flow across the pulpal/axial wall of the cavity into the line angles. The material is condensed by any of the methods described earlier. An even thickness of porcelain is maintained and the cavity is filled to one-half. Any excess is carefully wiped off with a sable hair brush. Overcontouring is not permissible except in areas of contact points or incisal angles, and that too only by amounts equal to the contraction that will take place during firing. It is established that well condensed porcelain shrinks by approximately one-sixth on firing. (Shrinkage occurs towards the bulk.) In order to compensate for this shrinkage, a number of methods can be employed.

Reducing the firing shrinkage: The methods, used either singly or in combination, for reducing firing shrinkage are:

1. *Ditching:* A ditch is cut into the porcelain around the inner margins of the matrix, leaving some porcelain on the margins (Fig. 21.10). Because porcelain shrinks towards the center, the ditch is enlarged, but the margins will remain partially covered. The ditch is filled with fresh porcelain and refired.
2. *Crosscutting:* A cut in the form of a cross is made with some sharp instrument through the porcelain to the platinum matrix (Fig. 21.11). This creates four sections in porcelain, which shrink individually during firing. Hence, distortion of the platinum matrix resulting from porcelain shrinkage is minimized. The contraction voids are filled with fresh porcelain and fired again.

   The matrix along with the condensed porcelain is subjected to firing by placing in a low heat absorption tray. This tray is constructed from a double thickness (0.001 inch) platinum foil. A thin layer of crystalline alumina (90 mesh) mixed with a luting cement in 50:50 concentration is fired in the tray to render it rigid and resistant to heat during subsequent firings. In order to dry the wet porcelain, the tray along with the matrix is placed in front of a preheated furnace muffle. After drying, the tray and the matrix are introduced into the rear of the muffle. When the door of the furnace is opened, the temperature drops by about 100°F. The temperature is brought back to its firing temperature, and the porcelain held at this temperature for 25 to 30 seconds. The porcelain should exhibit an underglaze, i.e. a medium (bisque) bake. Cooling takes about one minute. Some amount of shrinkage and distortion of the matrix occurs. The matrix and first bake of porcelain are placed back on the die, swaged and a sticky wax transfer performed. This permits re-adaptation of the matrix to the die cavity. However, fused porcelain may show cracks during the procedure.

   Small amount of porcelain present on the glass slab is remixed and deposited into the cracks by adequately vibrating the mix, so that no air is entrapped. The second build-up is performed in the same manner as the first build-up. The cavity is filled up to about seven-eighths at this stage. A cut is made deep down to the previously fused porcelain to bisect the build-up. Firing is carried out in the same way as before. The matrix with the fused porcelain is again swaged and a sticky wax transfer performed.

   The third porcelain build-up is carried out, care being taken to obtain the correct contour and marginal apposition. Slight overcontouring is beneficial at this stage since the porcelain will shrink on fusion. The porcelain is subjected to

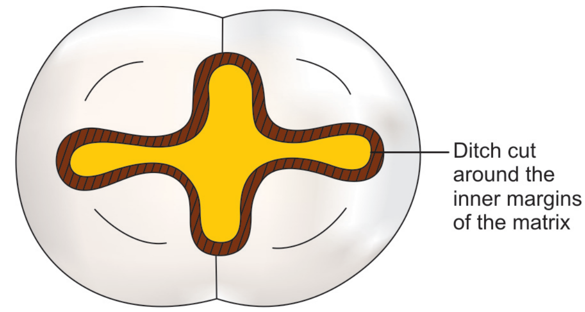


Fig. 21.10: Ditching method for reducing shrinkage in porcelain

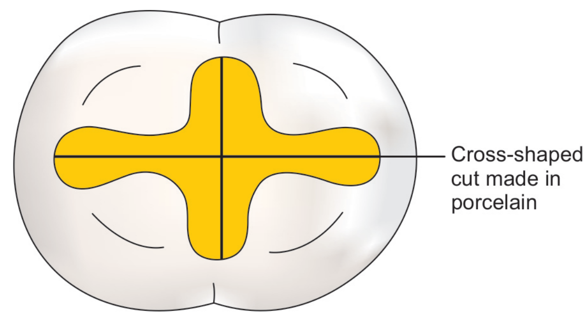


Fig. 21.11: Crosscutting method for reducing shrinkage in porcelain

firing, and if slight discrepancies develop in contour and/or marginal adaptation, they are corrected by adding small amounts of low fusing porcelain and 'refiring'. The inlay is tried in the oral cavity and ground to proper contour and occlusion with a fine stone, if required.

iv. Glazing is carried out by heating the inlay for an additional 2–3 seconds at the firing temperature.

v. The inlay along with the matrix is immersed in alcohol/water for one minute. Some matrix may remain adherent in the region of tears, which can be easily removed after acid etching by hydrofluoric acid or by dissolving it in aquaregia.

vi. The process of cementation is described in subsequent pages.

b. *Inlays Fabricated on Refractory Dies*

Inlays fabricated on refracting dies eliminate the use of a platinum foil, which may cause inaccuracy and deformation. After the cavity preparation, an impression is taken and a master cast is poured in die stone or epoxy resin. Die pins aid in forming a die (Fig. 21.12). The master cast is separated and trimmed (Fig. 21.13A, B). A die spacer is applied in the cavity preparation usually on the pulpal and axial walls (Figs 21.14 and 21.15). The master model is duplicated with a silicone impression and poured in refractory investment capable of withstanding porcelain firing temperatures. After hardening, the cast is fired at 1000°C to eliminate accumulated gas. It is soaked in a conditioning solution, which facilitates porcelain contraction.

Dental porcelain is added into the cavity on the refractory die and fired in an oven. A two- to three-step build-up technique is necessary to compensate for the sintering/firing shrinkage. The ceramic restoration is retrieved from the die (Fig. 21.16), cleaned and seated on the master die for adjustment

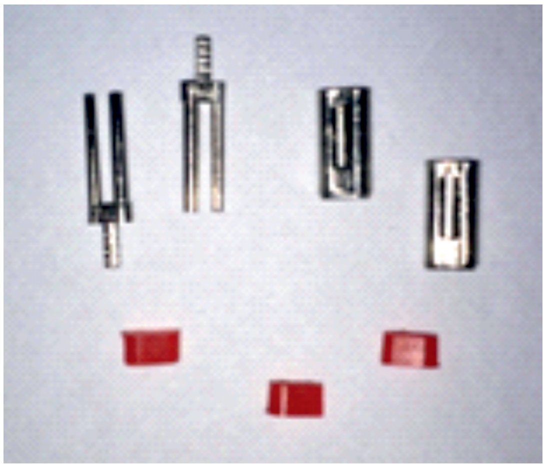


Fig. 21.12: Die pins used in forming a die

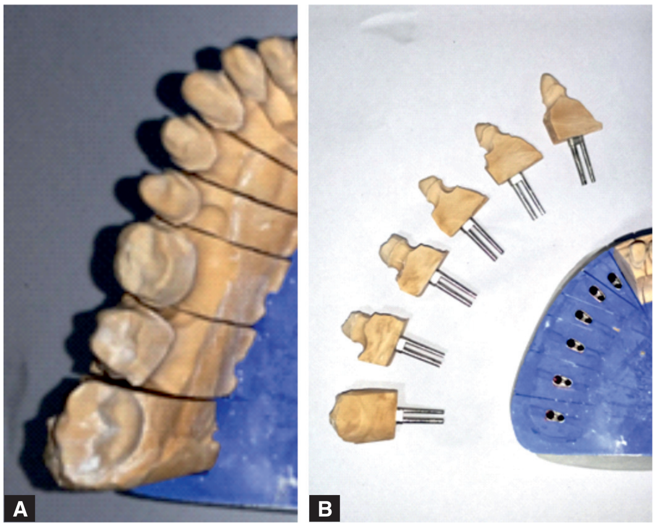


Fig. 21.13: Master cast and dies: **(A)** Master cast trimmed; **(B)** Separated dies

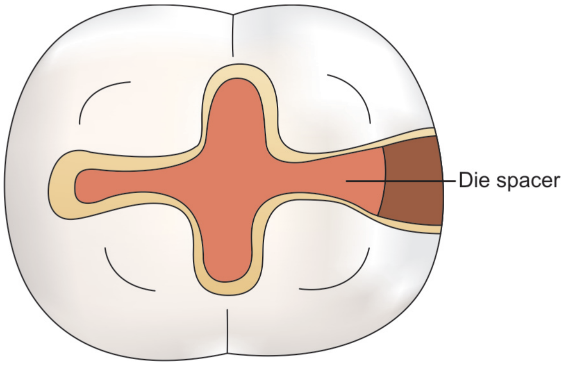


Fig. 21.14: Die spacer applied on the pulpal and axial walls of the cavity preparation

Fig. 21.15: Die spacer and die hardener

and finishing (Fig. 21.17). Occlusal contacts are adjusted and proximal overhangs, if any, are removed. After an accurate finishing of the margins, the restoration can be glazed.

Fig. 21.16: Ceramic restoration retrieved from die

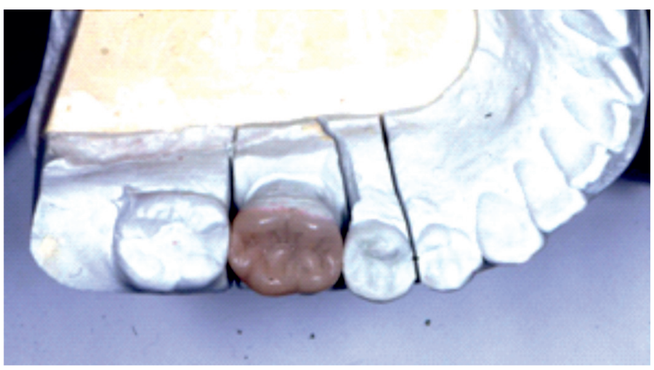


Fig. 21.17: Restoration on master die for finishing

The advantage with this technique is the compatibility with most existing ceramic ovens used in the laboratory. The disadvantages of the technique are its technique sensitivity and a higher incidence of fracture as compared to other ceramic systems.

c. *Inlays Fabricated by the Lost Wax Technique*

The cavity is prepared in routine (Fig. 21.18A).

An impression is made and a master cast, preferably in Epoxy resin die material, is prepared as it provides increased hardness and wear resistance. A die spacer is chosen and applied in two thin coats, avoiding the margins. Die lubricant is applied directly over the die spacer, and a wax pattern is made using conventional techniques. Occlusal detail can be carved into the pattern and retained throughout the subsequent process. The completed wax pattern is sprued (usually an eight gauze sprue is used) (Fig. 21.18B).

The pattern is invested with phosphate-bonded investment that produces 1.6% thermal expansion. A two-stage burnout is recommended. The ring is placed in a cold furnace and the temperature is slowly raised to 480°F (Fig. 21.18C). The temperature is further raised to 1750°F (950°C). The casting machine features a platinum electrical resistance type muffle mounted on an electrically driven straight centrifugal casting arm. It is maintained at a temperature of 2010°F (1100°C) for 10 minutes to preheat the muffle. The crucible loaded with ingot is placed inside the muffle. The temperature is raised to the casting temperature of 2476°F (1358°C). At this temperature, the ingot melts and this temperature is maintained for 6 seconds. The 'cast' switch is turned on; the casting arm spins and the casting is completed. The casting ring is allowed to bench cool for 45 minutes.

The casting is cleaned of any attached investment. The non-crystalline casting is placed in the embedment material for the ceramming process. (50 gm of the embedment material is mixed with 18 cc of distilled water.) It is allowed to set for 15–30 minutes, and placed in the ceramic furnace (Fig. 21.19). The furnace takes approximately 114 minutes to reach the ceramming temperature of 1960°F (1075°C) and maintains the temperature for 6 hours. The furnace is cooled for one hour and when the temperature has lowered to 392°F, the casting is removed.

The retrieved glass ceramic restoration is subjected to grit blasting (Fig. 21.20A). Any irregularities on the internal surface of the restoration are checked and removed with extra fine diamond points. Add-on porcelain can be applied, if need be. The casting is dried in front of an oven at 1290°F (700°C). It is placed in the muffle and fired in vacuum from 1290°F to 1775°F (700–900°C). The vacuum is released and the temperature maintained at 1775°F for one minute. The added fused porcelain is shaped and adjusted.

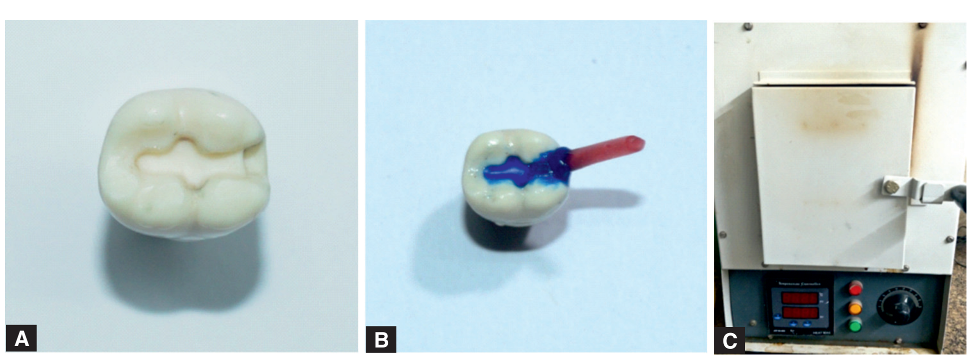


Fig. 21.18: Inlay fabricated by lost wax: **(A)** Cavity prepared; **(B)** Wax pattern; **(C)** Burnout furnace

Fig. 21.19: Ceramic furnace

After contour adjustments, shade porcelain is applied on the surface. The addition of shade porcelain determines the hue. More than one shade porcelain may be necessary to obtain the desired hue. The number of applications control the chroma. Generally, four applications are considered satisfactory. The additional color applications are fired at 1725°F (940°C) without hold time. The thickness of the coloring porcelain after four applications is approximately 125 µm. The restoration is finally tried on the preparation and necessary adjustments are carried out (Fig. 21.20B).

The cast glass ceramic restoration can be acid etched (with ammonium bifluoride) on its internal surface to aid in retention. The restoration is then cemented with a translucent glass-ionomer cement.

d. *Machined Ceramic Inlays*

Two approaches are utilized for fabricating ceramic inlays and other ceramic restorations, utilizing machine principle:

i. Analogous systems

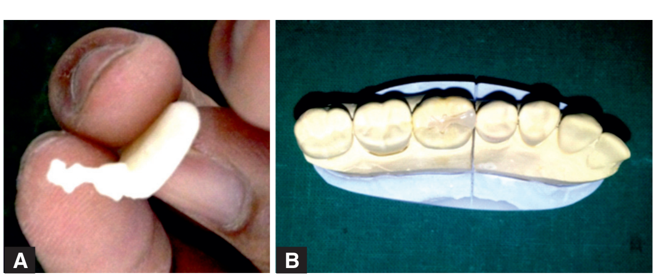


Fig. 21.20: **(A)** Ceramic inlay after grit blasting; **(B)** Inlay tried on cast

- Copy milling/grinding technique: automatic (Ceromatic II) and manual (celay)
- Erosion method

ii. Digital systems

- CAD-CAM generated

i. *Analogous system*

- ***Copy milling/grinding technique:*** In this technique, the restoration is milled using ceramic systems, like Celay, Ceromatic II, DCP, etc. (Celay is most common.) Originally, the system was developed to produce inlays and onlays; however, modifications in the system can fabricate other restorations. The copy milling technique utilizes fabricating a prototype inlay (proinlay), which is copied using a scanning tool or micropalpation (finger) method (Fig. 21.21A, B). The final restoration is milled from a preformed ceramic block. The proinlay is fabricated with a blue resin-based composite (Celay Tech) made either directly on a prepared tooth or indirectly on a die made from the impression. The prototype is fixed into the Celay unit. As the surface of the proinlay is scanned with a tracing tool (smooth discs), a coarse diamond-coated disc (124 µm grain size) simultaneously roughs out the shape of the ceramic restoration (A finger guide may also be used to trace the surface of the pattern). A fine white powder is applied to the proinlay and scanned. Using fine diamond discs and burs (60–70 µm grain size), refine the shape of the ceramic restoration. Once the white powder has been completely traced off, the milling of ceramic inlay is considered complete. Stains and glazes may be added before the inlay is etched and silanized. The time taken to mill the restoration depends upon the experience of the operator, complexity of the restoration and sharpness of the cutting discs. One problem, which may be frequently encountered

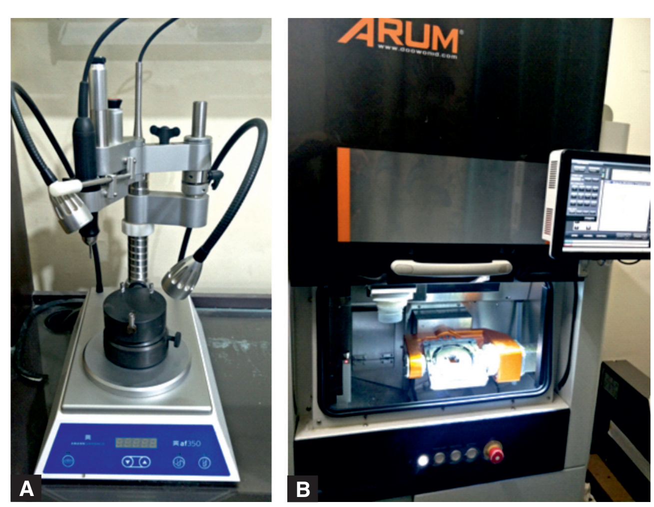


Fig. 21.21: Copy milling machines

Fig. 21.22: CAD-CAM unit

during the use of the copy milling technique, is the difficulty in obtaining accurate proinlays.

- ***Erosion method:*** Ultrasonic/sono erosion requires a metal-based negative form of the restoration, which is produced by wax molding and casting or by intensive copper plating of the impression. These are called 'sonotrodes'. Both sonotrodes fitting exactly together are guided onto a ceramic blank after connecting to an ultrasonic generator under slight pressure. The ceramic blank is surrounded by an abrasive suspension of hard particles, such as boron carbide, which on acceleration by ultrasonics, erodes the restoration.

ii. *Digital systems*

- ***CAD-CAM generated:*** CAD-CAM device consists of a three-dimensional video camera (scan head), an electronic image processor memory unit and a processor (computer), which is connected to a miniature milling machine.

  CAD-CAM system uses digital information of the cavity preparation to provide a computer-aided design (CAD) on the video monitor. Once the three-dimensional image of the restoration is accepted, the computer translates that image into a set of instructions to guide a milling tool (computer-assisted manufacturing) (Fig. 21.22).

Cavity Considerations for CAD-CAM Inlays

Tooth preparation for a ceramic inlay/onlay requires conventional cavity design with slight modifications to accommodate the computerized milling device. These modifications are:

- No convexities should be present on the pulpal and gingival walls. They may be flat or concave buccolingually.
- The occlusal step should be 1.5–2.0 mm in depth and isthmus should be at least 1.5 mm wide to minimize the possibility of fracture of the restoration.
- The buccal and lingual walls of the occlusal portion may converge towards the occlusal. This feature is unique to the Cerec system as it can automatically block out any undercuts during the optical impression. A more conservative cavity preparation is permissible along the occlusal aspect, especially when replacing old amalgam restorations where undercuts were purposely given for retention. The facial and lingual walls in the proximal box are prepared in the usual fashion with slight divergence towards the occlusal.
- Axial walls should be straight and not follow the convex contour of the proximal surface of the tooth.
- Cavosurface/marginal bevels are not indicated.

Fabrication

The steps involved in fabrication of CAD-CAM system are:

i. Surface digitization
ii. Designing
iii. Manufacturing
iv. Finishing

i. ***Surface digitization:*** A scanning device is used to collect information of the shape of the preparation. This step is referred to as the '*optical impression*'. An image of the preparation is displayed on the monitor. Repeated optical impressions are taken, until the most ideal is found; same is stored in the computer.

The optical sensors may not measure highly transparent/reflective surfaces; enamel has to be covered with a powder or a water-soluble color. The mechanical scanning conducted by a profilometer or pinpoint sensors are very precise; however, they have several shortcomings. The scanning tip produces errors in measuring cusp slopes and distorts easily. Undercut areas and fissures cannot be explored properly.

The 3-D scanning methods can be applied either directly onto the tooth or indirectly onto a model fabricated from an impression of the cavity (Fig. 21.23).

Advantages of the direct technique:

- The entire procedure is completed in one session (avoid inaccuracies of impression, etc.).
- Laboratory facilities are not required.
- An interim restoration is not necessary.

Disadvantages in the direct technique:

- Waste of chair time in case of a difficulty during milling or designing.

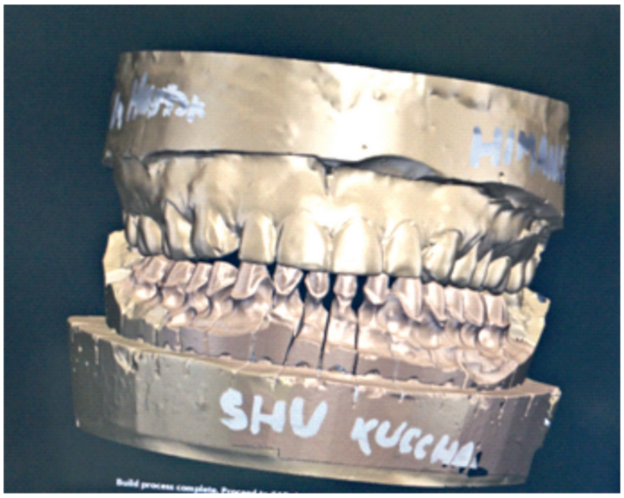


Fig. 21.23: 3-D scanning

The indirect method of scanning overcomes the limitations of direct method. An impression of the prepared tooth as well as adjacent teeth is taken in elastomeric or hydrocolloid impression materials. The impression is poured in die stone and a split cast model made.

ii. ***Computer-aided designing (CAD):*** This step involves three-dimensional image processing. The operator enters data and confirms the features of the preparation, like boundaries of the restoration, position of the gingival margins, proximal contacts and contours, buccal and lingual extensions, etc. Undercuts can be blocked at this stage.

iii. ***Computer-aided manufacturing (CAM):*** The cavity surface of inlays, onlays or crowns is milled to the dimensions of the scanned image with diamond discs or other instruments that are electrically driven and lubricated with water. Controlled cutting of the ceramic is carried out by rotation of the block, horizontal movement of the block into the wheel and vertical movement of the cutting wheel. The fit of the restoration is confirmed in the patient's oral cavity. Proximal contours and contacts can also be provisionally adjusted.

iv. ***Finishing:*** The detail protocol of finishing ceramic restoration is described in chapter 23.

Disadvantages of the CAD-CAM system:
- Initial high cost of Cerec unit
- Time consuming to master the technique
- Contouring of the occlusal surface may have to be carried out by the clinician.

A newer version of Cerec-Cerec 3 simplifies and accelerates the fabrication of ceramic restorations. Cerec 3 software simplifies occlusal and functional registration. Proper occlusion is established accurately and quickly. The grinding unit receives data from the control unit independent of its location in the practice. The second restoration can be designed while the first is being milled. The grinding unit is also equipped with a laser scanner and can be used for indirect applications through a personal computer. Since it is equipped with an intraoral video camera or a digital radiography unit, it can also be used for patient education and for user training.

Another system, Cicero (computer-integrated ceramic reconstruction) uses optical scanning, ceramic sintering and computer-assisted milling techniques to fabricate restorations with maximal static and dynamic occlusal contact relations.

Newer CAD-CAM Techniques

Dental CAD-CAM system utilizes two types of technique for fabricating restorations:

i. Machining the restoration from a block of sintered material
ii. Machining a block in partially sintered state, with final sintering in a furnace.

Both the techniques are widely used; however, one major drawback is the waste of material (may be more than 50% of the prefabricated block, which is also not reusable).

New technologies are being tried to overcome this problem. One technique is '*additive CAD-CAM*', also known as '*solid free-form fabrication*', in which restorations are prepared by means of adding layers, instead of grinding prefabricated blocks.

The newer techniques are:
- *Selective laser sintering/melting:* Laser beam sinters thin layer of ceramic.
- *Direct 3D printing:* Direct printing of ceramic suspension, like inkjet printer (Fig. 21.24).
- *Stereolithography:* Utilizes suspension containing ceramic particles mixed with resin component.

The advantage of these 'additive' techniques is the minimal or no waste; however, quality of restorations may not be up to the mark.

Surface Treatment and Cementation of Inlay

The cavity surface of the inlay is etched prior to cementation to aid in mechanical retention. After etching and washing, the etched surface can be treated with a silanating agent, which further improves the bond to the luting cements. An alternative treatment is sand blasting with 20 μm aluminum oxide particles under 40 psi pressure.

After the surface treatment, the inlay is ready for cementation. Mylar strip is positioned in the affected proximal surface and wedged. The cavity surfaces are conditioned and a bonding agent applied in a thin film (Fig. 21.25). A dual cure composite resin luting agent is preferred, so that curing is not hampered in difficult areas

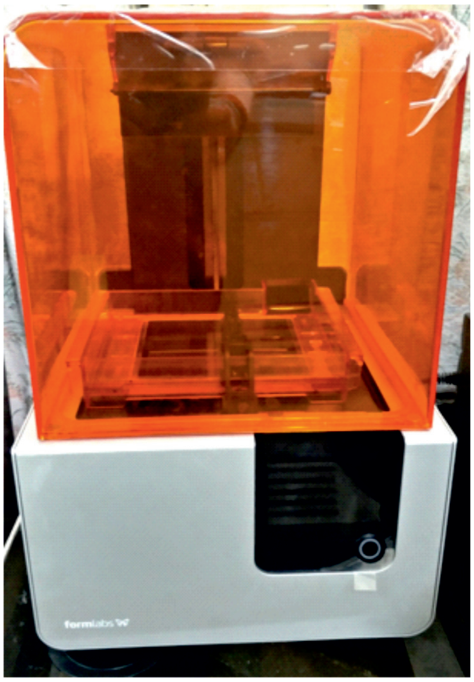


Fig. 21.24: 3-D printing

Fig. 21.25: Cavity surface etched and bonding agent applied

(Fig. 21.26). The cavity side of the restoration is coated with the cement. The inlay is inserted into the cavity using ball burnisher with minimum pressure. The excess composite is removed with a bladed instrument, taking care not to remove any cement from in-between the interface. The restoration is light cured from all three directions, i.e. occlusal, facial and lingual, for a minimum of 40 to 60 seconds in each direction (Fig. 21.27). Resin-modified glass-ionomer is preferred for cementation.

After curing, matrix strips and wedges are removed. All the margins are inspected visually and with an explorer for any deficiency or excess. The restoration is finally finished and polished (Fig. 21.28). The procedure for try in, cementation, finishing and polishing is the same for all types of ceramic inlays whether fired, cast or machined.

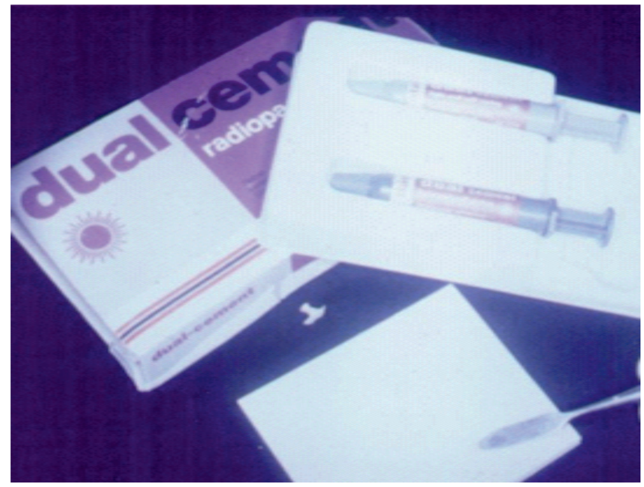


Fig. 21.26: Dual cure cement

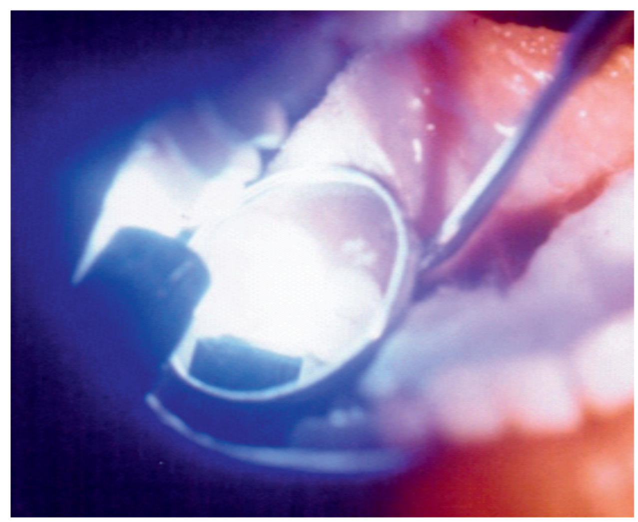


Fig. 21.27: Light curing the restoration

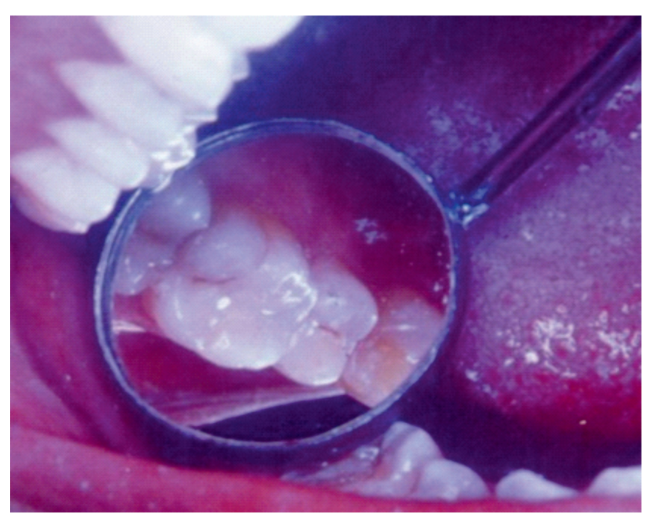


Fig. 21.28: Cemented restoration (finished and polished)

B. CERAMIC LAMINATES/VENEERS

Indications

- Discoloration (fluorosis, tetracycline staining, etc.)

- Enamel defects (enamel hypoplasias, enamel hypocalcification, etc.)
- Diastema
- Malpositioned teeth
- Malocclusion (changed incisal guidance or centric holding in malocclusion)
- Poor restorations on labial surface of anterior teeth.
- Aging (Color changes due to aging can be masked.)

Contraindications

- If sufficient enamel is not available around the periphery of the laminates.
- Deciduous teeth and extensively fluoridated teeth; may not etch effectively.
- Patients with habits, as bruxism or biting on foreign objects.

Advantages

- Better color control, color stability and natural appearance.
- Bond strength to enamel is considerably stronger.
- Glazed/polished surface do not allow plaque accumulation.
- Wear and abrasion resistance is exceptionally good.
- Inherent porcelain strength is greater than other materials.
- Resistance to fluid adsorption (Porcelain adsorbs less fluid than any other veneering material.)
- Esthetics is considerably better; stabilizes color and texture.

Disadvantages

- Time consuming
- Cannot be repaired, once luted to the enamel
- Technique sensitive
- Color cannot be modified after placement
- Overcontouring (mostly in cervical area)
- Extremely fragile
- Difficult to manipulate

Tooth (Enamel) Preparation for Laminates

The objectives of tooth (enamel) preparation are:

- Provide adequate space for the porcelain material.
- Remove convexities and provide adequate path of insertion. (Best path of insertion requires the least amount of enamel reduction, as modified by esthetic demands of the patient).
- Provide space for an opaquer, if required.
- Provide a definite seat to help position the laminate during placement.
- Obtain an enamel surface conducive for etching and bonding the laminate.
- Facilitate margin placement in the sulcus, especially in severely discolored teeth.

Procedure

The decision of depth of enamel reduction depends on the following biological and technical factors:

- Esthetics
- Relative tooth position
- Masking of tetracycline stains
- Margin placements
- Age and psyche of the patient
- Periodontal health

The preparation of tooth (enamel) for ceramic laminates involves the following steps:

a. Labial reduction
b. Interproximal reduction
c. Sulcular extension and margin placement
d. Incisal modification
e. Lingual reduction

a. Labial Reduction

The reduction should preferably remain within the enamel; certainly at all the peripheral margins to ensure an adequate seal to enamel. The inclination of labial enamel is to be respected and maintained.

Some amount of dentin, if exposed and limited to small areas, is not critical; margins should remain on enamel.

The depth-cutting diamond points LVS no. 1 and 2 (Fig. 21.29A, B) facilitate cutting of enamel (0.3–0.5 mm) (Fig. 21.30A, B).

The depth grooves are marked with color ink, which facilitate cutting up to the desired depth.

Small round bur can also be used as guide for depth during enamel preparation.

The remaining enamel is removed to the depth of these initial cuts (Fig. 21.30C).

b. Interproximal Extension

The proximal margin of the laminate should be hidden within the embrasure area (desirable to extend this margin about half way into the interproximal contact area) (Fig. 21.31).

Extension of the laminate beyond the mesiobuccal and distobuccal line angles ensures the wrap around effect. Margins are always placed before the contact; however, in case of diastema, the contact area can be involved.

c. Sulcular Extension and Margin Placement

It is desirable to place the margin just within the sulcus (0.05 to 1.0 mm). There is no need to extend it deep and hide it subgingivally as in crown and bridge procedures.

The sulcular preparation remains at a considerable distance from the biologic width, so there is little

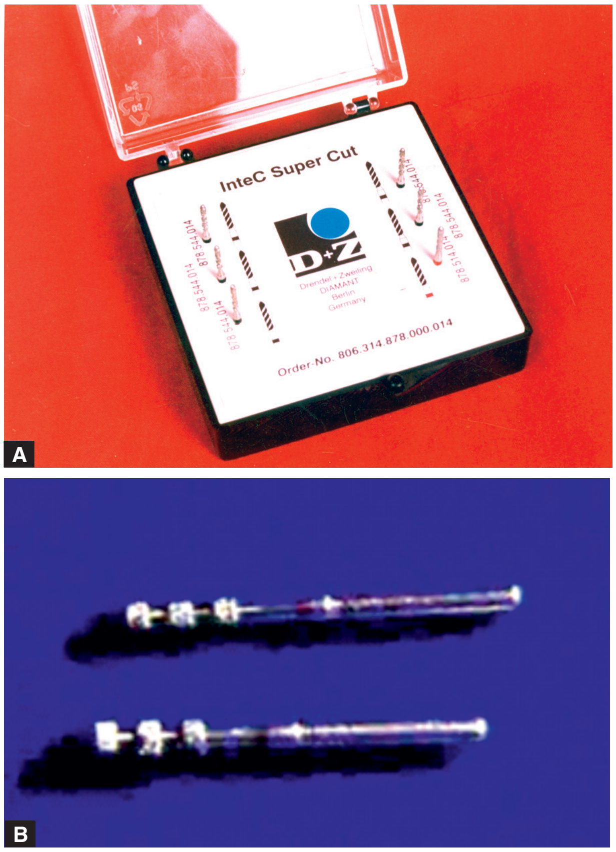


Fig. 21.29: Depth-cutting instruments for laminate preparation

potential for violating it and developing untoward gingival reactions. The margin must remain at a point, where after tissue displacement, it will be visible for finishing of the porcelain laminate.

The diamond point refines and defines the finish line; moves the finish line from being at the gingival margin to 0.2 mm or less into the sulcus (Fig. 21.32).

A chamfer or a beveled shoulder is the acceptable finish line for better impression making and also improves esthetics.

d. *Incisal Reduction*

The reduction should be at least 1.0 mm, if desired to restore the original length. Reshaping at the edge without vertical reduction will suffice, if the teeth are to be lengthened.

In general, never end the incisal edge reduction in a position where excursive movements of the mandible will cause shearing stress across the junction of porcelain laminate and the tooth. This potentiates fracture of the porcelain, causes debonding, and subsequent exposure of the resin lute in the crucial area.

e. *Lingual Reduction*

Any reduction of the incisal edge may necessitate some lingual enamel modification, so that there is no butt joint at the incisal/lingual junction. This modification ensures:

- Increased thickness of porcelain in the lingual area; being used for incisal guidance.
- Enamel bonds at right angles to those on the incisal edges, and increased strength.

Impression and Temporization

Impression is made in routine using rubber base material. Interims are usually not required; only in a few cases, indirect acrylics can be fabricated.

(For details, refer author's book 'Indirect Restorations' IInd edition—Vimal K Sikri).

A case wherein ceramic laminates were placed in maxillary anterior teeth is shown in Fig. 21.33A to E.

Repair of Ceramic Restorations

The clinicians usually encounter fractured/defective ceramic restoration. Such defects are most common in metal fused to ceramic restoration; however, all-ceramic restorations may also fracture at margins, requiring repair.

Ceramic restorations cannot be repaired with ceramics; only composites can repair the defect, providing satisfactory results.

The step-wise procedure of repair of defect in ceramic restoration is as follows:

i. The concerned tooth is isolated (rubberdam is preferred; however, cotton roles can be effective in small defects).

Fig. 21.30: Tooth preparation for ceramic laminate: **(A)** Creating depth grooves; **(B)** Depth prepared; **(C)** Labial reduction following groove depth

Fig. 21.31: Proximal extension of laminate preparation

Fig. 21.32: Sulcular extension (margin placement)

Fig. 21.33: Ceramic laminates: **(A)** Preoperative (maxillary anterior teeth); **(B)** Teeth prepared for laminates; **(C)** Laminates on cast; **(D)** Laminates showing incisal and lingual aspect; **(E)** Postoperative (laminates placed)

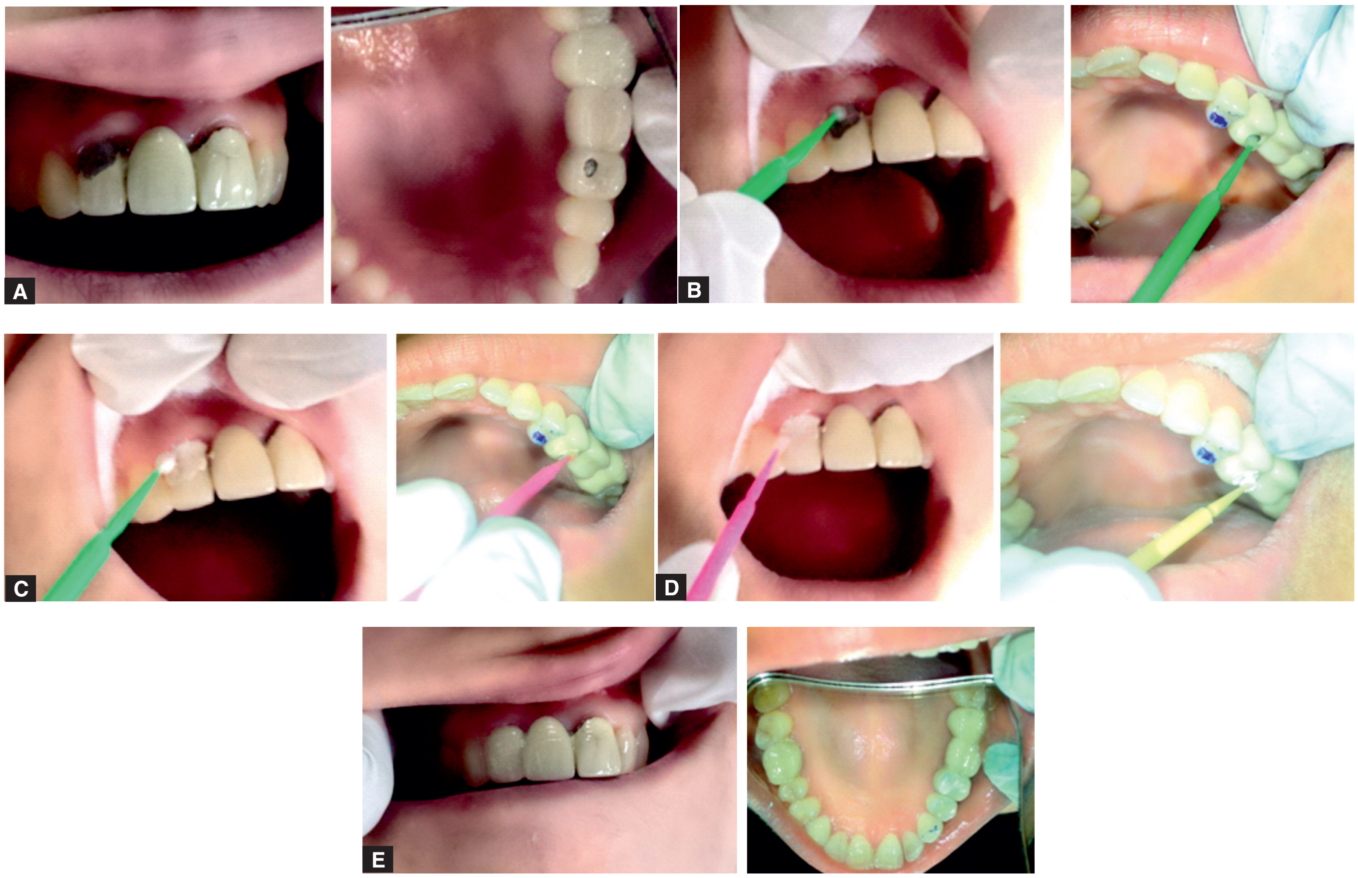


Fig. 21.34: Repair of ceramic restorations: **(A)** Preoperative; **(B)** Application of metal primer; **(C)** Application of bonding agent; **(D)** Application of opaquer; **(E)** Restoration repaired (postoperative)

ii. The area is cleaned of saliva or any other contaminants.
iii. Metal primer is applied over the exposed metal surface.
iv. The exposed area (metal and Ceramic) is coated with bonding agent.
v. Opaquer is applied over the metal surface.
vi. Area is filled with composite and merged with the existing restoration.
vii. The filled defect is finished and polished following manufacture's instructions.

The step-wise procedure of repair of defect in ceramic restoration is depicted in Fig. 21.34A to E.

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