CAD/CAM technology and materials are currently used in a number of clinical applications, including the fabrication of indirect restorations. CAD/CAM gives the dentist and the laboratory an opportunity to automate fixed restoration fabrication. Both chairside and chairside–laboratory integrated procedures are available. The properties of these restorative materials and their indications and appropriate use must be understood in order to enable the achievement of predictable and aesthetic results for patients.

Introduction

In the past decade, the demand for all-ceramic restorations has increased in both anterior and posterior teeth and the search for materials with improved properties has expanded. The need for a uniform material quality, reduction in production cost, and standardisation of manufacturing process has encouraged researchers to seek to automate the manual process via the use of CAD/CAM technology since 1980.

Computer-aided design (CAD) and computer-aided manufacturing (CAM) technology systems use computers to collect information and design, and to manufacture a wide range of products. The introduction of the first digital intraoral scanner for restorative dentistry was in the 1980s by a Swiss dentist, Dr Werner Mörmann, and an Italian electrical engineer, Marco Brandestini, that developed the concept for what was to be introduced in 1987 as CEREC by Sirona Dental Systems LLC, the first commercially CAD/CAM system for dental restorations. Ever since research and development sectors at a lot of companies have improved the technologies and created in-office intraoral scanners.

All the existing intraoral scanners try to face with problems and disadvantages of traditional impression fabrication process and are driven by several non-contact optical technologies and principles.

The purpose of this present publication is to provide an extensive review on the CAD/CAM technology and to emphasise the application of this technology in restorative dentistry.

CAD/CAM techniques

The major goals of the impression-taking process in restorative dentistry are obtaining a copy of one or several prepared teeth, healthy adjacent and antagonist teeth, establishing a proper interocclusal relationship and then converting this information into accurate replicas of the dentition on which indirect restorations can be performed.

Traditional restorative techniques for fixed restorations require the use of impression materials to record the contours and dimensions of the preparation. This
is followed by the pouring of stone models and dies prior to laboratory fabrication of the definitive fixed restoration. Taking an accurate impression is one of the most difficult procedures in dentistry, requiring careful retraction or removal of soft tissue around preparation margins, haemostasis, and selection of an appropriate impression material and tray for the technique used.

By using a CAD/CAM restorative technique, a number of steps can be simplified or eliminated.\textsuperscript{7} Digital systems now offer the opportunity to avoid traditional, analogue impressions, including the usual impression materials, time, and handling limitations associated with them. Intraoral scanners have the potential to offer excellent accuracy with a more comfortable experience for the patient and more efficient workflow for the office. But care must be taken to ensure that the whole preparation is scanned, to avoid introducing errors.

Two techniques can be used for CAD/CAM restorations: the chairside technique or the integrated chairside-laboratory procedure.

Chairside technique

The development of CAD/CAM technologies for dental applications has enabled clinicians to prepare and indirectly restore tooth tissue with an aesthetic all-ceramic restoration, manufactured at the chairside in a single patient visit.

Chairside CAD/CAM techniques offer advantages to the patient, including eliminating the laboratory procedure and the requirement for intra-visit temporisation of the prepared tooth structure.\textsuperscript{8}

It eliminates several cumbersome dental office tasks, such as selecting trays, preparing and using materials, disinfecting and sending impressions to the laboratory. It also removes a source of discomfort and gagging. Moreover, it enables the clinician to take a digital impression, design and mill the restoration in-office, and fabricate cosmetic crowns, onlays and veneers, with full management over contours and tooth shade. Finally, it enhances the accuracy of adaptation of the restoration to the preparation.\textsuperscript{9}

In summary, with these systems, final restorations are produced in models created from digitally scanned data instead of plaster models made from physical impressions.

There are three main sequences to this workflow. The first sequence is to capture or record the intraoral condition to the computer. This involves the use of a scanner or intraoral camera.

During scanning, the clinician must ensure that all margins of the cavity are captured by the scan and visualised. The accuracy of CAD/CAM restorations depends on the scanner’s ability to visualise the margin. A true laser scanner/digitiser takes precise digital images of the preparation, including the margin, the undercuts, the contours, the adjacent dentition, and the gingiva. It captures hundreds of thousands of points of reference with each image, and then utilises a million data points to create an exact replica of the prepared tooth and neighbouring dentition.

Depending on the system, a light and rapid dusting of an opacifier may be required prior to capturing the digital scans of the preparation arch, opposing arch, and buccal bite registration. Once the data has been recorded to the computer, a software programme is used to complete the custom design of the restoration. The preparation is shown on the monitor and can be viewed from every angle to focus or magnify areas of the preparation. Inadequate images are automatically detected.

The “die” is virtually cut on the virtual model, and the finish line is delineated by the dentist directly on the image of the die on the monitor screen. Then, a CAD system, called “biogeneric”, provides a proposal

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**Fig. 3.** Designed molar restorations using dental designer software. Lingual view.

**Fig. 4.** Designed molar restorations using dental designer software. Occlusal view.
of an idealised restoration and the dentist can make adjustments to the proposed design using a number of simple and intuitive on-screen tools.

The software identifies matching morphological characteristics (fissures, cusps, marginal ridges, gliding contact angle) and then inserts corresponding cusps, fossae, fissures, contacts, surface into the virtual model of the restoration. On the basis of the contact point distribution, the cusp apexes and the proximal contacts, the software is capable of creating a well-matched tooth and detecting possible collisions with the bite registration.

This biogeneric modelling process creates natural, individual and functional occlusal surfaces.

A pre-manufactured block is inserted into the machine and is milled using diamond burs. The final sequence requires a milling device to fabricate the actual restoration from the design data in the CAD programme.

_Digital systems_

The CEREC Bluecam (Sirona), E4D intraoral digitizer (Planmeca), and iTero scanner (iTero) are considered single-image cameras. They capture a series of individual digital images that overlap one another. The overlapping images are "stitched" together by the computer software programme to process a single three-dimensional (3-D) virtual model.

The CEREC AC system powered by Bluecam is a light-emitting diodes (LEDs) camera that projects a changing pattern of blue light onto the object using projection grids that have a transmittance random distribution and which are formed by sub-regions containing transparent and opaque structures.

Thus, the intensity of light detected by each sensor element is a direct measure of the distance between the scan head and a corresponding point on the target object. As a disadvantage of the system, the triangulation technique requires a uniform reflective surface since different materials (such as dentin, amalgam, resins, gums) reflect light differently. It means that it is necessary to coat the teeth with oporative powders before the scanning stage to provide uniformity in the reflectivity of the surfaces to be modelled.

The earlier versions of CEREC employed an acquisition camera with an infrared laser light source. The latest version employs blue LEDs; the shorter-wave-length intense blue light projected by the blue LEDs allows for greater precision of the output virtual model.

The E4D Dentist system was introduced in early 2008. It consists of a cart containing the design centre (computer and monitor) and laser scanner head, and a separate milling unit. The IntraOral Digitizer is a single image camera with red laser light. It also works by recording reflected data from the hard and soft tissues.

The Cadent iTero digital impression system by Cadent LTD, came into the market in early 2007. The iTero system employs a parallel confocal white and red laser light camera to record series of single images to create a 3-D model. The scanner emits a beam of light that is reflected off the tooth surface. Only data reflected back through the filtering device at the correct focal distance is recorded.

Using this technique, the iTero captures all structures and materials found in the mouth without the need to apply any reflective coating to the patient’s teeth.

_Integrated chairside–laboratory procedure_

An integrated chairside–laboratory technique requires two visits.

The clinician can either scan the preparation directly and then send the scan to the laboratory, or can
take a traditional impression, after which a stone model is poured and the laboratory scans the stone model. The digitalisation of the dies was performed by a laser scanner (Cercon eye, DeguDent) and the substructures were designed on the CAD programme of the system. Digital impression systems are designed to electronically transmit the recorded data file to the dental laboratory for restoration fabrication. Efficient chairside assistants will increase the overall production of dental practices by aiding dentists in completing their procedures more quickly and more effectively.

Other systems are also used by laboratories to create copings, substructures, and abutments by CAM, after which hand fabrication of any required ceramics and finishing is conducted either by the same laboratory or by the laboratory that scanned and referred the case for milling of the substructure. Ceramic blocks for laboratory-milled restorations are available as zirconia (zirconium oxide) and lithium disilicate glass blocks. Zirconium oxide can be used to create accurate and strong copings and bridge substructures. After milling, the unit can be adjusted using an external liner (Zirliner, Ivoclar Vivadent) that enables characterisation before the outer ceramic suprastructure is created. The external ceramic layer can be created either using press ceramics (in the same manner as for a traditional bridge) or layering ceramic material onto the substructure using a fine brush and powder/liquid.

Advantages of a laboratory CAD/CAM milled restoration include reduced chairside time and increased accuracy. Since a stone model is not used, stone pouring errors are eliminated as well as errors associated with abrasion of the adjacent and opposing teeth due to manipulation of the models during fabrication that could result in overcontouring, tight contacts, and excessive occlusal height. In addition, reduced time is required for fabrication of the substructure.

**Materials**

CAD/CAM restorative materials are currently available in number of sizes in many shades and translucencies, including multiple shades within one dense graded restorative block. The material used depends on functional and aesthetic demands and on whether a chairside or laboratory CAD/CAM restoration is fabricated. A range of dental ceramic substrates have been developed for chairside machining and are represented as prefabricated blocks, manufactured using processing routes identified to reproducibly control the resultant ceramic composition and microstructure.

For chairside CAD/CAM restorations, an aesthetic, strong material requiring minimal post-milling aesthetic adjustment to minimise chairside time is needed. Leucite-reinforced glass ceramics (IPS Empress CAD, Ivoclar Vivadent; Paradigm C, 3M ESPE) and lithium disilicate glass ceramics (IPS e.max, Ivoclar Vivadent) can be used for chairside and laboratory CAD/CAM single restorations. Leucite-reinforced material is designed to match the dentition for strength and surface smoothness and to offer aesthetic results by scattering light in a manner similar to enamel.

A study has been done to evaluate and compare the marginal gap, internal fit, and fracture load of resin-bonded, leucite-reinforced glass ceramic mesio-occlusal-distal (MOD) inlays fabricated by computer-aided design/ manufacturing (CAD/CAM) or hot pressing: as a result, they provided clinically acceptable marginal and internal fit with comparable fracture loads after luting.

Ceramic blocks for laboratory-milled restorations are available as zirconia (zirconium oxide) and lithium disilicate glass blocks. Zirconium oxide (IPS e.max ZirCAD, Ivoclar Vivadent; Cercon, DENTSPLY Ceramco) can be used to create accurate and strong copings and bridge substructures. Zirconia offers some significant physical properties that are advantageous for dental restorations besides its high strength. It has a similar colour to natural teeth, which reduces the need to opaque it or mask it as would be done for a metal substructure. Zirconia also has good opacity. This may be an advantage when trying to block out underlying discolored teeth or restorative materials. It may also be a disadvantage when trying to develop a more translucent appearance to the crown. Some manufacturers can colour the zirconia substructure to simulate dentine shades to improve the desired aesthetic result.

After milling, the unit can be adjusted using an external liner (Zirliner, Ivoclar Vivadent) that enables characterisation before the outer ceramic suprastructure is created. The external ceramic layer can be created either using press ceramics (in the same manner as for a traditional bridge) or layering ceramic material onto the substructure using a fine brush and powder/liquid.

Composite resin blocks are also available for CAD/CAM restorations. Another option is the use of a new resin nanoceramic block that consists of ceramic clusters within a highly cross-linked resin matrix. The resulting block is homogenous, and the restoration can be CAD/CAM-milled chairside or in the laboratory.
Marginal adaptation is an important factor affecting the longevity of all-ceramic restorations. Considerable research has been invested in the marginal fit and internal adaptation of CAD/CAM restorations.

Software limitations, as well as accuracy of milling devices, may affect the fit of CAD/CAM restorations. Most clinicians agreed that marginal gap should not be greater than 100 μm. It has been reported in the literature that restorations produced by CAD/CAM systems can have marginal gaps of 10–50 μm which is considered to be within the acceptable range.

Giannetopoulos and Al investigated and compared the marginal integrity of ceramic copings constructed with the CEREC3 and the EVEREST system, employing three different margin angle designs. They explored to what extent these CAD/CAM machines can produce acute marginal angles, creating restorations with acceptable margins. They found that the average chipping factor (CF) of the CEREC copings was: 2.8 per cent for the 0° bevel angle, 3.5 per cent for the 30° bevel angle and 10% for the 60° bevel angle. For the EVEREST copings, the average CF was: 0.6 per cent for the 0° bevel angle, 3.2% for the 30° bevel angle and 2.0 per cent for the 60° bevel angle. Univariate Analysis of Variance and multiple comparisons showed that there was a statistically significant difference in the quality of margins between the two systems for the 0° and 60° bevel finishing line. Variance and multiple comparisons showed that there was a statistically significant difference in the quality of margins between the two systems for the 0° and 60° bevel finishing line.30

Mjör and Al have evaluated CAD/CAM restorations and found that they have a marginal fit as good as or superior to that of traditional impressions. A further benefit found with CAD/CAM restorations has been the reduced incidence of secondary caries (the leading cause of direct restoration failure with both amalgam and composite materials), attributed to the high accuracy of the approximal fit and the ability to ascertain what extent these CAD/CAM machines can produce acute marginal angles, creating restorations with acceptable margins.

Another study evaluated the accuracy of marginal and internal fit between the all-ceramic crowns manufactured by a conventional double-layer CAD/CAM system and a single-layer system. Ten standardised crowns were fabricated from each of these two systems: conventional double-layer CAD/CAM system (Procera) and a single-layer system (CEREC 3D). Marginal discrepancies of Procera copings were significantly smaller than those of Procera crowns and CEREC 3D crowns (P > 0.05). On internal gaps, CEREC 3D crowns showed significantly larger internal gaps than Procera copings and crowns (P < 0.05). Within the limitations of this study, the single-layer system demonstrated an acceptable marginal and internal fit.31

On the other hand, depending on the preparation design, either an adhesive or a non-adhesive luting cement can be used with these materials.

CAD/CAM restorative materials can be cemented with either traditional luting cements such as zinc phosphate, polycarboxylate cement, glass ionomers, or resin-modified glass ionomers. Materials that can be sealed with these include zirconia, lithium disilicate, alumina, and resin nanoceramics.33,34

With regards to resin adhesive cements, they offer superior aesthetics and low viscosity. They chemically bond to the restoration surface and the tooth surface, either providing all of the retention or, for retentive preparations, improved retentive strength. They also have greater compressive strength.35

Meanwhile zirconia fixed partial dentures showed good to sufficient marginal integrity in combination with Panavia/ED, Compolute/EBS and RelyX Unicem.36

When evaluating the initial and the artificially aged push-out bond strength (PBS) between ceramic and dentine produced by one of five resin cements, there was a significant effect of resin cement (P < 0.0001): RelyX Unicem showed significantly higher PBS than the other cements. Syntac/Variolink II showed significantly higher PBS than SmartCem2 (P < 0.001). No significant differences were found between SpeedCem, SmartCem2, and iCem. The predominant failure mode was adhesive failure of cements at the dentine interface except for RelyX Unicem, which, in most cases, showed cohesive failure in ceramic.37

Digital impressions tend to reduce repeat visits and retreatment while increasing treatment effectiveness. Patients will benefit from more comfort and a much more pleasant experience in the dentist’s chair.38

The quality of adaptation of CAD/CAM–generated restorations is an area of current interest. Studies demonstrate the clinically acceptable durability of CAD/CAM restorations for colour matching, interfacial staining, secondary caries, anatomic contour, marginal adaptation, surface texture, and postoperative sensitivity.39–43

Adhesive cementation seems to be the key for the long-term clinical success of CAD/CAM inlays and onlays.44