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Part I: Comparative Analysis between Natural and Ceramic Teeth

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ABSTRACT

The aim of this study is to attain a general understanding regarding the developments in the composition and indications of ceramics in dental applications. An in-depth analysis of the evolution this material has undergone during the last century in order to obtain esthetic and functional dental prosthesis that replace natural teeth when they are missing.

MATERIALS AND METHODS

- Selected articles from the PubMed database. Ten scientific articles were selected.
- Key words: natural teeth, dental materials, dental ceramics, ceramic restorations.
- Selection criteria: 2000 to 2019
- Experts consulted: Professor Daniel Alter CDT/MDT, Professor Avis Smith CDT, experienced Ceramists.

INTRODUCTION

Dental Ceramic materials have physical and optical properties that attempt to mimic the properties of natural teeth. The fabrication of ceramic restorations for every case is a complex process due to the particularities that natural teeth exhibit. Dental technicians must work ceramic materials with the purpose of obtaining natural colors aiming to achieve proper esthetics, as well as functionality and durability. Valuable data for ceramic systems is becoming increasingly available and results can be obtained with many commercial materials, providing guidance, regarding proper indications, in order to obtain successful results. However, dental technicians are responsible for processing restorations that meet the particular and desired characteristics for each case, because they are to make the best decision with regards to the use of different ceramic materials.

RESULTS

Natural Teeth

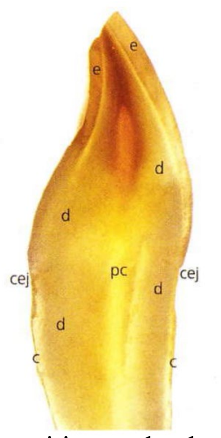

Figure 1. Tooth composition: pulp chamber (pc); enamel (e); dentin (d); cemento-enamel junction (cej); cementum (c)

Mature **enamel** is a **crystalline material**. Mature enamel is by weight **96% inorganic material, 1% organic material, and 3% water**. This crystalline formation consists mainly of **calcium hydroxyapatite/Ca10(PO4)6(OH)2**. CO3, Mg, K, Na, F are present in smaller amounts. The **ribbon-like crystals** of enamel are set at different angles throughout the crown area, each 30% larger than those in dentin. Enamel can endure crushing pressure of around **100,000 pounds per square inch**. Enamel appears **radiopaque (or lighter)**. Enamel alone is various shades of bluish white, which is seen on the incisal ridge of newly erupted incisors, but it turns various shades of yellow-white elsewhere because of the underlying dentin.

Mature **dentin** is a **crystalline material**. Mature dentin is by weight **70% inorganic material, 20% organic material, and 10% water.** This crystalline formation of mature dentin mainly consists of **calcium hydroxyapatite/Ca10(PO4)6(OH)2.** Small amounts of other minerals, such as carbonate and fluoride, are also present. The crystals in dentin are **plate like in shape.** Dentin also has **great tensile strength**, providing an elastic basis for the more brittle enamel. Because of the translucency of overlying enamel, the dentin of the tooth gives the white enamel crown its underlying **yellow hue**, which is a deeper tone in permanent teeth. Dentin appears more **radiolucent (or darker)**.

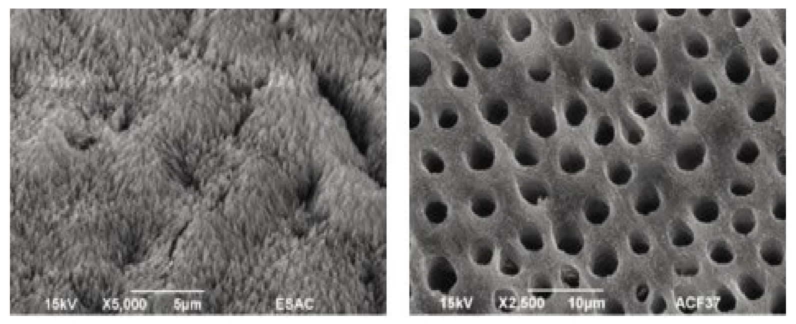

Figure 2. Structural Characteristics of Enamel (left) and Dentin (right)

Ceramic Teeth

Dental ceramics are characterized by their refractory nature, hardness, chemical inertness, biocompatibility and susceptibility to brittle fracture. They are usually referred as nonmetallic, inorganic structures primarily containing compounds of oxygen with one or more metallic or semi-metallic elements like aluminum, calcium, lithium, magnesium, phosphorus, potassium, silicon, sodium, zirconium & titanium.

Physical And Mechanical Properties. Ceramics and glasses are brittle, which means that they display a high compressive strength but low tensile strength and may be fractured under very low strain (0.1%, 0.2%) dental ceramics have disadvantages mostly due to their inability to withstand functional forces that are present in the oral cavity. The structure of porcelain depends upon its composition, surface integrity and presence of voids.

Table 1. Physical and Mechanical Properties of Dental Ceramics

Compressive strength	330 MPa
Diametral tensile strength	34 MPa
Transverse strength	62 - 90 MPa
Shear strength	110 MPa
MOE	69 GPa
Surface hardness	460 KHN
Specific gravity	2.2–2.3 gm/cm^3
Thermal conductivity	0.0030 Cal/Sec/cm^2
Thermal diffusivity	0.64 mm^2/sec
Coefficient of Thermal expansion	12 × 10-6/°C

Classification Of Dental Ceramics. Microstructure and Translucency are the two classifications to consider and focus on. However, dental ceramics classifications interrelate.

Table 1. Physical and Mechanical Properties of Dental Ceramics

CLASSIFICATION OF CERAMIC BASED MATERIALS	
Uses or indications	e.g. anterior, posterior crown, veneer, post and core, fixed prosthesis, ceramic stain, glaze
Composition	ceramics that are predominantly composed of glass, those made of particle-filled glass, and those consisting of polycrystalline
Principal crystal matrix phase	silica glass, leucite-based feldspathic porcelain, leucite-based glass ceramic, lithia disilicate-based glass-ceramic, leucite disilicate-based glass-ceramic, aluminous porcelain, alumina, glass-infused alumina, glass-infused-spinel, glass-infused alumina/zirconia
Processing method	casting, sintering, partial sintering and glass infiltration, slip casting and sintering, hot isostatic pressing, CAD-CAM milling and copy milling
Firing temperature	High-fusing (1,300°C), medium-fusing (1,101°C to 1,300°C), low-fusing (850°C to 1,100°C), and ultra-low-fusing (< 850°C)
Microstructure	**amorphous glass, crystalline, crystalline particles in matrix**
Translucency	**opaque, translucent, transparent**
Fracture resistance	Low, medium, hard
Abrasiveness	Comparison relative to enamel, against tooth enamel

Classification by Microstructure. At the microstructural ceramics are defined by the nature of their composition of glass-to-crystalline ratio. Ceramics can be broadly classified as non-crystalline (Amorphous Solids or glasses) and Crystalline ceramics. They can be broken down into four basic compositional categories, with a few subgroups:

1. Composition category 1 – glass-based systems (mainly silica)
2. Composition category 2 – glass-based systems (mainly silica) with fillers
3. Composition category 3 – crystalline- based systems with glass fillers
4. Composition category 4 – polycrystalline solids (alumina and zirconia)

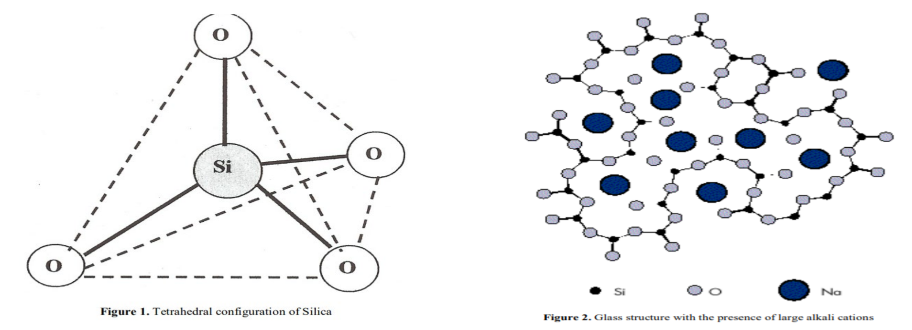

Figure 3. Dental Ceramics Based on Their Microstructure: (1) predominantly glass; (2) particle-filled glass; and (3) fully polycrystalline.

Classification by Translucency. A natural tooth derives most of its color as a result of the light reflectance from dentin that is altered by absorption and scattering by the enamel. Several factors affect the translucency of dental ceramics. Thickness of the material has the greatest effect, but translucency can also be affected by the number of firings, the shade of the substrate, and the type of light source or illuminant. Porcelain translucency is usually measured with the translucency parameter. or the contrast ratio (CR). The chemical nature, size, and number of crystals in a ceramic matrix will determine the amount of light that is absorbed, reflected, and transmitted compared with the wavelength of the source light.

Figure 4. Relation Between Translucency and Opacity

All teeth that are naturally covered by the enamel present opalescence. In ceramic systems, opalescence has been responsible to solve aesthetic problems making possible to produce unnoticeable restorations. The correct reproduction of opalescence involves careful observation of adjacent teeth and the selection and application of opalescent in appropriate locations.

Figure 5. Central Incisors Opalescence. Under Reflected Light (left). Under Transmitted Light (right)

Fluorescence is a luminescence phenomenon. Tooth fluorescence is usually associated with a blue-white chromatic appearance caused by the incidence of the UV wavelength. Under natural light, fluorescence makes teeth more luminous and shinier, giving them an internal luminescence. The incidence of UV wavelengths in a tooth restored with nonfluorescent material causes metameric failure and is responsible for highlighting the restorative material. Fluorescence must be present in restorative materials to obtain natural-looking results.

Figure 6. Central Incisors Fluorescence. Under Daylight (left). Under Black Light (Right)

DISCUSSION

The natural tooth section on the right is 0.55mm thick. From this cross section, it is easy to see the optical complexities of tooth structure. The feldspathic ceramic cross section on the left is 1.5mm thick. This cross section shows the different layers of material that are necessary to mimic natural teeth. The sample in the center is a replica of the left sample. It is made from monolithic zirconia. The zirconia cross section shows the optical challenges the dental technician faces when using this material to match teeth. Light scattering within homogenous monolithic materials makes the replication of teeth very difficult. Monolithic materials have gained in popularity, but present many esthetic challenges.

Figure 7. Natural Tooth Cross Section (Right). Fieldspathic Cross Section (Center). Zirconia Cross Section (right)

A shade value is taken when integrating tooth-colored restorative materials or artificial teeth or crowns within an individual dentition. The goal is to match the color of the patient's surrounding natural teeth as closely as possible. The optical properties of new generation porcelains mimic more closely the interaction of the natural dentition with light. The "illusion of reality" is developed by carefully blending opalescence, fluorescence, and translucency given by the composition of the dental ceramics to be used when fabricating ceramic prosthesis.

CONCLUSION

Dental ceramics is a material group that would continue to play a vital role in dentistry due to their natural esthetics and biocompatibility. However, there will always remain a compromise between esthetics and biomechanical strength. In order to achieve adequate mechanical and optical properties in the final porcelain restoration, the amount of glassy phase and crystalline phase has to be optimized. Good translucency requires a higher content of the glassy phase and good strength requires a higher content of the crystalline phase. For this reason, the two material phases need to be balanced. Success of the ceramic restoration depends on the collaborative work between dental clinicians and technicians and their ability to select the appropriate material to match intraoral conditions and esthetic demands.

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