Australian Dental Journal
The official journal of the Australian Dental Association

Australian Dental Journal 2011; 56:(1 Suppl): 97–106

doi: 10.1111/j.1834-7819.2010.01300.x

CAD/CAM systems available for the fabrication of crown and bridge restorations

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ABSTRACT

Dental biomaterials are widely used in all areas of routine dental practice. There are mainly two methods for their application. Firstly, dental biomaterials are placed into living tissues, such as teeth, to fill the space. Secondly, dental devices such as crown and bridge restorations and dentures are fabricated using various materials to restore the morphology and function of the dentition.

Crown and bridge restorations are one of the main treatment methods used by general practitioners to achieve lifelike restoration of form and function. The recent introduction of osseointegrated implants has expanded the application of crown and bridge restorations for partially edentulous patients.

Mechanical durability and precision fit are mandatory requirements for crowns and bridges. The development of various casting alloys and precise casting systems has contributed to the successful use of metal-based restorations. However, patient requests for more aesthetic and biologically 'safe' materials has led to an increased demand for metal-free restorations.

There is also a growing demand to provide all-ceramic restorations more routinely. New materials such as highly sintered glass, polycrystalline alumina, zirconia based materials and adhesive monomers, will assist dentists to meet this demand. In addition, new fabrication systems combined with computer-assisted fabrication systems (dental CAD/CAM) and various networks are now available. Dental technology was centred on lost-wax casting technology but we now face a revolution in crown and bridge fabrication.

This article reviews the history and recent status of dental CAD/CAM, the application of CAD/CAM fabricated tooth-coloured glass ceramic crowns, and the application of all-ceramic crowns and bridges using CAD/CAM fabricated zirconia based frameworks.

Keywords: CAD/CAM, networked CAD/CAM, digitizer, glass ceramics, zirconia.

INTRODUCTION

There is a long history of dental biomaterial use in routine dental practice. There are two main methods for the application of dental biomaterials. Firstly, raw dental biomaterials are transplanted into living tissue, such as tooth and bone, to fill the space instead of living organs or tissue transplantation. Secondly, dental devices such as crown and bridge restorations and dentures are fabricated from dental materials to restore dental morphology and oral function.

Crown and bridge restorations are commonly used by general practitioners after operative and endodontic treatments. In addition, the recent introduction of osseointegrated implants has expanded the application of crown and bridge restorations to restore edentulous spaces. Since mechanical durability and intimate fit to abutments are mandatory for crown and bridge restorations, metallic restorations and metallic frameworks covered by glass or resin composites have become popular. The development of both casting gold alloys and dental precision casting systems have contributed to the application of metallic restorations. However, patient requests for aesthetics and biosafety has increased the demand for metal-free restorations. Therefore, both new materials and new processing technology to meet patient demands are required.

We are currently in a new era of routinely providing all-ceramic restorations because of newly available materials such as highly sintered glass, polycrystalline alumina and zirconia based ceramic materials, and adhesive monomers.[1] In addition, new fabrication systems combined with a computer-assisted fabrication system (dental CAD/CAM) and networks are becoming increasingly available.[2] Dental technology that used to be centred on the standardized lost-wax casting technology has been greatly improved with the introduction of dental CAD/CAM systems.

In this article we discuss: (1) the history and recent status of dental CAD/CAM systems; (2) the application of CAD/CAM fabricated tooth-coloured glass ceramic crowns; and (3) the application of all-ceramic crowns and bridges using CAD/CAM fabricated zirconia based frameworks for general practitioners.

The history and recent status of dental CAD/CAM

Figure 1 shows the conventional fabrication process of crown and bridge restorations. An impression of an intraoral abutment is taken and a stone model is prepared as a replica of the abutment. Creating a model is the beginning of the laboratory work. When a metallic restoration is fabricated, wax patterns are manually fabricated, followed by precision casting. If necessary, final restorations are completed by veneering porcelain onto the metal framework.

Figure 2 shows the first generation of application of the dental CAD/CAM system by pioneers in dentistry. Duret and colleagues pioneered the dental CAD/CAM system in the early 1970s.[3] They fabricated restorations using a series of steps shown in Fig 2. The intraoral abutment is scanned by an intraoral digitizer to obtain an optical impression. Digitized data is reconstructed on the monitor as a 3-D graphic and then the optimal morphology of the crown can be 'virtually designed' on the monitor. The final crown is fabricated by milling a block using a numerically controlled machine. Duret and colleagues later developed the commercial Sopha system, but this system was not widely used. It is possible that this system was designed too soon to be applied in dentistry because of the lack of accuracy of digitizing, computer power and materials, etc.

However, Mormann and colleagues developed the CEREC system, and succeeded in producing a ceramic inlay restoration using computer-assisted technology.[4] Digitizing of the inlay cavity is performed directly in the mouth using a compact intraoral camera, which is technically less difficult compared with crown abutments. Design and fabrication of the ceramic inlays are performed using a compact machine set at the chairside in the dental surgery. This application was innovative, but the application was limited to inlays and occlusal morphology and contour was initially not available. The technical term of CAD/CAM became popular in dentistry with the introduction of the CEREC system throughout the world. The original idea of in-office restoration fabrication is still currently practised. Several reports have been published on this system, showing satisfactory long-term results.[5–7] A recent iteration of the system can fabricate not only original inlays and onlays, but also crowns and the cores/frameworks of bridges in both clinical and laboratory settings.

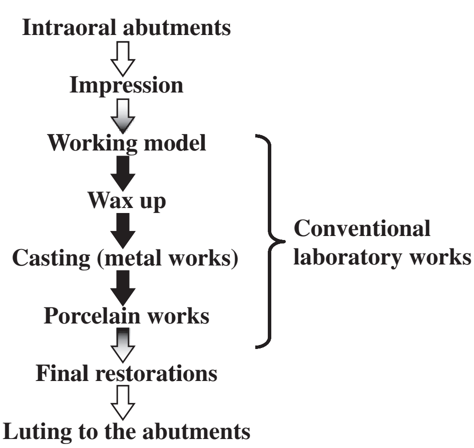

Fig 1. Conventional fabrication process of crown-bridge restorations.

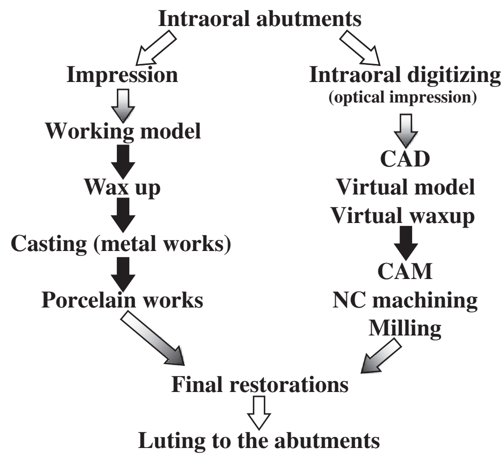

Fig 2. First generation of the dental CAD/CAM systems proposed by Duret and colleagues.

Based on the developments of Duret's laboratory system, many researchers worldwide, including our own laboratory, began in the 1980s to develop a system to fabricate a crown with an anatomical occlusal surface. However, we found it difficult to digitize the intraoral abutment accurately using a direct intraoral scanner. Therefore, we decided to prepare the conventional stone model to begin the CAD/CAM process for the fabrication of crowns, especially for dental laboratory use. The second generation of the application of dental CAD/CAM systems is illustrated in Fig 3.

Different digitizers such as a contact probe,[8] laser beam with a PSD sensor, and a laser with a CCD camera were developed. Sophisticated CAD software and compact dental CAD/CAM machines were also developed.[2] Consequently, both metallic and ceramic restorations were able to be fabricated by the second generation CAD/CAM systems.[9–16]

In the early 1980s, nickel-chromium alloys were used as a substitute for gold alloys because of the drastic increase in gold prices at that time. However, metal allergies became a problem, especially in northern Europe, and a transition to allergy-free titanium was

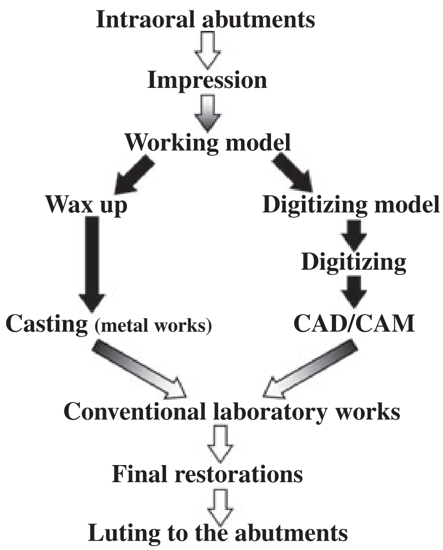

Fig 3. Second generation of the dental CAD/CAM systems as a part of dental laboratory works.

proposed. Since the precision casting of titanium was still difficult at that time, Andersson and colleagues attempted to fabricate titanium copings by spark erosion and introduced CAD/CAM technology to the process of composite veneered restorations.[17] This was the first application of CAD/CAM in a specialized procedure as part of a total processing system. This system later developed as a processing centre networked with satellite digitizers worldwide for the fabrication of all-ceramic frameworks using industrial dense sintered polycrystalline alumina known as the Procera system.[18,19] Since these high strength industrial ceramics were not available to conventional dental laboratories, the application of networked CAD/CAM in a processing centre was innovative in the history of dental technology (Fig 4). Such networked production

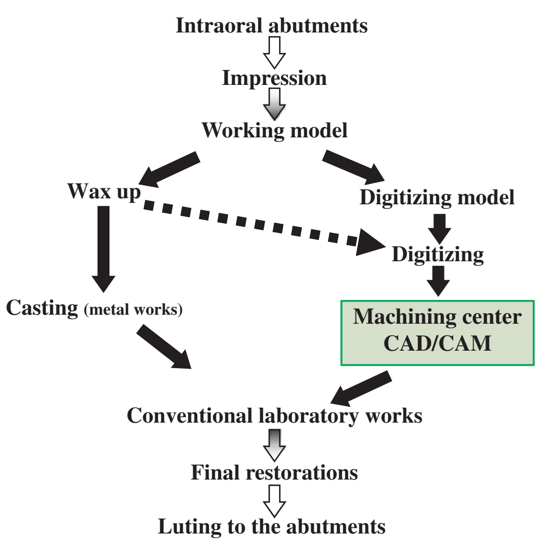

Fig 4. Third generation of the dental CAD/CAM systems using a machining centre.

systems are currently being introduced by a number of companies worldwide.[20–22] The production of zirconia frameworks has become very popular in the world market (Table 1).

The application of CAD/CAM is currently limited to laboratory processing. For example, even if the zirconia framework is fabricated using a CAD/CAM process in the machining centre, final restorations are completed by veneering conventional porcelain using conventional manual dental technology by dental technicians. Nevertheless, there are advantages to using CAD/CAM: new materials are safe, aesthetically pleasing and durable; increased efficiency in laboratory processing; quick fabrication of the restoration; and quality control of restorations such as fit, mechanical durability and predictability. These advantages will ultimately benefit our patients.

Because of rapid progress in new technologies, especially optical technology, new intraoral digitizers are now available.[23–26] The application of dental CAD/CAM systems is expected to shift to the fourth generation, as illustrated in Fig 5. At least four commercial intraoral scanners are on the market. Information is still limited and manipulation and digitizing accuracy appears unclear. However, the fourth generation is expected to be available for use in the clinic in the near future. Besides the tools for fabrication of restorations, computer technology is now available for communication tools with patients, examination and diagnosis, treatment planning and guided surgery in all fields of dentistry. Digital dentistry is becoming a keyword for the future of dentistry.

Dental ceramics

Porcelain has been used in dentistry for 100 years. Aesthetics is its major advantage, but brittleness for load bearing restorations its weakest point. The conventional powder build-up firing process was innovative but is still technically sensitive. Therefore, porcelain fused to metal restorations has been the first choice to meet both restoration aesthetics and durability requirements. There are two methods proposed for shifting to all-ceramic restorations (Fig 6).[27–29] The first method is to apply reinforced glassy materials to single crowns. CAD/CAM is efficiently applied to fabricate a single crown of reinforced glassy materials. The second method is to fuse porcelain to high strength ceramics instead of alloys. Dense sintered zirconia polycrystalline material appears to be promising for the application to the framework of bridges and even the superstructure of implants.

The mechanical properties of brittle ceramics can be evaluated by fracture toughness and bending strength. Conventional porcelain is a glassy material; fracture toughness is approximately 1.0 MPa $m^{1/2}$ and bending

Table 1. Popular CAD/CAM systems available for the fabrication of zirconia frameworks

CAD/CAM system (Manufacture)	Dizitizing Method	Restoration type				Material						Central machining centre
		In	Veneer	Cr	Br	Resin	Titanium	Gold	Ceramic	Alumina	Zirconia	
Etkon (Etkon AG)	PSD/Laser			○	○	○	○	○	○		○	○
Everest (KaVo electrotechnical work GmbH)	CCD/White light	○	○	○	○		○		○		○	Available
Lava (3M ESPE Dental AG)	CCD/White light			○	○		○		○		○	Available
Pro 50, WaxPro (SYNOVAD)	CCD/Color light			○	○		○	○	○		○	○
Procera (Nobel Biocare Germany GmbH)	Touch Probe		○	○	○		○		○	○	○	○
Hint ELs DentaCAD systeme (Hint-ELs GmbH)	CCD/White light			○	○	○	○				○	Available
KATANA system (Noritake dental supply co., LTD)	CCD/Laser			○	○						○	Available
Cercon smart ceramics (DeguDent GmbH)	CCD/Laser			○	○						○	Available
CEREC3/inLab (Sirona Dental of system GmbH)	CCD/Laser	○	○	○	○				○		○	Available
DCS Dental (DSC Dental AG)	PSD/Laser	○	○	○	○	○	○		○		○	Available
ZENO® Tec System (Wieland Dental & Technik GmbH)	CCD/Laser			○	○	○	○			○	○	Available

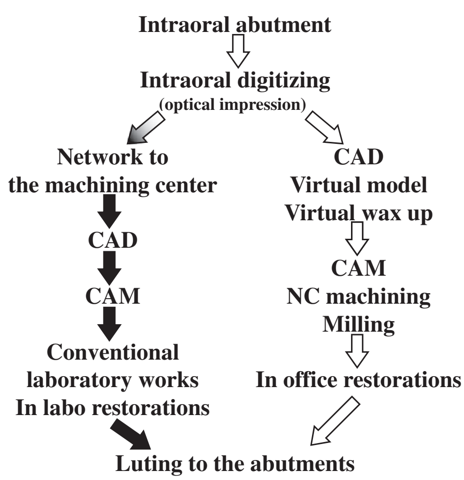

Fig 5. Fourth generation of the dental CAD/CAM systems using an intraoral digitizer.

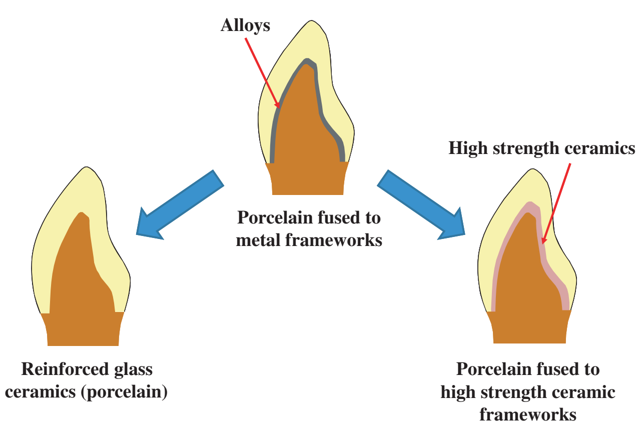

Fig 6. Two directions of all-ceramic restorations replacing conventional porcelain fused to metal frameworks.

strength is approximately 100 MPa. This material is not strong enough for load bearing molar restorations. New dental ceramics have improved the mechanical properties of conventional porcelain (Fig 7).[30–32]

Initially, porcelain was reinforced by dispersing crystals. Aluminous porcelain is widely available. Since conventional powder build-up and the firing procedure is technique-sensitive, new, more easily manipulated ceramic materials have been developed. In response to this demand, castable and pressable ceramics were developed and are available for single aesthetic restorations. In addition, prefabricated reinforced glass ceramic blocks are available for milling using a CAD/CAM device. The fracture toughness of these materials range from 1.5 to 3.0 MPa $m^{1/2}$. However, these are still available only for single restorations.

Another type of ceramic includes alumina and other fine ceramic powders that are porously sintered and glass is infiltrated among the pores. These materials are called glass infiltrated ceramics and include the well-known brand In-Ceram. Their fracture toughness ranges from 3 to 5 MPa $m^{1/2}$. These materials have been applied to bridge restorations but the prognosis has not been satisfactory.

Finally, industrial dense polycrystalline ceramics such as alumina, zirconia and alumina-zirconia composites are currently available with the application of CAD/CAM technology using a networked machining centre. In particular, yttrium partially stabilized tetragonal zirconia polycrystalline (YTZP) has a very high fracture toughness from 5 to 10 MPa $m^{1/2}$. When a crack initiates on the YTZP, the concentration of stress at the top of the crack causes the tetragonal crystal to transform into a monoclinic crystal with volumetric expansion. This prevents further crack propagation.[33]

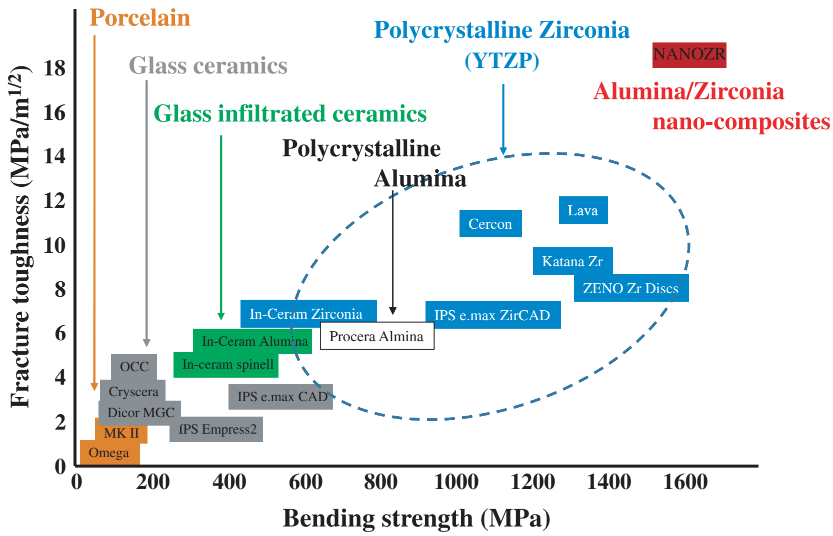

Fig 7. Mechanical properties of new dental ceramics.

In addition, alumina-zirconia nano-composites developed in Japan are very tough with a fracture toughness of 19 MPa $m^{1/2}$ and a bending strength of 1400 MPa.[34]

Application of CAD/CAM fabricated tooth-coloured glass ceramic crowns

Currently, prefabricated reinforced glass ceramic blocks are available for milling using a CAD/CAM device. Table 2 illustrates the mechanical properties of a typical leucite-reinforced glass ceramic compared with those of tooth enamel. Mechanical properties of leucite-reinforced glass ceramics are equal or superior to those of tooth enamel. However, materials with these properties were conventionally not available to replace enamel, even for a single crown.

Glass ceramic crowns can be automatically fabricated without any sensitive manual labour using a CAD/CAM process (Fig 8).[35] In addition, conventional finishing procedures such as add-ons, staining, and glazing are available because of the same porcelain base materials as a glass ceramic block for milling. Figure 9 shows a hemi-sectioned surface after cementing. There is no porosity inside because of the prefabricated block used at the factory. The fit of the crown is excellent with a cement thickness at the margin of less than 20 μm.

Figure 10 illustrates the result of a fracture test of a CAD/CAM fabricated crown luted to an abutment with and without luting cement.[36] When a crown was fractured on the abutment without luting cement, the fracture force was only 700 N. The fracture load increased to 2000 N when the crown was luted with a luting cement but without adhesive. Interestingly, the fracture load increased to 4000 N when the crown was luted using luting cement with silane-coupling agents and adhesive monomers. Therefore, glass ceramic crowns are reinforced by adhesive treatment.

Table 2. Mechanical properties of leucite-reinforced glass ceramics and tooth enamel

	Glass ceramics	Tooth enamel
Bending strength (MPa)	100∼120	85
Fracture toughness (MPa·$m^{1/2}$)	1.2∼1.5	1.2
Elastic modulus (GPa)	68∼72	65
Hardness (H_v)	500∼650	350

CAD/CAM glass ceramic (porcelain) crowns are clinically useful because of their easy manipulation without technically sensitive build-up processes. They are user-friendly because finishing work such as conventional staining, add-ons and glazing techniques are available. They are also promising because of their excellent fit and aesthetics, strong durability with adhesive resin cements and quick fabrication. However, they are only available for a single crown.

Application of all-ceramic crowns and bridges using CAD/CAM fabricated zirconia based frameworks

Zirconia is available for fabricating frameworks of bridge restorations instead of metal bonded restorations because of its higher fracture toughness. There are two types of zirconia blocks currently available for distinct CAD/CAM applications. The first application is the use of fully sintered dense blocks for direct machining using a dental CAD/CAM system with a grinding machine. The second application is the use of partially sintered blocks and green blocks for CAD/CAM fabrication followed by post-sintering to obtain a final product with sufficient strength. The former application has a superior fit because no shrinkage is involved in the process, but is disadvantaged by inferior machinability associated with heavier wear on the milling tool. In addition, microcrack formation on the material during

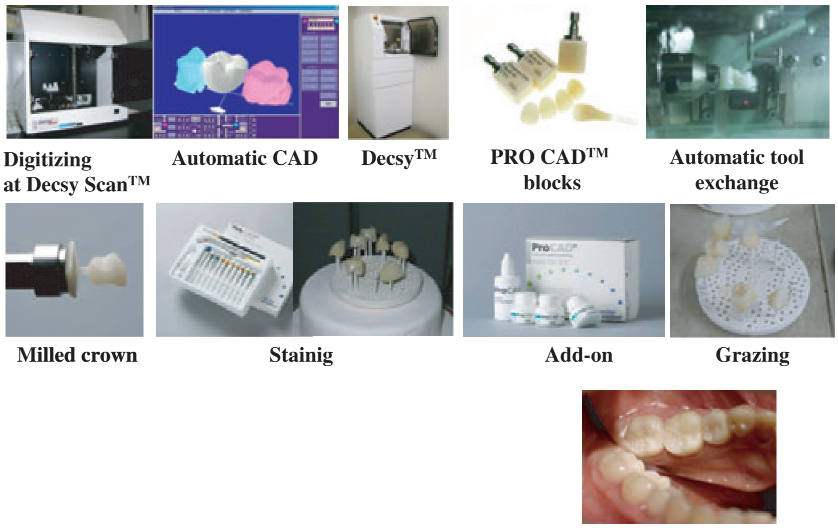

Fig 8. Fabrication of glass ceramic crowns using the CAD/CAM system of Angel crowns™ (Media, Japan).

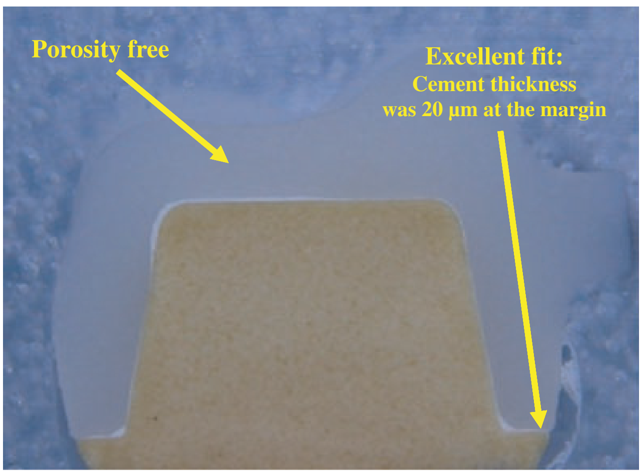

Fig 9. Sectioned surface of a CAD/CAM fabricated ceramic crown after cementing.

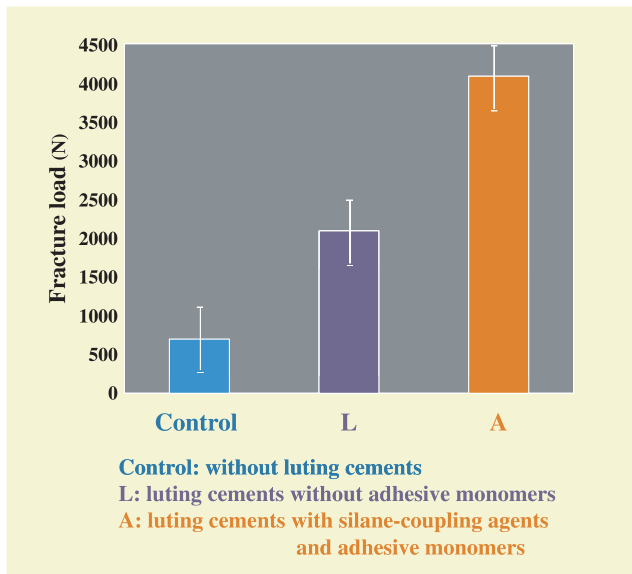

Fig 10. Result of a fracture test of a CAD/CAM fabricated crown luted to an abutment.

the milling procedure might deteriorate the mechanical durability of the restoration.[20,37] The latter application has the advantage of easy machinability without as much wear on the tools or chipping of the material. However, because of extensive shrinkage during the post-sintering process, the fit of the frameworks must be compensated for by the dimensional adjustment of CAD procedures involving the frameworks.[37,38]

We conducted a fitting test of zirconia frameworks fabricated by the CAD/CAM process.[39] Zirconia frameworks were fabricated using a standardized metal abutment. After luting frameworks to the abutment with luting cement, the thickness of the cement layer was measured. In this study, the cement space was designed beforehand on the abutments by the CAD process. The red dotted line shows the designed cement thickness. Figure 11 shows that the fit of a single crown coping was perfect. When the number of pontics increases, the cement thickness of the margin of the crown of the pontic side tends to increase, but this is still within clinically acceptable levels.[40–42]

On the other hand, according to the results of a fitting test using the angled type bridge model,[36] even if the fit of the margin of the crowns was excellent, similar to the straight type models, there was slight distortion of the framework. Therefore, there is a need to be aware of the difference between zirconia frameworks and metal frameworks, especially the implant superstructure. When there is a discrepancy in metal frameworks at a trial insertion, they can be adjusted by separation and soldering, but this cannot be done with zirconia frameworks.

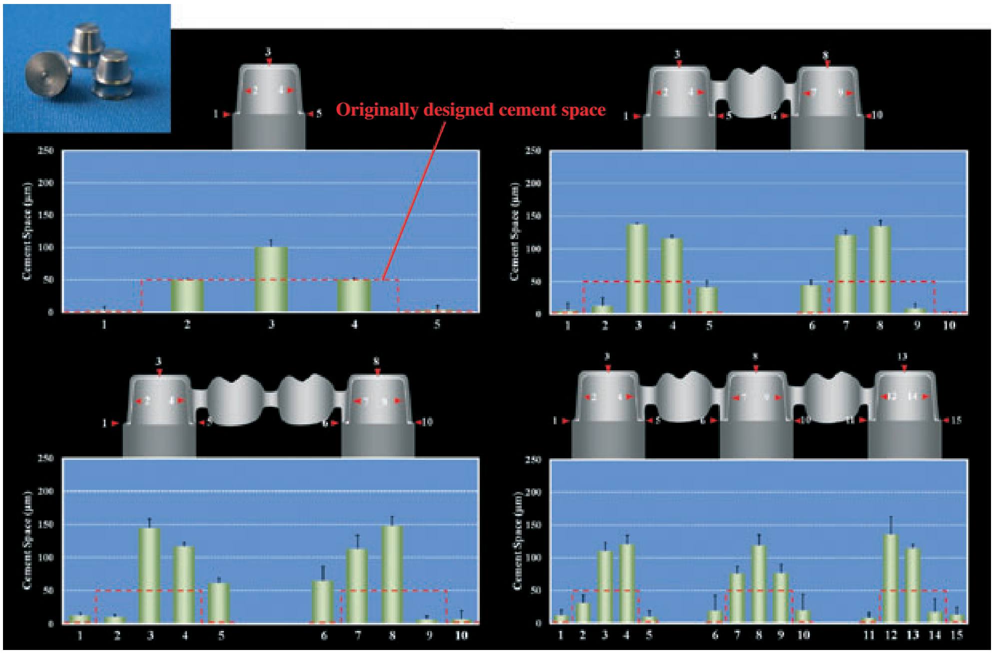

Fig 11. Result of a fitting test of zirconia frameworks fabricated by the CAD/CAM system of KATANA™ (Noritake, Japan).

Table 3. Commercial veneering porcelain products available for zirconia frameworks

	Thermal expansion coefficiency (10^{-6}/°C) (25–500°C)	Firing temp. (°C)	Compatible Zirconia
Cerabien ZR (NORITAKE)	9.1	930–940	KATANA, Procera Zirconia
Vintage ZR (SHOFU)	9.3–9.4	900–940	NANOZR
Initial Zr (GC Europe)	9.4	810	All products
Cercon®Ceram S (Dentsply DeguDent)	9.5	810–850	Cercon
Ceramco®PFZ (Dentsply Ceramco)	–	890–930	Cercon
Lava™ Ceram (3M ESPE)	10.0	810	Lava Zirconia
Vita VM®9 (Vita)	8.8–9.2	900–940	In-Ceram YZ Cubes
NobelRondo™ Zirconia (Nobel Biocare)	9.3	890–980	Procera Zirconia
IPS e. max®Ceram (Ivoclar vivadent)	9.5 (100–400°C)	800	IPS e. max ZirCAD
IPS e. max®ZirLiner (Ivoclar vivadent)	9.8 (100–400°C)	960	IPS e. max ZirCAD
Zirox®(WIELAND)	10.0	900	ZENO™ Zr
Creation ZI (Creation Willi Geller International AG)	9.5	810	YTZP

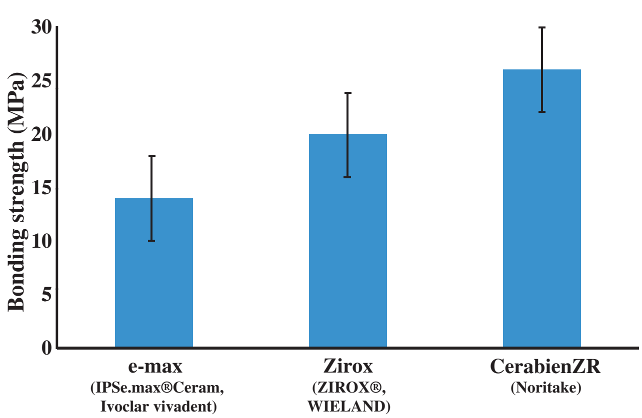

Fig 12. Result of a bonding test of three porcelain products conventionally fused to zirconia plates (IPS e-max ZirCAD, Ivoclar Vivadent) under the ISO 9693.

The final restoration is completed by veneering conventional porcelain on the zirconia frameworks by conventional dental technological manual work. Even though zirconia is tougher than conventional dental ceramics, veneering porcelain is as brittle as conventional porcelain. Debonding and chipping of veneering porcelain sometimes occurs. Therefore, the properties of porcelain and processing of veneering materials are still very important for the prognosis of the final zirconia restorations. Each manufacturer recommends surface treatment of zirconia frameworks prior to porcelain fusing, such as sandblasting and heat treatments. However, the effect of surface treatments on the bonding strength of porcelain to zirconia is still controversial.[43] Table 3 shows the list of commercial

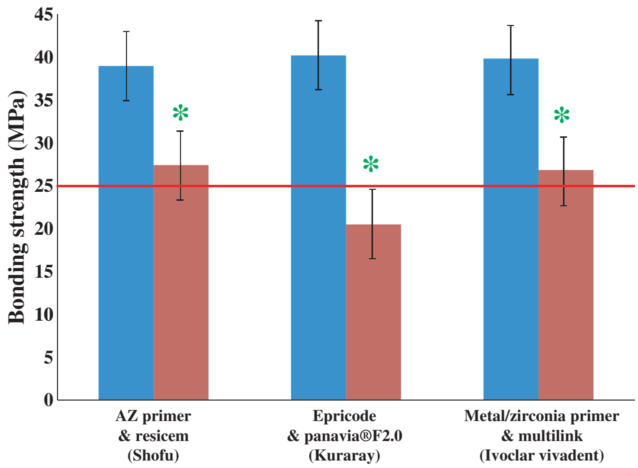

Fig 13. Result of a bonding test of the milled porcelain plate (IPS Empress CAD, Ivoclar Vivadent) adhered to the zirconia plate (IPS e-max ZirCAD, Ivoclar Vivadent) using three adhesive monomers under the ISO 9693. * indicates the bonding strength after thermal cycles of 10 000 times at 5~60 °C.

veneering porcelain products for zirconia frameworks. There are differences in the thermal coefficients of expansion and firing temperatures among the products, indicating a different composition of powder.

We tested the bonding strength of porcelain fused to zirconia frameworks (Fig 12).[36] Three commercial porcelain powders were fused to the zirconia plate for a bending test (in accordance with ISO 9693) for the porcelain fused to the metal crowns. We determined the differences of the products based on the bending strength. Compared with the recommended strength of porcelain fused to metal system (25 MPa), the bonding strength of porcelain fused to zirconia frameworks appeared to be inferior to that of metal ceramics. Improvement needs to be made to the compatibility of the thermal expansion coefficient based on the powder composition.

On the other hand, adhesive treatment of zirconia using alumina sandblasting and adhesive monomers is available and appears to be positive.[44,45] Bending specimens of the same ISO standard were prepared using a milled porcelain plate adhered to the zirconia plate with three adhesive monomers and resin cements. As shown in Fig 13, even the bonding strength is decreased after thermal cycling, and the bonding strength of adhered specimens is higher than that of fused specimens.[36]

Therefore, a new hybrid structure of CAD/CAM porcelain crowns adhered to the CAD/CAM zirconia framework (PAZ) has been proposed (Fig 14).[36] In this system, zirconia frameworks are digitized and porcelain crowns are also fabricated by the CAD/CAM process. Milled porcelain crowns are adhered to zirconia frameworks using adhesive resin cements and the final restoration is completed. Manipulation of the structure is reproducible and reliable without conventional manual porcelain work. Adhesive treatments reinforce the durability of porcelain. Even if porcelain chips, repairing it is easy using the preserved data. (Figure 15 shows a clinical case of the PAZ bridge.)

CONCLUSIONS

This article reviews the current state and future perspectives of the application of dental CAD/CAM systems, particularly in the field of fabrication of crown and bridge restorations. CAD/CAM is a panacea for fabricating glass ceramic (porcelain) single crowns. However, adhesive treatments are mandatory for durability. Porcelain fused to CAD/CAM zirconia frameworks appears to be a favourable option in the

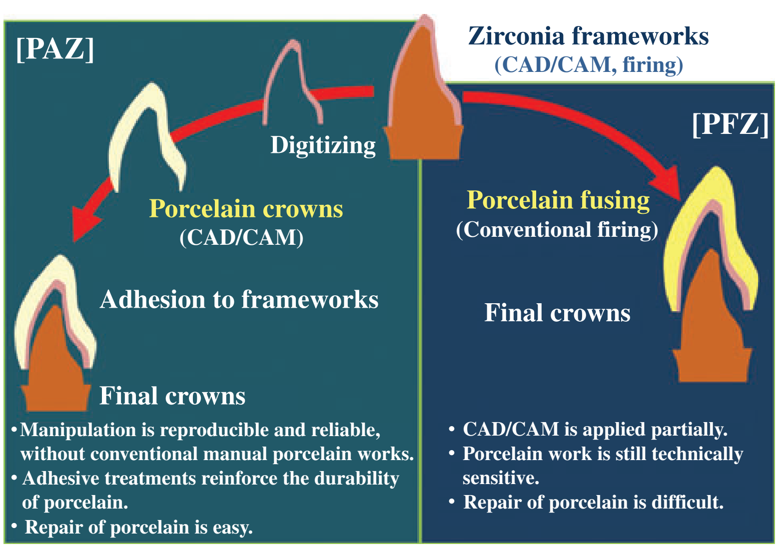

Fig 14. Schematic illustration of a novel fabrication system of a hybrid structure of CAD/CAM porcelain crowns adhered to the CAD/CAM zirconia frameworks (PAZ) and conventional porcelain fused to the CAD/CAM zirconia frameworks (PFZ).

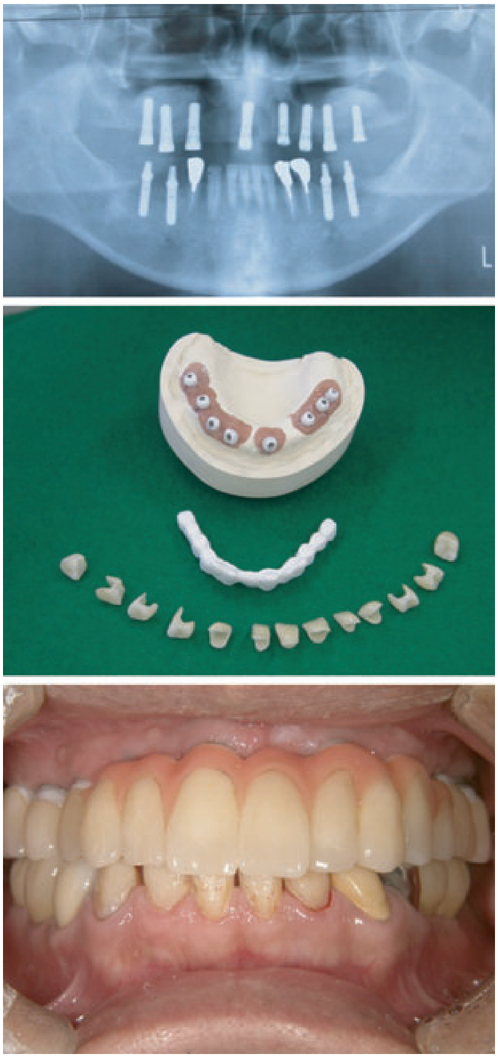

Fig 15. Clinical application of PAZ restorations to the maxillary implant prostheses (Courtesy of Dr Higuchi, Showa University Dental Hospital).

clinic. However, the challenge still remains to fix standardized surface treatments of frameworks and develop more compatible porcelain powders. Pressing porcelain is a potential candidate for conventional porcelain work but is still technically sensitive. There should be a shift to digital dentistry in the future. A hybrid structure of CAD/CAM porcelain crowns adhered to CAD/CAM zirconia frameworks is a promising option because manual porcelain work is not technically sensitive and porcelain is easy to repair.

The application of CAD/CAM technology in dentistry provides an innovative, state-of-the-art dental service to patients and is also beneficial for general practitioners. Conventional laboratory technology and dental technician skills remain important because dental restoration and prostheses are not just industrial products but medical devices that need to function in the body. Therefore, we must combine new technology and conventional technology to meet patient demand.

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