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Introduction

Ceramics include a broad swath of materials in our world and are defined as neither metallic nor organic. Ceramic dental items have been produced from naturally occurring, inorganic minerals and purified chemicals using a bewildering array of formulas and forming methods, often with the aid of heat and sometimes pressure. Ceramic-containing dental products have been used for a vast range of procedures, including esthetic (biomimetic in appearance) replacements of teeth.

This text includes a potpourri of information on dental history, medical device regulation and standards, ceramic manufacturing, and clinical dental uses of ceramics. This text was constructed as an introduction to ceramic technologies that have improved oral public health. The dental ceramics described herein are based on history and praxis; theories for optimizing some property derivations are left to other texts and authors. Dental textbooks and review articles are included in the references for in-depth reading and learning clinical issues. Some morsels from each chapter may be useful for bioengineers of all types, inventors, and dental clinicians for future dental ceramics. Any dental ceramic product begins with an idea and a market need, abbreviated as business, as shown in Figure 1.1; quality and regulatory aspects combine with manufacturing methods to create products; clinical feedback on the products is often the spark for further improvements in this cycle.

Modern dental researchers and companies like to label the evolution of dental materials as “generations” to distinguish improved formulas and products as they become available (1, 2). The differences among generations can be confusing because researchers disagree on the classifications, the generations may overlap, some may not be the distinctions that a materials scientist would use, and others are inaccurate characterizations of materials’ distinctions. Therefore, descriptions of the materials were used herein in lieu of labeling the generations of the materials.

Dentistry’s progression spans three eras: ancient, 18th to 20th centuries, and the 21st century, as in Figure 1.2. Dental treatments have improved from merely extractions

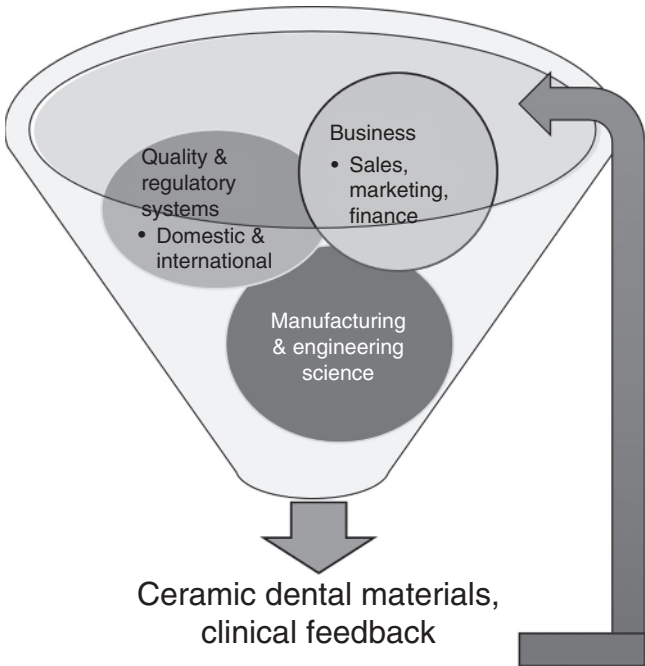


Figure 1.1 This diagram depicts the combination of disciplines required for ceramic dental materials production, and the importance of feedback from their clinical use for improvements.

Eras of dental practice

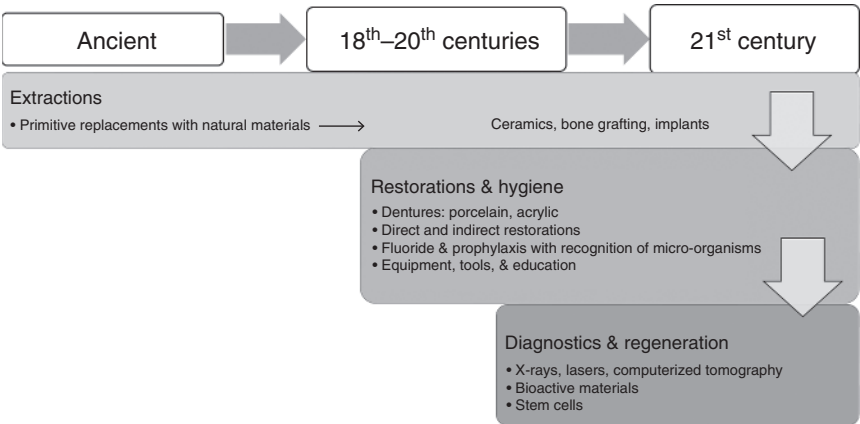


Figure 1.2 This diagram depicts the eras of dentistry over the millennia from primitive to restorative and preservation.

(ancient) to tooth treatments and tooth preservation (18th to 20th centuries), and diagnostics for regeneration (21st century). The emphasis is now on minimally invasive dentistry, supported by evidence-based medicine (EBM) (3): “the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients ... integrating individual clinical experience with the best available clinical evidence from systematic research.”

The goal of this text is to provide an éclaircissement of the intertwined history of ceramic formulas and manufacturing methods, to meet dental needs for all sorts of health problems and health maintenance.

Keywords and Materials in this Text

Alumina
 Bioceramic
 Bioactive
 Biomineralization
 Calcium aluminate cement
 Calcium phosphate
 Calcium silicate cement
 Calcium sulfate
 Cement
 Resin-based composite
 Glass
 Glass–Ceramic
 Glass ionomer cement
 Hydroxyapatite
 Lithium disilicate
 Porcelain
 Radiopacity
 Silica
 Zinc oxide
 Zirconia

Terminology

Following is a list of some of the common terms in dentistry used in this text. Other dental-related definitions are in various International Standards Organization Standards listed in Chapter 4 and ISO 1942 or ADA 33 standards on vocabulary.

- American Dental Association (ADA): a professional organization that supports the advancement of public health provided by the dental community, including standards for dentistry.

- Anterior teeth: teeth that are in the front of the mouth.
- Apical: the region at the end of the tooth root(s) in the jaw.
- Alveolar bone: the bone surrounding the tooth roots.
- Bridge: a prosthodontic device that spans more than one tooth.
 - Bridges may be fixed (cemented permanently) or removable (by the patient).
- Buccal: an adjective to describe the side of the tooth facing the cheek.
- Cement: a material used to affix a dental device onto a tooth. Examples of devices are crowns (caps), bridges, and orthodontic brackets.
 - A ceramic powder that reacts with water to form a hard substance; calcium silicate and calcium aluminate ceramic cements are water-setting cements used in some dental procedures but are not used for adhesion of devices unless combined with other materials.
- Cementing: affixing something in the mouth.
- Cementum: the outer layer of teeth below the gum lines, as part of the periodontium that allows attachment of alveolar bone to the teeth.
- Class of restoration: the location on the tooth where a restorative dental material is placed. See Chapter 2 for the locations.
- Compomer: restorative material that combines mainly resin composite with some glass ionomer components.
- Composite (resin-based composite-resin): a monomer with ceramic filler that the dentist cures on the tooth, also known as a resin composite, dental composite, or, colloquially, a “filling.”
- Coping: a thin, custom-made covering for the coronal portion of the tooth, as a base for another material used to create the anatomy of a crown or bridge.
- Core: the center coronal portion tooth that is needed to be the foundation for a crown.
 - A core may need to be “rebuilt” with dental materials in some decayed teeth.
- Coronal: the upper, outermost part of a tooth, protruding from the gums tooth.
- Crown: a dental device with tooth anatomy to cover the coronal part of a tooth that is missing.
 - Crowns replace the occlusal anatomy of one tooth, colloquially known as “caps.”
- Dental laboratories: a place where dental materials are processed into something for the dentist to use in the operatory where the patient is treated.
- Dentin: partially mineralized (calcium hydroxyapatite) tissue under the enamel, enveloping the dental pulp from the coronal to the apical area.
- Denture: a complete or partial replacement for missing teeth that is removable by the patient.
- Die: replica of one tooth, used in a dental laboratory for making a dental device.
- Direct restoration: a procedure where the dentist directly fashions the restorative material in the patient’s mouth, on their teeth.

- Enamel: a thin, translucent, outer covering of a tooth called the crown and is the visible part of the tooth in the mouth composed of hydroxyapatite.
 - Or a glassy coating on a metal or ceramic, also known as porcelain enamel.
- Endodontics: dental specialty that treats the pulp and the roots of teeth.
- Esthetic or cosmetic dentistry: related to imitating or improving the appearance of a patient's original tooth tissues in coloring, form, and texture, which may blend with or imitate surrounding teeth.
 - Use of biomimetic dental materials or methods to create the desired cosmetic results in the oral cavity, which may include teeth, the jaw, or soft tissues.
- Feldspathic porcelain: a misnomer for high thermal expansion porcelain containing leucite crystals in a glass matrix.
- Fixed prosthodontics: the crowns or bridges that are cemented in a patient's mouth, not removable by the patient.
- Furcal: the area under the coronal area of teeth where the roots diverge in multi-rooted teeth.
- Grain size: the size of crystals in a ceramic (or metal); sometimes, the size of powder particles.
- Glass-ceramic: glass items that have intentionally, been partially or fully devitrified (crystallized) under controlled conditions via a special heat treatment.
- Glass-ionomer restorative or cement (GI or GIC): a glass and polycarboxylate/polyacrylic acid material used for affixing dental devices to teeth and for restoring decayed teeth.
- Grain growth: the phenomenon during powder sintering where the particles coalesce and become larger.
- Hydroxyapatite: the calcium phosphate ceramic crystal that is the primary component of teeth and bones.
 - a naturally occurring mineral, $\text{Ca}_5(\text{PO}_4)_3(\text{OH})$ or $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$, abbreviated as HA or HAP; it may be partially carbonated, or partially fluoridated, with partial substitution for the hydroxide.
- Implant: a device that is placed in the alveolar bone that replaces the roots and the crown(s) of missing teeth.
- Indirect restoration: a dental procedure where the dentist shapes the tooth for a restorative material and that device is fashioned outside the mouth; also known as fixed prosthodontics.
- Interproximal: area between the teeth or the tooth structure between teeth.
- International Organization for Standardization (ISO): an independent, non-governmental organization that has developed 24,500 international standards covering almost all aspects of technology and manufacturing, including dentistry.
- Labial: the side of the teeth that is on the front of the anterior teeth, the side of the teeth most apparent when one smiles.

- Lingual: the side of the teeth facing the tongue.
- Luting: the process of cementing a device onto the tooth, usually considered to be mechanical and frictional, not chemical adhesion.
- Mandibular teeth: lower teeth.
- Margins: the edge of a dental restoration or device where it meets the underlying tooth structure.
- Maxillary teeth: upper teeth.
- Microleakage: the ingress of bacteria around the perimeter (margin) of a restoration, or through a root canal from which the pulp has been removed.
- Microstructure or microscopy: structure of a material as revealed by an optical or electron microscope.
 - Optical microscopy requires a flat sample; magnification is less than 1000x.
 - Electron microscopy is used in scanning or transmission modes.
- Mineral trioxide aggregate (MTA): a tricalcium silicate containing cement used for vital pulp therapy and other endodontic indications.
- Model: a replica of several teeth.
- Obturation: the filling of an area, especially the anatomy of the root canal.
- Occlusal: the biting surface of teeth.
- Occlusion: the contact between the upper and lower teeth.
- Odontoblasts: cells that line the pulp cavity of a tooth, from which dentin is formed.
- Operatory: area where the patient is treated and separate from the dental laboratory.
- Organic material: a material containing carbon–carbon (C–C) or carbon–hydrogen (C–H) covalent bonds.
- Orthodontics: dental specialty that moves the position of teeth and the jaws for better occlusion and appearance.
- Pediatric (and adolescent) dentistry: dental specialty that treats the primary teeth or developing permanent teeth.
- Periodontics: dental specialty that treats the tissues surrounding the teeth, including periodic cleaning and diseased tissue.
- Porcelain: a ceramic material consisting of glass and dispersed crystalline particles but not a glass–ceramic.
- Prosthodontics: the aspect or specialty of dentistry that treats missing teeth and extensive tooth anatomy.
 - Fixed prosthodontics: dental devices that are permanently cemented onto one or more teeth to replace missing teeth.
 - Removable prosthodontics: devices that replace missing teeth and may be removed by the patient for cleaning. The device may attach to remaining teeth, e.g., a removable partial denture. Full dentures are also removable prosthodontics.
- Pulp: a living tissue including blood vessels and nerves that circulate and service the teeth's sensations and connects to the body's nerve tissues and blood vessels through the apical foramen of the roots.

- Radiopacity: the quality of absorbing X-rays so that an item can be distinguished in an X-ray image enabling identification of dental materials, decayed teeth, tooth structure, infections, growths around the teeth, bone loss, or other oral health tissues.
- Radiopaque: materials having higher atomic number elements than calcium and phosphorous that absorb X-rays more strongly than dentin or enamel and appear whiter on an X-ray image.
- Resin-modified glass ionomer (RMGI or RMGIC): a combination of a dental resin-based composite material with some glass ionomer cement.
- Restoration or restorative material: a substance used by the dentist to replace the missing anatomy of a tooth.
 - Direct restorations: the material is applied and shaped in the mouth and set (hardened, cured) by a dentist.
 - Indirect restoration: a preformed restoration made outside the mouth that a dentist cements in the mouth.
- Scanning electron microscopy or microscope (SEM): use of an electron beam to create high depth-of-field images of surfaces, usually operated under vacuum.
 - Some SEMs use field emission electron beams, and some operate in air as environmental SEM.
 - Ceramic materials usually need a metallic or graphite coating to create clear images, unless a field electron microscope is used.
 - The images may be low to high magnification (>1000x).
- Sealer: a medium viscosity paste (syrup-like) that endodontists use for filling and sealing root canals after a pulpectomy (removal of the pulp).
- Sealant: a material used to fill the grooves (fissures) and pits of the occlusal part of teeth with the objective of inhibiting bacterial infection in these anatomical details.
- Sintering: the process of consolidating powders, ceramic or otherwise, to reduce the surface area of the powders, usually achieved by heating the powders.
- Transmission electron microscopy (TEM): an imaging technique that uses an electron beam passed through a very thin sample.
- Veneers: thin dental restorations, of ceramic or resin-based composite materials, cemented onto the labial side of anterior teeth to improve the smile's appearance by covering discoloration, restoring anatomy, or creating better alignment.

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