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Review

Ceramic dental biomaterials and CAD/CAM technology: State of the art

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ABSTRACT

Purpose: Ceramics are widely used as indirect restorative materials in dentistry because of their high biocompatibility and pleasing aesthetics. The objective is to review the state of the arts of CAD/CAM all-ceramic biomaterials.

Study selection: CAD/CAM all-ceramic biomaterials are highlighted and a subsequent literature search was conducted for the relevant subjects using PubMed followed by manual search.

Results: Developments in CAD/CAM technology have catalyzed researches in all-ceramic biomaterials and their applications. Feldspathic glass ceramic and glass infiltrated ceramic can be fabricated by traditional laboratory methods or CAD/CAM. The advent of polycrystalline ceramics is a direct result of CAD/CAM technology without which the fabrication would not have been possible.

Conclusions: The clinical uses of these ceramics have met with variable clinical success. Multiple options are now available to the clinicians for the fabrication of aesthetic all ceramic restorations.

Contents

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1. Introduction

Ceramics used in dentistry are mostly based on silicon, Si, and usually in the form of silica (silicon dioxide), SiO_2, or various silicates. Silicates consist of Si-tetrahedrons (SiO_4) as built-up units. The use of all ceramic prosthesis in restorative treatments has become popular and many of these restorations can be fabricated by both traditional laboratory methods and CAD/CAM machination [1–4]. The traditional methods of ceramic fabrication have been described to be time-consuming, technique sensitive and unpredictable due to the many variables and CAD/CAM may be a good alternative for both the dentists and laboratories [3]. CAD/CAM may also reduce the fabrication time of high strength ceramics such as InCeram^{TM} (Vita Zahnfabrik, Bad Sackingen, Germany) by up to 90% [2]. Furthermore, industrially fabricated blocks are more homogenous with minimal flaws and CAD/CAM restorations have been found to compare favourably with other restorative options [5,6]. We may say that the advances in CAD/CAM technology are instrumental in the research and development of high strength polycrystalline ceramics such as stabilized zirconium dioxide [7,8] which could not have been practically processed by traditional laboratory methods [9,10]. These materials have made possible the use of all ceramic crowns and short span bridges in posterior load bearing regions [3,11,12]. In this review, we make an overview on materials used in dental CAD/CAM technology.

2. CAD/CAM glass ceramics

2.1. *CAD/CAM-compatible feldspathic ceramics*

The first CAD/CAM produced inlay was fabricated in 1985 using a ceramic block comprising fine grain feldspathic ceramic (Vita^{TM} Mark I, Vita Zahnfabrik, Bad Sackingen, Germany) [13]. The block was fully sintered for hard machining. The clinical performance of these CAD/CAM inlays and onlays was evaluated in a 10-year prospective study and a success rate of 90.4% was achieved [14]. However, a much higher breakage rate of up to 36% after 2 years was also reported [1].

Vita^{TM} Mark II (Vita Zahnfabrik, Bad Sackingen, Germany), introduced specifically for CEREC (Cerec^{TM} 1 – Siemens GmbH, Bensheim, Germany) in 1991, exhibited better mechanical properties [2] with a reported flexural strength from about 100 MPa [15] to 160 MPa when glazed [16]. Vita^{TM} Mark II blocks are made of materials similar to the conventional feldspathic ceramic but produced in a different process known as *extrusion moulding*. A plasticized ceramic mixture is pressed and extruded through a nozzle to give its form. The blocks are then dried over several days before sintering [17]. Clinical studies of Vita^{TM} Mark II inlays showed survival rates of 94.7% after 5 years, 90.6% after 8 years and 85.7–89% after 10 years [18–20]. An *in vitro* study of mandibular crown specimens machined out of Vita^{TM} Mark II blocks using Cerec^{TM} 3 (Sirona Dental Systems, Bensheim, Germany) showed that the marginal gap within the range of 53–67 μm could be achieved [21].

Vita^{TM} Mark II is monochromatic but available in multiple shades. The newer Vitablocs^{TM} TriLuxe^{TM}, Triluxe^{TM} Forte and RealLife^{TM} blocks (Vita Zahnfabrik, Bad Sackingen, Germany) contain multi-shade layers and offer a gradient of colour and translucency. Cerec^{TM} Blocs (Sirona Dental Systems, Bensheim, Germany) are similar in structure to Vita^{TM} Mark II but use a different shading system. They are also available in aesthetically pleasing multi-shade blocks.

The traditional type of dental porcelain is based on feldspar and comprises a tectosilicate mineral feldspar ($KAlSi_3O_8$), quartz (SiO_2), or kaolin ($Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O$). These feldspathic ceramic materials have excellent aesthetic properties [16] and have been recommended for use in fabricating veneers [22], inlays/onlays [14,19,20] and single anterior [23] and posterior [17] crowns. However, the material is not considered to be strong enough for posterior load bearing areas [24] although, when used in premolar region, the fracture load was found to be similar to natural teeth [24,25]. In addition, a cumulative survival rate of 94.6% after 55 months was reported when Vita^{TM} Mark II molar crowns were examined [26]. Feldspathic ceramics may be bonded to tooth tissues using a combination of airborne particle abrasion (50 μm Al_2O_3), followed by etching with hydrofluoric acid (HF) [27–29] and the use of a silane coupling agent [30,31] which is used to bond dissimilar materials.

2.2. *CAD/CAM and mica-based ceramics*

The mica minerals are a group of sheet silicate (so-called phyllosilicate) minerals, consisting of varying complicated formulae of Si, K, Na, Ca, F, O, Fe and Al [29]. Dicor^{TM} (Dentsply, York, USA) is a mica based glass ceramic marketed for both laboratory ceramming and machining. The machinable version Dicor^{TM} MGC is industrially produced and has up to 70% crystalline phase, as compared to the 45% crystalline content of Dicor^{TM} which may explain the reported increased flexural strength to about 229 MPa [32]. Its machinability is made possible by the presence of tetrasilicic fluormica, $K_2Mg_5Si_8O_{20}F_4$, crystals which are highly interlocked within the glassy matrix [33]. It has been shown that Dicor^{TM} MGC and Vita^{TM} Blocs were very similar in clinical performance [18,34] but its cumulative breakage at 2 years was found to be higher than for Vita^{TM} Mark II [1] Although both Dicor^{TM} and Dicor^{TM} MGC were very well studied, the materials are no longer in the market.

2.3. *CAD/CAM with leucite-reinforced ceramics*

ProCAD^{TM} (Ivoclar-Vivadent, Schaan, Liechtenstein) was introduced in 1998 to be used with the CEREC^{TM} inLAB (Sirona Dental Systems, Bensheim, Germany). It is a leucite reinforced ceramic, similar in structure to the heat pressed ceramic Empress^{TM} (Ivoclar-Vivadent). The marginal gap, internal fit and fracture load also compared favourably with Empress^{TM} in an *in vitro* study [35]. In a clinical study of partial crowns observed for 1–4 years, no fracture was reported with a survival rate of 100% after 2 years [36]. A mid-term evaluation of a 5-year clinical split-mouth investigation of all-ceramic partial coverage on molars reported a survival rate of 97% after 3 years [37]. Empress^{TM} CAD (Ivoclar-Vivadent), introduced in 2006, is the successor to Empress^{TM} ProCAD. Its main difference is in the optimizing manufacturing procedure and it has about 45% leucite with a finer particle size of about 1–5 μm that helps resist machining damages [38]. The main components therefore correspond to IPS Empress (Ivoclar-Vivadent) but the powder is first pressed into blocks and then sintered. It was developed for chair-side single unit restorations and has a flexural strength of about 160 MPa. Clinically it is recommended for single tooth restorations and is available in High Translucency (Empress^{TM} CAD HT), Low Translucency (Empress^{TM} CAD LT) and polychromatic (Empress^{TM} CAD Multi) blocks. The milled restoration can in the next step be stained and glazed. Another example in this category is Paradigm^{TM} C (3M ESPE, Seefeld, Germany).

2.4. *CAD/CAM milling lithium disilicate reinforced ceramics*

Lithium disilicate, Li_2SiO_5, glasses have their flexure strength between 350 MPa and 450 MPa. This is higher than that of leucite-reinforced dental ceramics [17,28]. A lithium disilicate CAD/CAM ceramic IPS^{TM} e.max CAD (Ivoclar-Vivadent) was introduced in 2006 and is a chair-side monolithic restorative material. The blocks are manufactured in a process based on the so-called pressure-casting procedure used in the glass industry. They are available in A–D and Bleach shades as well as in 3 translucencies (one of which is of medium opacity) and are supplied in a pre-crystallized so-called blue state. The blue ceramic contains metasilicate and lithium disilicate nuclei and exhibits a flexural strength of 130 ± 30 MPa. At this state, the block can be easily milled after which the restoration is re-crystallized in a chair-side ceramic oven at 850 °C in vacuum for 20–25 min. During this heat treatment, the metasilicates are dissolved, lithium disilicate crystallizes and the ceramic is glazed at the same time. The block also changes from blue to the chosen shade and translucency. In this state, the ceramic contains 70 vol% of crystals of approximately 1.5 μm in size and the strength increases dramatically to 360 MPa [39]. Laboratory studies have shown that fully anatomical e.max^{TM} CAD crowns may be resistant to fatigue in cyclic loading [40] and that its fracture load is significantly higher than the one for ProCAD^{TM} and Empress^{TM} CAD [41]. The material has been recommended for use in fabricating inlays, onlays, veneers, anterior and posterior crowns and implant supported crowns [42]. So far, few clinical studies on e.max^{TM} CAD are available to provide evidence for the recommendations but reports from short term clinical trials on single crowns showed survival rates between 97.4% [43] and 100% [44], after two years. It has been reported that silane [28,31] treatment followed by hydrofluoric acid etching enhances the microtensile strength when bonded to tooth structure [45].

2.5. *CAD/CAM and glass infiltrated alumina and zirconia ceramics*

The Vita^{TM} InCeram Classic group of ceramics (InCeram^{TM} Alumina, Spinell and Zirconia, Vita Zahnfabrik, Bad Sackingen, Germany) are slip cast, glass infiltrated ceramics that have at least two interpenetrating phases intertwined throughout the material. Alumina (Al_2O_3) and zirconia (ZrO_2) are discussed in more details below. The materials can also be fabricated by CAD/CAM machination since 1993. The blocks are manufactured by *dry pressing* the ceramic powder into a mould and compacted until the open pore microstructure is reached. The number of macro-pores is lower but more homogenous as compared to slip-casting technique [46]. The material is then sintered and infiltrated by La-glass. The flexural strength for InCeram^{TM} Alumina, Spinell and Zirconia were reported to be 450–600 MPa, 350 MPa, and 700 MPa, respectively [16]. After the substructure is milled, veneering composite is applied for characterization. CAD/CAM InCeram^{TM} Spinell has been reported to yield survival rates of 91.7% [23] to 100% [47] after 5 years. It is the most translucent material of the group and is recommended especially for anterior crowns. CAD/CAM InCeram^{TM} Alumina has been recommended for single anterior and posterior crowns. It was reported a survival rate of 92% after 5 years for premolar and molar crowns fabricated with a CEREC^{TM} 2 system (Sirona, Beinsheim, Germany) [47]. It was reported a lower survival rate of 87.7% for posterior InCeram^{TM} crowns fabricated using the GN-I system^{TM} (GC, Tokyo, Japan) [48]. Another study using the same system reported the mean marginal gap for anterior, premolar and molar crowns of 66.8 μm [49], which was considered clinically acceptable. The manufacturer also recommends its use as anterior bridge substructures with no more than one pontic unit.

Acid etchants have no appreciative effects on aluminium trioxide (Al_2O_3) [28,50] and conventional cements such as glass ionomer cement has been suggested for luting [51]. Air particle abrasion with 50 μm aluminium trioxide with the use of tribochemical silica-coating [30,31] for bonding to a silane coupling agent [31] have also been suggested to be effective [50,52,53].

CAD/CAM InCeram^{TM} Zirconia is an example of glass infiltrated zirconia (ZrO_2) toughened alumina (ZTA) and has the highest strength of this group of materials [54]. However, the opacity of zirconia has limited its use to the posterior region as substructures for crowns or bridges with one pontic [55]. The flexural strength of CAD/CAM InCeram^{TM} Zirconia was found to be favourable for fixed partial denture (FPD) frameworks [46]. *In vitro* studies showed that posterior FPD made of CAD/CAM InCeram^{TM} Zirconia produce a better fit than the slip cast InCeram^{TM} Zirconia [56] and the accuracy was similar to ceramo-metal conventional FDPs [57]. An *in vitro* study has shown that when surface treated with a tribochemical silica-coating followed by the use of a silane coupling system, the bonding of InCeram^{TM} Zirconia can be significantly increased [58].

3. CAD/CAM compatible polycrystalline alumina and zirconia

Polycrystalline ceramics, such as alumina and zirconia, have no intervening etchable glassy matrix and all the crystals are densely packed into regular arrays and then sintered [10,38]. The dense crystal lattice reduces crack propagation resulting in excellent mechanical properties. However, at the same time, the increase in strength means that well-fitting prosthesis could not be practically fabricated without CAD/CAM systems. Polycrystalline ceramic is relatively opaque by nature and is indicated for the fabrication of crown and bridge copings upon which a veneering ceramic is layered for the required aesthetic result [10]. It is noteworthy that fully sintered material can be fabricated by *hot isostatic pressing* [59]. This process utilizes a high isostatic pressure treatment to an encapsulated system in which the ceramic powder is enclosed. The high force is maintained during the sintering and the resultant ceramic block is milled to the actual dimensions required. Milling of these blocks has been so-called hard machining [3].

3.1. *Alumina based polycrystalline ceramics*

Procera^{TM} AllCeram (Nobel Biocare, Göteborg, Sweden), the first fully dense dental polycrystalline ceramic [38] was introduced in 1993 [60]. This core material contains more than 99.9% alumina and has a flexural strength of about 600 MPa [61,62]. In this process, the milling machine has a milling tool of the same dimension as that of the digitizer which reduces any transcription error. A die duplicate, enlarged by a factor of 0.2 to compensate for the sintering shrinkage, is milled onto which aluminium trioxide is densely packed and then sintered. The outer contour of the coping is milled to the programmed thickness and dimension and is then veneered with aesthetic porcelain with a compatible coefficient of thermal expansion.

Given this, although polycrystalline ceramic is relatively opaque, it was reported that when all ceramic materials at the respective clinically relevant thickness were compared, the translucency of Procera^{TM} AllCeram is between that of Empress^{TM} and Empress^{TM} 2 (Ivoclar-Vivadent, Schaan, Liechtenstein) [63]. Its use as laminates for patients with discoloured anterior teeth has been described [64]. The cumulative survival rates of Procera^{TM} AllCeram anterior and posterior crowns have been found to be about 97% after 5 years and 93.5% after 10 years [65,66]. Studies have reported a tendency for more failures in the posterior region and that crown failures were generally higher in molars than premolars [65–68]. But in a prospective clinical study including 103 posterior crowns (76% of total number), it was reported that there was only 1 crown fracture on a second molar where there was insufficient clearance [69]. The marginal fit of Procera^{TM} AllCeram restorations have been tested to be consistently between 60 and 80 μm [70,71] and within the range of clinical acceptance [72].

Procera^{TM} AllCeram has been used in the fabrication of FPD's [73]. The framework is waxed up as individual copings and scanned. The units are then milled separately and fused together with a special ceramic. However, clinical data regarding this use is scarce and awaited by clinicians. CAD/CAM alumina based polycrystalline ceramics can also be used as metal free super-structures on implant abutments as introduced [74]. In the earlier version, a prefabricated aluminium oxide cap is selected onto which porcelain is fused. A cumulative success rate of 93.7% was achieved after 5 years [75]. The authors of this study were in the opinion that the data from the study can be compared to that of Procera^{TM} AllCeram as the same base material and principle were used in the fabrication. Fully custom designed copings can now be fabricated and a procedure by which the all-ceramic coping is totally milled has been described [76]. The cumulative success rates of 98.3% after 4 years and 91% after 6 years have been reported [77,78]. In both studies, the crowns provided excellent aesthetics and colour stability in the observation period and that excessive parafunctional forces were considered a major reason for the ceramic fractures reported.

Similar to InCeram^{TM}, the ceramic surface cannot be satisfactorily etched for bonding but airborne particle abrasion with 50 μm aluminium oxide at 80 psi enhances the shear bond strength when resin cement is used for cementation [50]. Another study reported that silica coating with silanization yields higher bond strength than air abrasion [79].

A similar CAD/CAM ceramic is the Vita^{TM} InCeram AL cubes (Vita Zahnfabrik, Bad Sackingen, Germany), introduced in 2005. However, it should be differentiated from InCeram^{TM} Classic Alumina (which has also been referred to as InCeram^{TM} or InCeram^{TM} Alumina) in that this is glass-free, polycrystalline in structure and manufactured by a different process. It was tested in a laboratory study to have a flexural strength of 488 MPa for a failure probability of 5%. The authors of this study conjectured that the high crystalline content and low porosity of the ceramic contributed to its superior mechanical properties [80]. InCeram^{TM} AL cube is indicated by the manufacturer for the fabrication of substructures for anterior single crowns and short span bridges and posterior single crowns.

3.2. *Stabilized zirconia based polycrystalline ceramics*

Zirconia is a polymorphic ceramic material in its unalloyed state and it has three crystallographic forms: monoclinic (M) from room temperature to 1170 °C, tetragonal (T) from 1170 °C to 2370 °C and cubic (C) from 2370 °C to the melting point [2,3]. With the addition of stabilizing oxides such as ceria (CeO_2), magnesia (MgO) or yttria (Y_2O_3), a multi-phase material known as partially stabilized zirconia (PSZ) is formed at room temperature with cubic crystals as the major phase and monoclinic and tetragonal crystals as the minor phases [81]. It is also possible to form a mono-phasic material consisting of tetragonal crystals only and the material is then called tetragonal zirconia polycrystal (TZP).

3.3. *Transformation toughening of zirconia*

The tetragonal phase is metastable and can transform to the monoclinic phase in response to mechanical stimuli such as a crack on the surface of the ceramic [81]. Stress is built up at the tip of the crack which will trigger the transformation. This T–M transformation at the fracture site is accompanied by an increase in volume of about 4% as monoclinic crystals are larger in size. This induces compression stress at the tip of the crack which increases the work of the fracture and at the same time the energy is dissipated during the transformation [82,83]. This mechanism is called *transformation toughening* and it effectively hinders (*i.e.*, arrests) the crack propagation [81] resulting in an increase in mechanical properties. Zirconia has high fracture toughness, 9–10 MPa m^{-1} and the flexural strength, 900–1200 MPa, is about twice that of alumina [83,84]. Given this, it should be noted that the propagation of a crack is not totally prevented, it is merely hindered, and the material would still fail under a sufficiently high stress.

3.4. *Low temperature degradation of zirconia*

The biomedical application of zirconia in orthopaedics for the manufacture of acetabular ball heads for hip replacements was introduced in the 1980s [85]. Unexpectedly, in 2001, roughly 400 femoral heads failed in a short period of time and the failure was associated with an accelerated ageing in specific batches of the zirconia products [86]. The ageing process is the result of the progressive spontaneous transformation of the metastable tetragonal phase into the monoclinic phase in the presence of water at relatively low temperatures, a phenomenon known as low temperature degradation (LTD). It is a slow transformation that starts in isolated grains on the zirconia surface leading to an increase in volume. This stresses the vicinal grains and a microcrack appears allowing water to penetrate and the process progresses [3,86] ultimately resulting in a remarkable decrease in strength. This strength degradation is different for various zirconia ceramics and the variation is related to factors such as stabilizer concentration and distribution, grain size [81] and the presence of residual stresses [87]. A recent study showed that ceria-stabilized zirconia (12Ce-TZP) was resistant to simulated hydrothermal ageing and its flexural strength remained unaffected at a low level of 500 MPa [88]. Although some concern was raised by the degradation of the femoral heads 20 years ago, no direct correlation has been established between LTD and clinical failure of zirconia in dentistry [86,89].

3.5. *Yttria partially stabilized tetragonal zirconia polycrystals*

Biomedical grade zirconia (3Y-TZP) contains 3 mol% yttria and since the 1990s it has been used in dentistry as orthodontic brackets [90], endodontic posts [91], crowns [92],FDPs [73], implants [93] and implant abutments [94]. Natural zirconia is dull white, X-ray opaque and it has an obvious advantage over metal alloys as a substructure material [95]. However, the translucency decreases with an increase in crystalline content and the opacity of zirconia is comparable to metal [63]. In this aspect it is useful in masking discoloured teeth or metal substructures such as metal posts and cores [55] but its use in the aesthetic zone is limited to the fabrication of frameworks. Coloured zirconia frameworks are now available that may produce a more clinically acceptable colour match [96].

In a recent review of all-ceramic restorations [89] it was reported that long term clinical studies on zirconia-supported restorations were scarce and in the studies reviewed, the clinical survival rates were 92.7–100% after 3 years for single crowns and 94–96% for 3- to 4-unit FPDs after 4 years. Although some studies have shown that zirconia based FPDs can possibly withstand physiologic occlusal forces [97], occlusal overloading caused by bruxism and insufficient framework thickness were cited as the major factors causing catastrophic fracture within the zirconia core, most commonly occurring in the connector areas of FPDs [98]. However, the most frequent reason for failure was a cohesive fracture within the veneering ceramic, irrespective of the veneer system. Veneer fracture rates were reported to reach as high as 9% for single crowns after 2–3 years, up to 36% for FPDs after 1–5 years and up to 53% for implant supported zirconia based restorations [89]. The reasons for the fracture have yet to be elucidated but contributing factors may include weakness of the veneer material or the core/veneer bond [99], stresses and distortion due to the veneering process [100], unsupported veneering porcelain and configuration of the core and veneer [101], residual stresses arising from coefficient of thermal expansion mismatch and rapid cooling rates after heat treatment [102]. To summarize, per today, some common CAD/CAM systems for fabrication of 3Y-TZP restorations in use are LAVA^{TM} (3M ESPE), Cercon^{TM} (Dentsply), e.Max^{TM} ZirCAD (Ivoclar-Vivadent), Procera^{TM} Zirconia (NobelBiocare) and Vita^{TM} YZ blocks (Vita Zahnfabrik) which use partially sintered blanks while DCS-President^{TM}, DC Zirkon^{TM} (Smartfit Austenal, Chicago, USA) frameworks are milled from fully sintered zirconia blocks.

3.6. *Magnesium partially stabilized zirconia*

This type, abbreviated as Mg-PSZ, is a bi-phase ceramic material consisting of tetragonal crystals in a cubic matrix. This material has a higher wear rate due to residual porosities [81]. The material is stabilized by magnesia but the difficulties in obtaining Mg-PSZ precursors free of impurities result in a decrease in stability in the tetragonal phase in a wet environment and lower mechanical properties when compared to 3Y-TZP after veneering [81,103]. The material has not been widely used and an example is the Denzir-M^{TM} (Dentronic, Skellefteå, Sweden) for hard machining.

3.7. *Ceria stabilized zirconia/alumina nanocomposite (Ce-TZP/A)*

Ce-TZP itself is resistant to LTD but has a low flexural strength [88]. Homogeneous dispersion of nanoscale alumina in the matrix increases the flexural strength without affecting the fracture toughness [104] and preliminary results of a prospective case series have shown Ce-TZP/A (Nanozir, Hint-Els, Griesheim, Germany) to be a reliable framework material for posterior FDPs [105].

3.8. *Precision of fit of stabilized zirconia based polycrystalline ceramics*

The marginal fit of zirconia restorations is dependent on the configuration and design of the teeth preparations, the accuracy of the scanning system, the type of machining and the veneering procedures but ageing does not seem to influence the long term marginal integrity [9,57]. Depending on the study design and variables, the absolute marginal fit of zirconia FPDs have been reported to be between 9 μm and 206.3 μm and most of the available systems provide clinically acceptable marginal adaptation [9].

3.9. *Bonding to zirconia*

Interests in the use of zirconia has increased due to its superior biocompatibility [106] and biomechanical properties [9,10,16,94], but it has been concluded that conventional adhesive techniques do not yield a high enough bond strength to substrates [107]. Researches are under way to establish a reliable, reproducible and commercially viable resin composite bonding protocol for zirconia [108] – and for porcelain zirconia bonding [8]. Grinding or air-abrasion to create a rough surface for micromechanical interlocking may introduce initial surface flaws that may compromise its strength and reliability [109,110]. Other surface modification (roughening) techniques [111] being investigated include Selective Infiltration Etching (SIE) [112], application of fused glass micro-beads and the use of a hot chemical etching solution [113], and laser treatment [114]. The use of silica-coating, tribochemical coating and new approaches in priming the so-called novel silane systems [115,116] have been reported to increase the bond strength, but which may decrease after long term storage *in vitro*. The use of primers such as phosphate monomers has also been tested to improve the bond strength of resin cement to zirconia [117–120]. A recent meta-analysis reported that a combination of mechanical and chemical pretreatments appeared crucial to obtaining durable bonding while the cement choice was not revealed as a determining factor so long as composite luting cement was used [121].

4. Conclusion

Advances in CAD/CAM technology have catalyzed the developments of aesthetic all ceramic restorations with superior biomechanical properties. Although none of these materials exhibit ideal clinical properties for universal applications, intense research efforts are under way to promote the strength, aesthetics, accuracy and an ability to reliably bond to dental substrates. The field of CAD/CAM ceramics in dentistry is strongly evolving with evidence from materials development and from longer-term clinical studies.

Conflict of interest

The authors declare no conflict of interest.

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