Chapter

Novel Prosthetic Solutions for High-Quality Aesthetics

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Abstract

Human teeth play an important role in facial aesthetics. The modern society trends for more and more demanding aesthetics strongly reflect in teeth appearance. Perfect shaped, aligned, and white teeth are considered the business card of an appealing smile. Fixed prosthetics not only aim to restore the lost function of human teeth but also their aesthetics. The ideal in this matter is to provide an indirect restoration that perfectly matches the neighboring teeth or aims to improve the overall appearance of the patient's teeth, depending on the situation. However, the choice of aesthetic materials and technologies has experienced a significant development in recent years. By far, dental ceramics are the state-of-the-art material when a high-quality indirect fixed prosthetic restoration is the goal. This chapter will provide information on this class of materials and their indications in fixed prosthodontics, focusing on novel manufacturing technologies, as well.

Keywords: fixed prosthetic restoration, dental ceramics, CAD/CAM milling, 3D printing

1. Introduction

Human teeth play an important role in facial aesthetics. The modern society trends for more and more demanding aesthetics strongly reflect in teeth appearance. Perfect shaped, aligned, and white teeth are considered the business card of an appealing smile.

Humans attempted to replace the lost teeth or to improve their look through teeth ornamentation since immemorial times. For instance, in ancient Egypt, "donated" teeth were tied to the patient's remaining teeth with golden wires. Mayans used to adorn their teeth with precious stones or even painted them [1]. In the Middle Ages, the main procedure to treat dental issues was extraction, so, prosthodontics made of ivory, precious metals, and other materials were imagined. However, only rich people could afford them, and played mostly an aesthetic role, because they were quite uncomfortable [2].

In the eighteenth century, Pierre Fouchard, the founder of modern dentistry, attempted to use posts, manufactured removable dentures retained by arches, and proposed covering damaged teeth with gold crowns, coated with porcelain, for aesthetic reasons. He founded the first workshop for dental prostheses, and trained jewelers as the first dental technicians. His vision opened the way for the first dental schools and for recognizing dental surgery as a separate medical profession [3].

In 1746, Claude Mouton used a post, retained in the root canal, covered by a gold crown [4], and in the late 1700s, Dubois de Chemant patented the "mineral paste" porcelain artificial teeth [5].

In 1825, in Philadelphia, commercial porcelain teeth were produced [6]. Later on, screw joint retention between the pontic and abutment was introduced by Winder, opening the way to bridge manufacturing [7].

Starting with the twentieth century, the evolution of fixed prosthodontics became fulminant. In 1903, Charles Land first introduced the porcelain jacket crown. In 1907, William Taggart described the lost wax technique, which was a cornerstone for prosthetic dentistry [8]. In 1926, Ante's law, postulated in 1926, still represents the standard principle for abutment selection [9]. The introduction of the high-speed by John Borden in 1957, operating at 300,000 rotations/minute, enabled much easier abutment preparation for fixed prosthodontics [10]. In 1962, porcelain fused to metal was introduced by Weinstein et al. [7]. In 1973, the Rochette bridge concept lead to the idea of minimal tooth reduction [11]. Starting in 1985, with the introduction of CAD/CAM systems, prosthetic dentistry experienced a tremendous transformation, both for patients and practitioners [12].

Fixed prosthetics not only aim to restore the lost function of human teeth but also their aesthetics, aiming to regain the patient's overall comfort and satisfaction. For a successful result, every detail should be considered, starting with the patient's interview, diagnosis, treatment plan, and subsequent phases, as well as follow-up once the restoration is placed.

The ideal in this matter is to provide an indirect restoration that perfectly matches the neighboring teeth or aims to improve the overall appearance of the patient's teeth, depending on the situation. In the quest for the best result, various dental materials for prosthetic restorations have been attempted over time, including rubber, porcelain, aluminum, and later plastic.

However, the choice of aesthetic materials and technologies has experienced significant development in recent years. By far, dental ceramics are the state-of-the-art contemporary material, when a high-quality fixed prosthetic restoration is the goal. This chapter aims to provide information on this class of materials and their indications in fixed prosthodontics, focusing on novel materials and manufacturing technologies.

2. Brief history of dental ceramics

Following Dubois de Chemant's "mineral paste" porcelain teeth, in the beginning of the nineteenth century, Giuseppangelo Fonzi developed single-tooth dental prostheses, held in place thru an embedded platinum pin. The porcelain material, "earth-metal" as he called it, to distinguish it from Chemant's type, was made available in 28 different colors [6].

The era of modern ceramic restorations begins in the 1900s when Charles Land patented the all-ceramic jacket crown, which, despite its low strength, was extensively used until the 1950s, when porcelain-fused-to-metal was developed by Abraham Weinstein [13]. This type of restoration provided adequate strength and reasonable aesthetics, however, diminished by the presence of the opaque layer.

Early air-fired dental porcelain consisted of large-size particle powders, resulting in entrapped air bubbles and increased porosity. Upon the emergence of vacuum-fired porcelain in the 1960s, its appearance improved, due to reduced internal porosity.

Adding leucite filler to feldspathic porcelain intended to tailor their thermal expansion/contraction behavior, to match it with the alloys they were fired on. It also contributes to slow crack propagation [14].

All-ceramic restorations gained interest once again in 1965 when John W. McLean attempted adding alumina (40–50%) to feldspathic porcelain, developing a new version of the all-ceramic jacket crown. Because of the alumina core, it had twice the strength of the traditional one, but still could be used only for anterior teeth. Its major drawbacks were due to high opacity, brittleness, and poor marginal adaptation [15].

During the 1980–1990s, several new ceramic technologies were introduced. Some of them were later abandoned, and some of them were further developed, resulting in the modern all-ceramic pressed and computer-aided design/computer-aided manufacture (CAD/CAM) systems.

The introduction of the Cerestore (Johnson & Johnson, New Brunswick, NJ, USA) "shrink-free" all-ceramic crown system and the Dicor (Dentsply International, York, PA, USA) castable glass-ceramic crown system in the 1980s provided innovative processing methods, such as pressing and centrifugal casting, and further stimulated the renewed interest for all-ceramic restoration. Both were later on abandoned, because of the high fracture incidence, doubled, in case of Dicor, by the difficult and high processing cost [16].

The high-leucite pressed ceramic IPS Empress 1 was introduced by Ivoclar Vivadent (Schaan, Liechtenstein) in the late 1980s. In this case, a heated ceramic ingot is being pressed into a mold, by means of a special pressing furnace (**Figure 1**). Despite its increased strength, IPS Empress 1 was still not suitable for usage in the posterior area, due to frequent fractures, but became popular due to ease of use and high aesthetic appearance. The second generation, IPS Empress 2, released in 1998, is a lithium disilicate ceramic, suitable for single and multiple-unit restorations of the anterior teeth. The IPS e.max system was introduced in 2005. It includes lithium-disilicate IPS e.max Press (Ivoclar Vivadent, Schaan, Liechtenstein), with high strength, which enables fabricating single-tooth restorations and bridges in the anterior and

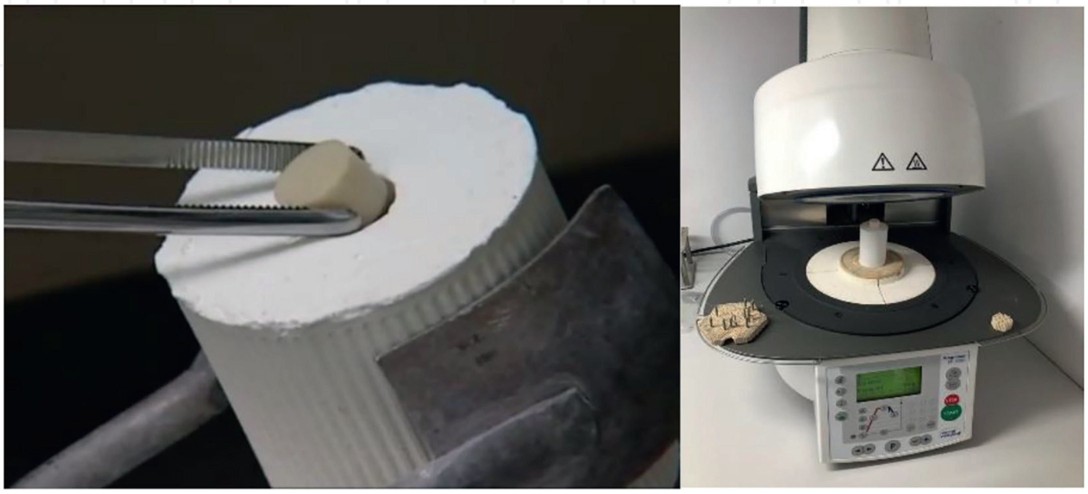

Figure 1.
Pressing of a ceramic ingot.

premolar area, as well as thin inlays, onlays, and veneers. The ingots are available in 4 levels of translucency and 2 sizes and are subsequently stained or layered for better aesthetic results [17].

Back to the year 1989, Vita developed the In-Ceram system (Vita Zahnfabrik, Bad Sackingen, Germany), initially consisting of a glass-infused porous alumina ceramic core, indicated for the anterior region. To increase its aesthetic appearance, the alumina core was later replaced with spinel, resulting in a restoration material suitable for the anterior teeth. The third variant of In-Ceram is zirconia, obtained by mixing alumina with zirconium oxide, gaining a doubled flexural strength, compared with the alumina type. Its indications include posterior crowns and bridges. Following sintering, the core is layered for gaining the final aesthetic result [18, 19].

Dental computer-aided design/computer-aided manufacture (CAD/CAM) applications also became available in the late 1980s-early 1990s. Since then, due to continuous developments, the CAD/CAM technology, either subtractive or additive, has metamorphosed itself not only in the greatest success of contemporary prosthodontics but also disseminated in other dental specialties, as well as in promising emerging domains, such as tissue engineering and regenerative medicine, with outstanding future applications in the dental field [20].

3. The CAD/CAM era

The godfather of digital dentistry and inventor of dental CAD/CAM is considered the French professor Francois Duret, who, in the 1970s, developed a CAD/CAM system capable to fabricate single-tooth restorations. The Duret system was later patented and marketed as the Sopha Bioconcept System, but it did not last long on the dental market, due to its cost and complexity [21].

The first viable dental CAD/CAM system was developed in 1987 by Werner Mormann and Marco Brandestini, under the name of Cerec (Sirona, Bensheim, Germany). It was initially chair-side, used to fabricate feldspathic ceramic inlays. The material used was Vita Mark I feldspathic ceramic (Vita Zahnfabrik, Bad Sackingen, Germany). The Cerec 1 milling unit used a grinding wheel. Short after, Cerec 2, equipped with an additional cylinder diamond, enabled manufacturing of partial and full crowns. Cerec 3 introduced the two-bur system, followed, in 2006, by the “step bur”, gaining high precision. In 2000, inLab, its sibling for the dental laboratory, was released. The Cerec dedicated software developed, as well, the two-dimensionally displayed design of Cerec 1 and 2 became three-dimensional in 2003, accompanying Cerec 3. The current version of Cerec is currently used worldwide, with a high rate of clinical success, and various choices of prosthetic restorations, including inlays, onlays, veneers, anterior and posterior crowns and bridges, copings, bridge frameworks, telescope crowns, bars, attachments, provisionals, denture bases, as well as implant mesostructures and surgical guides [22–24].

Another pioneer CAD/CAM system is Procera AllCeram (Nobel Biocare, Zurich, Switzerland), developed by Matts Anderson and Agneta Oden in 1993. Introducing a new ceramic material, consisting mainly of alumina, subsequently layered with a feldspathic ceramic, enabled the fabrication of strong and aesthetic all-ceramic single-unit restorations. Later on, it evolved to multiple-unit restorations, and zirconia copings, as well. However, the technique is extremely sensitive, as it uses enlarged dies to precisely match the shrinkage of the sintered copings. Currently, the centralized production Procera milling centers offer the advantage of possibility of producing high-quality restorations [25, 26].

Top dental manufacturers developed their own CAD/CAM milling systems, such as DCS Precident (Dental Concept Systems, Wesertal, Germany), Cercon (Dentsply Sirona, Charlotte, NC, USA), Arctica and Everest (KaVo, Biberach, Germany), Lava (3 M ESPE, Seefeld, Germany), ZenoTec (Wieland Dental, Pforzheim, Germany), and Tizian (Schutz Dental, Rosbach, Germany). Some started as only CAM or synchronous copy milling systems and have developed later on, adding up the CAD part and different milling units.

3D printing in dentistry was first used in the 1990s, but, until recently, ceramic materials were not suitable for this particular technology. Mainly, different types of resin-based materials and alloys were used for fabricating prosthetic restorations. By means of 3D printing, not only various prosthetics can be fabricated, but tissue constructs, as well [20].

CAD/CAM systems have three major components. The data acquisition unit collects the data from the area of the preparation, adjacent, and opposing structures by means of intraoral scanners. The collected data, either through intraoral scanning or indirectly, by scanning a conventional impression or a model (**Figure 2**) obtained by means of a conventional impression, are converted into virtual models. The second component is the software, used for designing the virtual restorations on the virtual model (**Figure 3**), then sending the data as an STL file and computing the milling parameters (**Figure 4**). Third, the milling machine is used for manufacturing the restoration from a solid block of restorative material (**Figure 5**). In case of CAD/CAM additive manufacturing, the third component is a 3D printing device.

Since its beginning, more than 30 years ago, CAD/CAM subtractive systems have undergone substantial changes [27]. The data acquisition methods evolved from optical cameras to contact digitization and laser scanning. Various intraoral and extraoral digitizing systems are currently available. Complex designing software and the 5-axis modern milling machines, the possibility of dry or wet milling choice, enable the fabrication of complex shapes, including fixed and removable prosthetic devices. The development of novel ceramic materials, such as alumina and zirconia, with

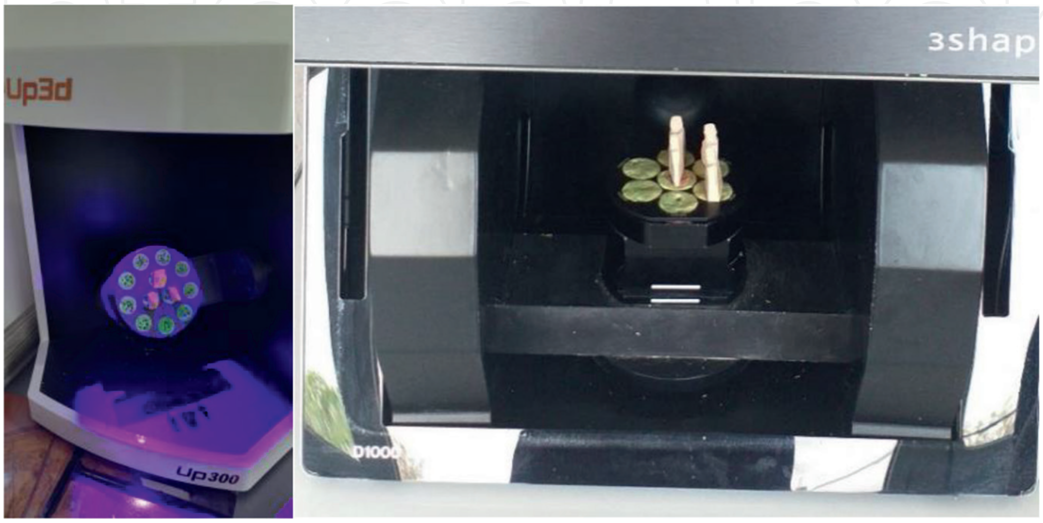

Figure 2.
Scanning of a model.

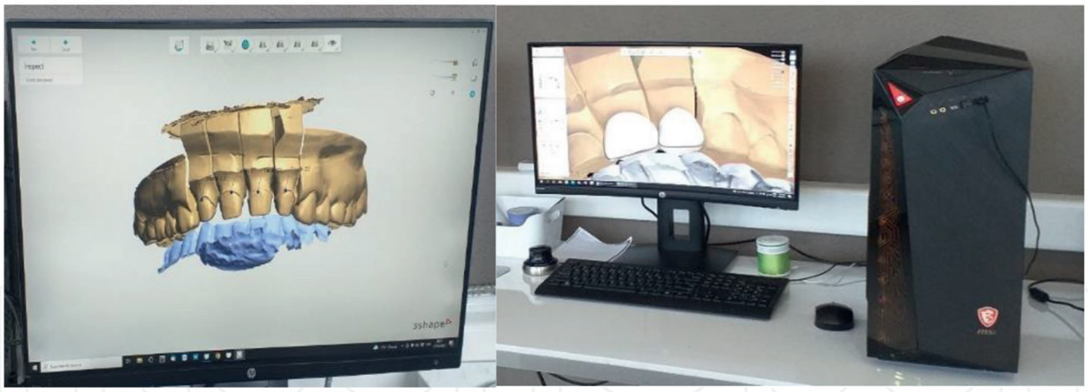

Figure 3.
Designing the restorations on the virtual model.

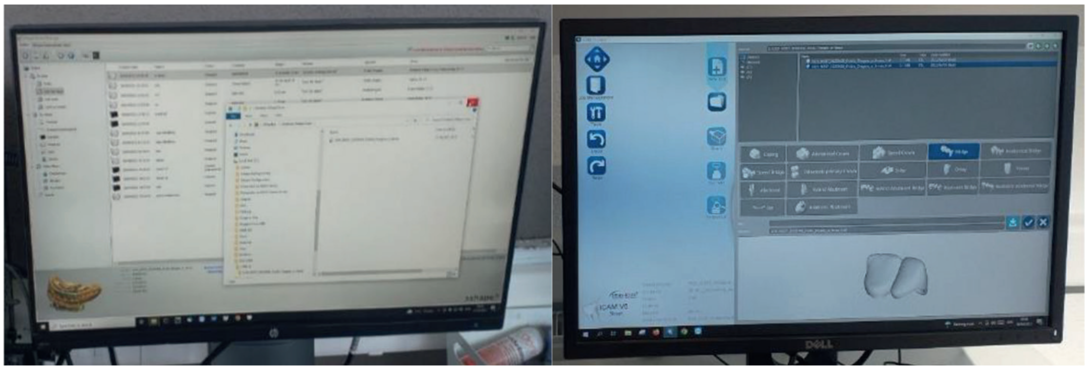

Figure 4.
Sending data, saved as an STL file, and choosing the milling parameters.

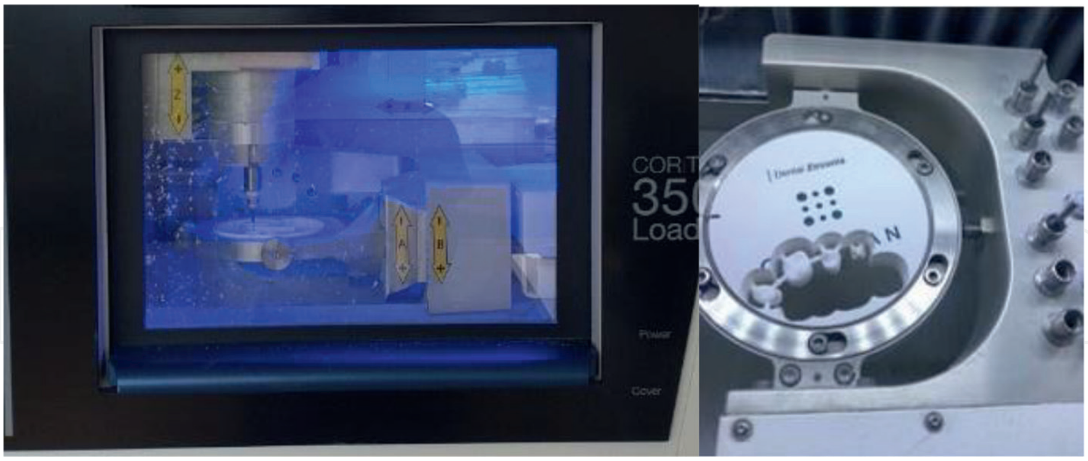

Figure 5.
Milling of a ceramic block.

high strength and excellent machinability, as well as extending the materials range to different types of alloys, resins, and composite materials, currently offers a wide range of possibilities. Integration of the technological advances resulted in the three categories of currently available CAD/CAM systems: chairside, laboratory (**Figure 6**), and centralized production milling centers.

Figure 6.
Components of a laboratory CAD/CAM system.

CAD/CAM can be classified into open and closed systems, according to data sharing. The workflow of closed systems does not permit interchangeability with other manufacturers' systems, the data acquisition scanner, virtual design software, and restoration manufacturing unit are provided by the same company. In case of an open system, the digital data generated by the scanner, transferred in a standard format, allows reading by different manufacturer's milling units, offering more versatility [28].

Automation of fabrication, increased quality, short manufacturing time, reduced infectious cross-contamination hazards, and minimized inaccuracies are some advantages offered by the CAD/CAM technology. One major disadvantage of the chairside and laboratory systems is the high initial cost, a large-scale production being necessary for the investment to pay off. The solution stands in the acquisition of a scanner, scanning and designing the restoration in the laboratory, and then transferring data to a centralized production milling center for fabrication. In case it is needed, subsequent layering is accomplished in the laboratory [28].

4. Ceramic materials for CAD/CAM systems

All-ceramic restorations may be classified as dual restorations (bicomponent or ceramo-ceramic), which consist of two chemically different types of ceramics, which are mechanically and aesthetically compatible, and monobloc restorations (single-component or monolithic), consisting of one type of ceramic. In case of dual ones, the milled ceramic framework is subsequently layered with the second type of ceramic, to finalize its form and aesthetic appearance. In case of monolithic restorations, only a surface makeup is used to ensure the aesthetics [29].

The large choice and structural variety of all-ceramic materials for CAD/CAM systems may represent a tough dilemma, as no material is ideal for all clinical situations, and the selection of the best option is of most importance for accomplishing the best prosthetic restoration [30].

According to their chemical nature, milled ceramics are classified into four categories: vitreous ceramics, glass-infiltrated ceramics, polycrystalline ceramics, and resin matrix ceramics.

4.1 Vitreous ceramics

Vitreous ceramics are further divided into feldspathic ceramics and reinforced glass ceramics.

4.1.1 Feldspathic ceramics

Feldspathic ceramics, consisting of vitreous and crystalline phases, were the first used for CAD/CAM, as Vita Mark I blocks (Vita Zahnfabrik, Bad Sackingen, Germany) for Cerec (Sirona, Bensheim, Germany), but their unsatisfactory clinical performance leads to the development of monochromatic, multiple shade Vita Mark II blocks and the multi-layered Triluxe, Triluxe Forte, and Real Life (Vita Zahnfabrik, Bad Sackingen, Germany), with better mechanical properties, but still only indicated for inlays, onlays, veneers, and anterior crowns. The main plus of feldspathic ceramics is their remarkable aesthetics, due to a blend of luminosity, shade, and saturation [30].

4.1.2 Reinforced glass ceramics

Reinforced glass ceramics contain different minerals: leucite, lithium-disilicate, or zirconia, as fillers, in their crystalline phase.

Empress ProCAD (Ivoclar Vivadent, Schaan, Liechtenstein) was the first block of leucite-reinforced glass ceramic, introduced in 1998, and substituted in 2006 by Empress CAD (Ivoclar Vivadent, Schaan, Liechtenstein), which contains 35–45% fine size leucite particles. It has better resistance to machining, but due to low resistance to flexion, its indications are limited to veneers and anterior crowns. Three types of blocks are available: low and high-translucency and multi.

The lithium disilicate-reinforced glass ceramic, provided in a pre-crystallized stage, is easily milled, and subsequently crystallized in the oven. The blue-colored IPS e.max CAD (Ivoclar Vivadent, Schaan, Liechtenstein) blocks thus gain the shade and translucency of choice. The resistance to flexion is three times higher than that of the leucite-reinforced type. Its indications include veneers, inlays, onlays, anterior and posterior crowns, and even three-unit anterior bridges, extending to the premolar area [31].

In 2013, lithium silicate-reinforced glass-ceramic doped with zirconium dioxide was released, aiming to combine the properties of the components. It has proven to display a higher mechanical resistance to the propagation of fissures in comparison with the lithium disilicate-reinforced glass ceramic, because of the inclusion of 8–10% zirconium dioxide particles. Two commercial products are Celtra Duo (Dentsply Sirona, Charlotte, NC, USA), in a completely crystallized form and Vita Suprinity (Vita Zahnfabrik, Bad Sackingen, Germany), in a partially crystallized phase, requiring an additional crystallization treatment after milling. It has better translucency compared to lithium disilicate-reinforced glass ceramics and is indicated for veneers, inlays, onlays, and anterior and posterior crowns [32].

4.2 Glass-infiltrated ceramics

The blocks for CAD/CAM milling, belonging to this category, were introduced in 1993, based on the original In-Ceram Alumina, Spinel, and Zirconia ceramics (Vita Zahnfabrik, Bad Sackingen, Germany), with indications for crowns and bridges frameworks, up to three elements, depending on the type. Subsequently, layering with a feldspathic ceramic is needed to obtain the final form and aesthetics [33].

4.3 Polycrystalline ceramics

Due to the fact that this type of ceramic is integrally composed of oxides, and does not include a vitreous matrix, they are characterized by excellent mechanical properties, as their dense crystal network opposes the propagation of fissures. It comprises of two types: alumina-based and zirconia-based.

4.3.1 Alumina-based polycrystalline ceramics

Alumina-based polycrystalline ceramics, introduced by Procera AllCeram system (Nobel Biocare, Zurich, Switzerland), consist of more than 99.5% aluminum oxide.

Vita In-Ceram AL for inLab (Vita Zahnfabrik, Bad Sackingen, Germany) pre-sintered blocks consist of the same type of ceramic. They are easily processed, resulting in enlarged bridge and crown frameworks. Shrinkage occurs during the subsequent dense sintering process in a high-temperature furnace. The highly stable and precision-fit frameworks are indicated for anterior and posterior crowns and short anterior bridges, and are to be layered with corresponding ceramic [26].

4.3.2 Zirconia-based polycrystalline ceramics

Zirconia is a polymorphic material, showing three temperature-depending crystallographic phases: monoclinic (from room temperature up to 1170°C), tetragonal (from 1170 to 2370°C), and cubic (from 2370 to 2716°C). Noticeable volumetric changes are associated with these transformations. When sintered above 1170°C, during the monoclinic to tetragonal transformation, a 5% decrease in volume occurs. At cooling, the reverse phenomenon takes place, the change from tetragonal to monoclinic phase is accompanied by a 3–4% volume expansion, leading to a subsequent high level of stress within the sintered material, which often leads to fracture [34] (**Figure 7**).

In order to force it to maintain its tetragonal and/or cubic phases until reaching room temperature, stabilizing oxides: CeO_2, MgO, CaO, or Y_2O_3 have been added.

This allows the generation of the multiphase partially-stabilized zirconia (PSZ), consisting, at room temperature, of cubic zirconia as the major phase, with monoclinic and tetragonal zirconia precipitates as the minor phase [35].

The presence of a small amount of stabilizing oxides, such as 2–3% mol of Y_2O_3, at room temperature, enables obtaining a monophasic material, which consists of tetragonal structured crystals only, known as tetragonal zirconia polycrystal (TZP) [30]. The Y-TZP zirconia blocks are frequently used materials for CAD/CAM dental applications, because of their high mechanical properties and thermodynamically metastable tetragonal phase [36].

Figure 7.
Temperature-related phase transformation of zirconia.

Zirconia has the capacity of auto-reparation, which makes it resistant to crack propagation. The mechanism is as follows: a propagating crack applies stress, which determines the transformation of the tetragonal particles into monoclinic ones. The phase transformation is accompanied by a 3–5% increase in volume, which results in compression at the crack tip, stopping and squeezing the fracture, and shielding it from its surroundings. This capacity to transform in response to stress makes zirconia a smart material [37].

The high flexural strength of Y-TZP and its fracture resistance recommend it as an alternative to metallic frameworks, with indications for long-range prosthetic pieces [36].

Because of its lower translucency, compared to glass ceramics, initially, the zirconia infrastructure was designed to be layered with feldspathic ceramic, but a relatively high percentage of fracture of the layering ceramic was detected (**Figure 8**). In order to solve the problem, monolithic restorations were attempted (**Figure 9**). Monochromatic

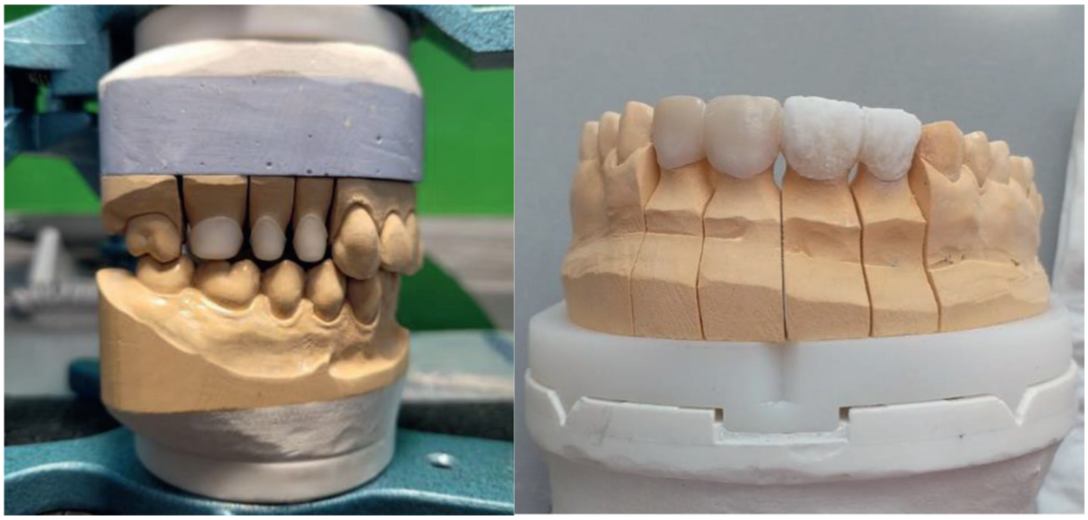

Figure 8.
Layering of a zirconia framework.

Figure 9.
Monolithic zirconia crown (1.6) and zirconia framework to be layered with feldspathic ceramic (2.6).

blocks, which can be colored if needed, and polychromatic zirconia blocks, which imitate the variation in color from dentin to enamel were put on the market. The first polychromatic zirconia block, Katana Zirconia ML, was released in 2013 by Kuraray Noritake (Tokyo, Japan). Much more, different types of zirconia blocks with increased translucency, such as Lava Plus (3 M ESPE, Seefeld, Germany), Cercon ht. KL (Dentsply Sirona, Charlotte, NC, USA), Zenostar T (Wieland Dental, Pforzheim, Germany), and Vita YZ HT, ST, XT (Vita Zahnfabrick, Bad Sachingen, Germany) are currently available. Another possibility is pressing fluorapatite glass-ceramic ingots onto CAD/CAM milled zirconia frameworks: IPS e.max ZirPress (Ivoclar Vivadent, Schaan, Liechtenstein), which allows pressing onto IPS e.max ZirCAD (Ivoclar Vivadent, Schaan, Liechtenstein), Zenostar Wieland Dental (Pforzheim, Germany), and other zirconia frameworks with a CTE of 10.5–11.0. The press-on technique is indicated for multi-unit bridges and crowns and implant superstructures [38–40].

Three chemically identical types of zirconia are available for dental application, characterized by slightly different physical properties: green stage, pre-sintered, or the completely sintered blocks. The zirconia powder is shaped into ceramic preforms using cold isostatic pressing, producing chalk-like non-sintered, green-stage Y-TZP blocks. Further stabilizing and condensing by sintering in special furnaces, results in pre-sintered blocks. Additional compression by hot isostatic pressing (carried out at 1000 bar and 50°C below the sintering temperature) removes residual porosity, resulting in dense, fully-sintered zirconia blocks, usually of gray-black shade, requiring subsequent oxidizing to restore their whiteness [41].

Green-stage zirconia blocks can be milled using dry milling and carbide burs, pre-sintered zirconia blocks require wet milling and carbide burs, and fully-sintered zirconia blocks need diamond burs and wet milling.

Green and pre-sintered zirconia frameworks need milling in an enlarged form to compensate for the sintering shrinkage, and can be individualized by pigmentation, in the green-stage faze (**Figure 10**). The sintering takes place in special furnaces (**Figure 11**) [42].

Each type of zirconia has its advantages and disadvantages. Fully-sintered zirconia is denser, with less porosity and increased resistance to fracture. On the other hand, milling of fully-sintered zirconia is time-consuming, causes greater wear of the milling device, and is more expensive [43].

Figure 10.
Zirconia blocks before and after staining and sintering. The shrinkage is easily observed.

Figure 11.
Sintering zirconia frameworks.

4.4 Resin matrix ceramics

Resin matrix ceramics, specially designed for CAD/CAM milling, were intended to match the elastic modulus of dentin. They are easily milled and adjusted, compared to CAD/CAM ceramics. Resin matrix ceramics consist of an organic matrix reinforced by inorganic filler particles [44, 45].

The three types of resin matrix ceramics are resin nano ceramic, glass-ceramic in a resin interpenetrating matrix, and zirconia-silica ceramic in a resin interpenetrating matrix.

Resin nanoceramics: Lava Ultimate (3 M ESPE, Seefeld, Germany) is indicated only for inlays, onlays, and veneers. Glass-ceramic in a resin interpenetrating matrix: Vita Enamic (Vita Zahnfabrik, Bad Sackingen, Germany) is described as a hybrid ceramic, consisting of a paired polymer network and feldspathic ceramic, in 86:14% ratio. It is indicated for crowns, inlays/onlays, veneers, and contraindicated for bridges, in cases of para-functional habits. Zirconia-silica ceramic in a resin interpenetrating matrix: Paradigm MZ100 (3 M ESPE, Seefeld, Germany) was introduced in 2000. It has 85% inorganic content, consisting of ultrafine zirconia-silica ceramic particles and 15% organic polymer matrix, and a patented ternary initiator system. In fact, it is a factory-processed version of the Z100 restorative resin¸ indicated for inlays, onlays, veneers, and crowns [46–48].

4.5 3D printed ceramics

The subtractive method has the advantage of using homogenous materials, but its major drawbacks result from material loss and high costs. Additive manufacturing or 3D printing is an alternative technology that addresses the drawbacks of subtractive manufacturing in the CAM step. In this case, the prosthetic devices are fabricated by layering materials, and it enables manufacturing of ceramic, as well as polymeric materials and alloys, with lower costs [49].

Zirconia ceramics are suitable for 3D printing by different technologies: vat photopolymerization (stereo-lithography and direct light processing), selective laser sintering, material jetting, fused deposition modeling, enabling fabricating crowns, bridges, and implants [50].

Vat Photo-polymerization uses a slurry of fine ceramic particles incorporated in a photo-curable solution. Because ceramic particles are inert to light emission, polymerization occurs exclusively in the organic phase, resulting in uniformly dispersed ceramic particles in the organic network. Each layer is photo-polymerized until the full 3D ceramic prosthetic is constructed. Following, de-binding is carried out to remove the remaining organic resins and sintering, which removes the pores between the particles, resulting in fully dense, high-performance zirconia prosthodontics [51].

Selective laser sintering (SLS) uses powder beds containing loose ceramic particles to construct the prosthetic restoration. The ceramic powders are either combined with a polymer binder, or no polymer binder is employed. In the first case, the laser melts the binder, bonding the ceramic particles together, followed by de-binding and sintering. In the second case, the laser beam directly sinters the ceramic particles, no further de-binding or sintering is required. Because of its high melting point, zirconia is difficult to process by SLS, and thermal stress might result in cracks development [49].

Material jetting technology allows manufacturing of ceramic restorations with full density, low porosity, high accuracy, complicated shapes, and minimal material usage at a low cost. It uses a suspension of ceramic particles, in form of droplets, which are selectively deposited onto a substrate by the print nozzle. When the droplets come in contact they experience a phase transition and solidify. The low porosity results in the formation of a solid portion [52].

Fused deposition modeling is a material extrusion-based technique, in which the ceramic material, in a filament form, is heated and extruded through a nozzle. It needs de-binding and sintering for densification. The flexible ceramic filament is difficult to obtain, because of the brittle nature of polymer binder and ceramic powder mixture. Surface roughness is the main concern for this technique [49].

5. Conclusion

Duret's prediction regarding CAD/CAM, made in 1991: "The systems will continue to improve in versatility, accuracy, and cost-effectiveness, and will be a part of routine dental practice by the beginning of the twenty-first century," proved to be accurate [53].

The evolution of CAD/CAM systems provided increasing user-friendliness, improved quality and complexity, a wide range of applications, and extended capabilities. The new classes of ceramic materials, specially designed for usage with CAD/CAM systems, enable fabrication of aesthetic and functional crowns and bridges [54].

The modern demands for aesthetic and function have channeled the evolution of fixed prosthodontics in seeking new paths of restoring patients' comfort and health, doubtlessly, will reflect in the future perspectives of this field.

Conflict of interest

The authors declare no conflict of interest.

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