ABSTRACT
CAD/CAM dentistry was a transformational change for dentistry. It is now possible to accurately scan and fabricate restorations, models, abutments, bars, prostheses and diagnostic wax-ups, as well as to use CAD/CAM for implant and orthodontic planning. Within the restorative dentistry discipline, in-office options for indirect restorations include traditional impressions, CAD scanning for traditional or CAM restoration fabrication, or CAD/CAM with chairside milling. The accuracy, versatility and reliability of CAD/CAM systems as well as their ease-of-use, portability and cost are all considerations. In addition, different types of scanners have different attributes as do the programs supporting digital impressions and CAD/CAM. CAD/CAM has been proven to offer esthetic and durable solutions in esthetic dentistry.

EDUCATIONAL OBJECTIVES
The overall goal of this article is to provide the reader with information on the delivery of indirect restorations using CAD/CAM dentistry. On completing this article, the reader will be able to:

1. Describe the types of procedures that can be performed using CAD/CAM systems;
2. Review the considerations and features available when selecting a CAD/CAM system;
3. List and describe the properties and benefits achieved with laboratory fabricated CAD/CAM restorations versus chairside milling; and
4. Outline the sequence of steps when providing a CAD/CAM laboratory fabricated indirect restoration.

INTRODUCTION
The introduction of dental computer-aided design (CAD) and computer-aided design/computer-aided manufacturing (CAD/CAM) into dentistry has revolutionized the way in which dentistry can be practiced. This transformational development has resulted in advances in the areas of restorative, implant and reconstructive dentistry, as well as orthodontics. From the beginning, CAD/CAM technology has been a promising development.1-4 In particular, digital intraoral scanners have gained in popularity over the last few years as many new systems have been introduced to the market. The development of CAD/CAM dentistry owes its origins to the transfer of technology from industrial manufacturing, just as is the case with initial adhesive technologies. Early CAD/CAM devices offered dentists the ability to capture a digital scan and create an indirect chairside-milled inlay—at that time, inlays were the only type of restoration that was possible using CAD/CAM.

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Dental material advances have also accelerated, with an increased demand from patients for esthetic direct and indirect restorations. The advent of CAD/CAM brought with it the development of new metal-free esthetic materials such as zirconia and high-strength ceramics that can be milled chairside or in the laboratory and that meet these demands. While experimental, CAD/CAM milling of an extracted third molar to create a restoration for a severely compromised tooth was recently reported.

Dental practitioners in multiple disciplines now have several options for incorporating CAD/CAM into the practice. Options for restorative dentistry include: Taking a digital scan and milling the restoration chairside in the office; taking a digital scan and sending the scan data to a dental laboratory for fabrication of the restoration; taking a traditional impression that is then scanned to create a digital impression from which the indirect restoration can be designed in the laboratory; or, pouring a gypsum model from a traditional impression, and scanning the model to recreate it digitally for CAD design. This last option also enables CAD/CAM design and restoration fabrication if there is no scanner available in the office or lab that can directly scan impressions. Although scanning traditional impressions digitizes the information and this data can be used to CAM fabricate models, dies and restorations, it also replicates any errors that were present in the impression. However, it removes the possibility of operator error associated with traditional model pouring and restoration fabrication. The sections below review some of the considerations in using CAD/CAM systems and their properties.

![Figure 1. Digital virtual diagnostic wax-up](image)

<table>
<thead>
<tr>
<th>TABLE 1. CAD/CAM system restorative capabilities</th>
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<tbody>
<tr>
<td><strong>Crows Bridges Veneers Inlays Onlays Implant Abutments Digital Shade Matching Powder Natural Color Scans HD Photos System</strong></td>
</tr>
<tr>
<td>3M True Definition</td>
</tr>
<tr>
<td>3Shape TRIOS</td>
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<tr>
<td>CEREC (Bluecam)</td>
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<tr>
<td>CEREC (Omnican)</td>
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<tr>
<td>PlanScan/E4D NEVO</td>
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CAD/CAM systems

CAD/CAM systems vary in capabilities. Some are now able to scan images for all types of indirect restorations as well as implant components and have modules for different disciplines, while other systems are more specialized by discipline and type of restoration. The versatility of systems in scanning for indirect restorations has increased considerably, and several systems now offer a broad range of indirect restorative options. Diagnostic wax-ups and models are now also options with some systems, as well as CAD/CAM creation of implant abutments and components, without the need for additional programs. Combining CBCT scans with digital impressions is another option, for accurate implant planning and digital manufacturing of surgical guides using 3D printers. Table 1 shows the scanning capabilities of current systems for restorations.

Different systems use differing methods for image acquisition and processing routes to obtain data for restorations. Methods used for image acquisition include blue light emitting diode (LED) light (note that if the blue LED Light is shortwave, it will not produce color images), blue laser technology, multiple single images that are then stitched together to create a 3D image, optical scanners, continuous acquisition (“streaming”) of optical images. All are designed to produce high accuracy images.

Differentiating factors include the use of powder and scanning versatility. While the earliest systems used powder, increasingly systems have evolved to where powder is not required to scan preparations. Systems providing color images enhance the visibility of the scans in colors that approach real life, which helps the clinician read the scan and identify any areas of concern that may need adjusting or rescanning. If physical models are required, rather than virtual models, these can be milled or printed in the laboratory using CAD/CAM and sent to the office. These models are free of the defects associated with pouring stone/plaster models from traditional impressions, and are stronger than traditional models as well. Models have been found to be reliable and accurate with blue LED light scanning when measured against laser-based scanning.

Shade matching is now also automated in CAD/CAM with one system, which also takes digital intraoral photographs. Traditional shade matching is subject to error - when using a Vita shade guide, daylight and artificial light sources influence the shade perceived by the user, which can result in false readings and shade requests. In addition, the color of lipstick and clothing affects the perceived shade when using the naked eye to determine shade(s) as do variances in the optical abilities of individuals. The scanner automatically reads the shades of the adjacent teeth while scanning the area for the preparation(s) and adjacent topography. This removes the possibility of human error/misperception of shades, and also saves time by removing a step in the process. The shades are automatically noted on the images at several points and can be viewed on the screen. There is no need to write a shade on the prescription since it is automatically entered into the data. The ability to separately take intraoral photographs using a CAD/CAM scanner is an additional new option. These can be superimposed over the scanned image, with the potential to improve readability and detection of any areas of concern.

**Footprint, Portability and Flexibility**

Further considerations include the space required for the scanning device (and in-office milling machine if this is being considered). A system that uses a cart system offers flexibility to move it between operatories. The ultimate in portability is obtained with a portable “pod” solution that uses a laptop into which the scanner is plugged via a USB port. This degree of flexibility with a scanner system means that the same device can be used in different locations; in other words, only one device need be purchased if, for instance, there are two locations and its use is not highly intensive at both locations. Conversely, where CAD/CAM scanning will be performed in only one operatory, depending on the system an alternative solution to a cart or pod is to integrate the system into the chair.

**TABLE 2. CAD/CAM options and attributes**

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Chairside Milling:</strong></td>
<td>Removes need for a separate seat appointment</td>
</tr>
<tr>
<td></td>
<td>No provisional is required</td>
</tr>
<tr>
<td></td>
<td>Greater chairside time is required</td>
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<tr>
<td></td>
<td>Cost of equipment is high, but no lab fees</td>
</tr>
<tr>
<td></td>
<td>Requires space in the operatory</td>
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<tr>
<td><strong>Laboratory Milling:</strong></td>
<td>Still requires a separate seat appointment</td>
</tr>
<tr>
<td></td>
<td>A provisional restoration is required</td>
</tr>
<tr>
<td></td>
<td>Reduces cost of equipment in-office; incurs lab fees</td>
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<tr>
<td></td>
<td>Enables collaboration with laboratory</td>
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<tr>
<td></td>
<td>More complex customization is possible</td>
</tr>
<tr>
<td></td>
<td>Simplifies process for clinician (polishing/glazing in lab)</td>
</tr>
<tr>
<td></td>
<td>Reduces chairside time</td>
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PAGE 3
Laboratory fabrication or chairside milling
The process following image acquisition represents fundamental differences between CAD/CAM systems. The ability of some to enable chairside fabrication using an in-office milling machine allows same-visit creation and seating of indirect restorations. This saves the patient having to return a second time, potentially receiving a second local anesthetic and removes the need for a provisional restoration and the cost involved. By avoiding a second appointment, some office time including turnaround time is also saved.

On the other hand, digitally transmitting scanning data from the office to the laboratory or a central manufacturing location is quick and saves chair time although a provisional restoration and separate seat appointment are necessary. If a scan is first sent to the laboratory, a provisional restoration can be fabricated using CAD/CAM and delivered to the office as an alternative to chairside or traditional laboratory fabrication. Laboratory milling/fabrication also means that staining and glazing is not required in the office, which saves time in the dental office, and more complex esthetic tailoring of the restorations can be achieved. Polishing, staining and glazing in the laboratory simplifies the process for the clinician. A CAD/CAM restoration that is laboratory milled/fabricated does obviously incur a lab fee; however, the CAD/CAM scanner is significantly less expensive than also acquiring a milling machine and provides a less expensive point of entry for clinicians. Restoration customization is enhanced when required.

When considering purchase of a CAD/CAM system that will be used collaboratively with your laboratory, it is helpful to consult with your dental lab technician. He/she may have excellent knowledge of digital dentistry and may have experience with the software of several systems as well as open architectures that are compatible with several types of CAM milling devices. In this regard, the lab may be able to give you advice that will enhance collaboratively working on CAD/CAM dentistry. Some CAD/CAM systems’ software programs are ‘closed’ meaning that the files can only be transferred and used for specific devices. Other systems are ‘open’, meaning that the digital files can be transferred with an ‘open connection’ that allows the laboratory to use virtually any CAD/CAM system for fabrication. This increases flexibility and versatility.

Ultimately, scanners are vehicles for obtaining dental images in CAD/CAM dentistry — they still require a suitable preparation design and accurate image acquisition. The latter relies on the scanner being able to “access” the area, which requires soft tissue retraction around the margins where these are subgingival or equigingival as well as adequate isolation. Options for soft-tissue retraction, when required, remain the same as with traditional techniques and include the use of either gingival retraction cord (with or without hemostat), a displacement cap, or the use of a putty-like retraction paste that also provides for hemostasis. A further option is a soft-tissue laser, which troughs the tissue (rather than retracting it, soft tissue is ablated) and also provides for hemostasis.

Regardless of which CAD/CAM option is chosen and regardless of which retraction method is selected, accurate image acquisition of the preparation as well as the adjacent dentition and opposing arch is still paramount in delivering accurate, functional and long-lasting indirect restorations and prostheses.19-22 The case below shows the methodology, scanning and imaging results and final indirect restorations using CAD/CAM dentistry.

Case Presentation
The patient in this case was a 45-year-old female. Her chief complaint was a tooth on her lower left that was painful on biting. On examination, tooth #19 was found to have multiple fractures in the tooth structure surrounding a large occlusal amalgam (Figs. 2, 3). Pain on biting was isolated to the mesiolingual cusp. A full mouth examination was performed, and radiographs were taken that included bitewings and periapicals. No pathology was found on tooth #19 other than the fracture. After discussing this with the patient, a decision was reached to treat this tooth with a full cuspal coverage porcelain restoration. It was also decided that a digital impression system would be used – this was particularly advantageous since the patient was a gagger and would not tolerate traditional impressions well.

At the first treatment appointment, local anesthesia was given to the patient and the preparation was created. The old restoration and fractures were removed, resulting in a full cuspal coverage preparation. No buildup material was needed due to the selection of a high-strength ceramic that would be adhesively bonded. As mentioned earlier in this article, accurate image acquisition is still essential, and the margins must be accessible for the scanner. Soft tissue retraction was not needed in this case as the preparation margins were all supragingival.

The Trios pod was used for scanning (3Shape, Copenhagen), using the handheld scanning handpiece plugged into a laptop via the USB port. A scan was taken of the preparation together with the adjacent teeth. Scanning the adjacent teeth provides for built-in detail shade mapping, which ultimately results in an excellent restoration shade match. Scans were also taken of the lower opposing quadrant, which took around 1 minute, and of the opposing arch. Next, a high-definition clinical image was taken using the scanning handpiece.

During scanning, the patient was able to hold an iPad connected via Bluetooth to the computer and watch the scanning procedure. This engages patients with the technology, keeps them involved in their treatment and helps during diagnosis of other issues. Once connected, an iPad also can be used as a touch screen by the clinician during scanning and analysis.

After image acquisition was complete, the case was digitally analyzed to double check that there was sufficient interocclusal space and a suitable insertion profile. The scan
Figure 2. Presentation of tooth #19

Figure 3. Tooth #18 following removal of the old amalgam restoration

Figure 4. Inter-occlusal space verification with green color coding indicating appropriate space is present

Figure 5. Insertion profile

Figure 6. Scan of opposing arch

Figure 7. Interface of the scan and clinical image. Note the true-to-life color imaging, making visualization easier

Figure 8. Scan prepared for transmission to laboratory

Figure 9. Margin line on the virtual model
of the preparation and the opposing arch were checked and found to be satisfactory (and could otherwise have been rescanned in specific areas without rescanning the whole arch). The photograph was also digitally superimposed over the scan to view the high-definition margins of the prep (Figs. 4-7).

The scans were then prepared for transmission to the laboratory, together with the case’s digital prescription form and the automatically generated shade measurements that were present on the scan image of the preparation and adjacent teeth (Fig. 8).

The patient was provided with a provisional crown, which was checked after seating. At the same visit, the leaking occlusal amalgam and caries in the adjacent molar was removed and replaced with a composite. Selective etching was performed on the enamel margins and a single-component, light-cured adhesive was used prior to restoring with a nanohybrid resin composite. The patient was then dismissed.

When the virtual model and dies were developed in the laboratory, these were digitally viewed in the office along with the proposed crown form (Figs. 9-11). One of the advantages of the CAD/CAM scanner system used is that it is an open system, allowing the laboratory to determine the CAD/CAM fabrication method that it preferred.

The crown was fabricated using monolithic lithium disilicate. On delivery, at the patient’s seat appointment, the fit, margins, occlusion and shade were first checked; no adjustments were necessary. A one-step universal adhesive was applied and cured, the crown was then luted using a transparent shade dual-cured resin cement, and the occlusion again checked. The patient was pleased with the esthetic result and appearance of the crown (Fig. 12).

Conclusion

CAD/CAM dentistry has opened up new possibilities in dentistry in several disciplines. Esthetic restorative care has been streamlined with CAD/CAM, with several options available – the clinician can digitally scan the preparation and either mill the restoration chairs side or send the digital files to the laboratory. There are advantages to both methods. CAD/CAM system selection needs careful consideration of the scanning device and software, its versatility and flexibility, accuracy, and ease-of-use. When it is planned to use a laboratory for fabrication of the restorations, it is also helpful to discuss with your laboratory technicians and to find out what their experience has been with different systems. Using a scanning system that also automatically provides for shade matching and intraoral imaging at the same time as scanning the preparation(s), adjacent teeth and opposing arch saves time and further streamlines the process. Regardless of which system is used, accurate image selection is essential.
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PAGE7