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Contents

ICDAS Code	Description
0	Sound tooth surface
1	First visual change in enamel
2	Distinct visual change in enamel
3	Localized enamel breakdown due to caries with no visible dentin
4	Underlying dark shadow from dentin (with or without enamel breakdown)
5	Distinct cavity with visible dentin
6	Extensive distinct cavity with visible dentin

Figure 1.2 ICDAS caries classification system.

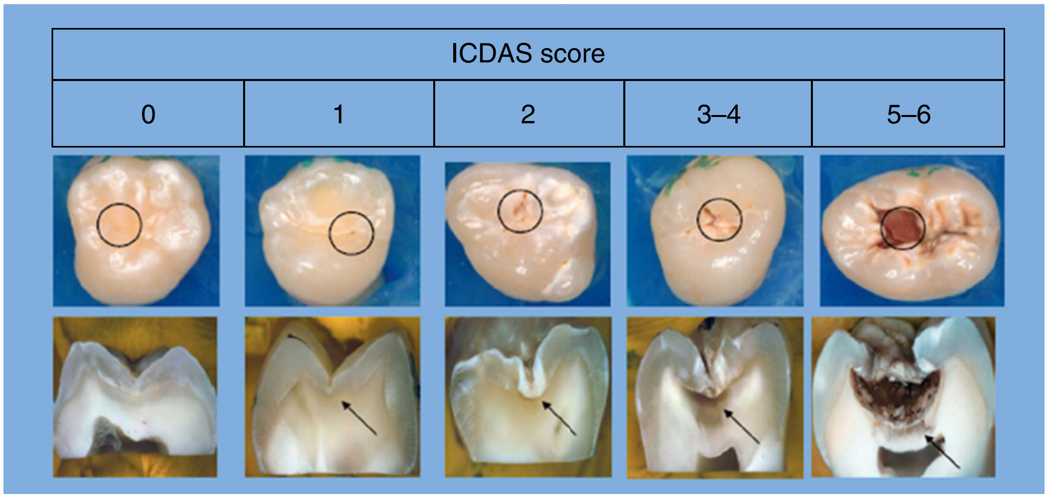


Figure 1.3 ICDAS clinical examples.

conservative therapies (Bravo et al. 1997, Marinho et al. 2003, Petersson et al. 2005). This scenario for managing teeth with early caries will hopefully make some inroads into the decades-old practice of restoring small demineralized areas because they are going to need fillings anyway and you might as well fill them now instead of waiting until they get bigger (Baelum et al. 2006). Continuing to stress the preventive approach to managing early caries begins with early diagnosis. What better way to "do no harm" to our patients than to avoid placing restorations in these teeth with early demineralized enamel lesions and remineralize them instead?

1.1.4 Non-Radiographic Methods of Caries Diagnosis

1.1.4.1 Quantitative Light-Induced Fluorescence

It has been shown that tooth enamel has a natural fluorescence by using a CCD-based intraoral camera with specially developed software for image capture and storage quantitative light-induced fluorescence (QLF) Patient, Inspektor Research Systems BV, Amsterdam, The Netherlands. QLF technology measures (quantifies) the refractive differences between healthy enamel and demineralized, porous enamel with areas of caries and demineralization showing less fluorescence. With the use of a fluorescent dye, which can be applied to dentin, the QLF system can also be used to detect dentinal lesions in addition to enamel lesions. A major advantage of the QLF system is that these changes in tooth mineralization levels can be tracked over time using the documented measurements of fluorescence and the images from

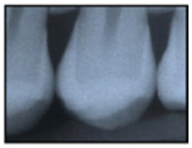
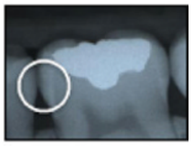
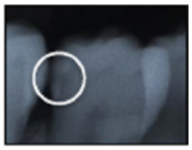
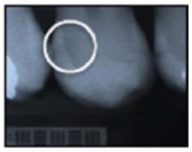
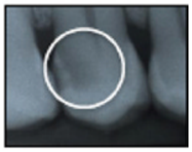
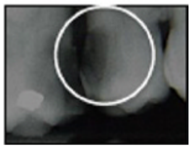
	ICDAS Radiographic scoring system			
ICCMS™ Caries Categories	0	No radiolucency		No radiolucency
	RA: Initial stages	RA 1		Radiolucency in the outer ½ of the enamel
		RA 2		Radiolucency in the inner ½ of the enamel ± EDJ (enamel-dentine junction)
		RA 3		Radiolucency limited to the outer 1/3 of dentine
	RB: Moderate stages	RB 4		Radiolucency reaching the middle 1/3 of dentine
	RC: Extensive stages	RC 5		Radiolucency reaching the inner 1/3 of dentin, clinically cavitated
		RC 6		Radiolucency into the pulp, clinically cavitated

Figure 1.4 ICDAS radiographic scoring system.

the intraoral camera. The third generation Qraycam system has been shown to produce markedly improved results at caries detection when compared with earlier models (Angmar-Månsson and Ten Bosch 2001, Pretty and Maupome 2004, Amaechi and Higham 2002, Pretty 2006, Park et al. 2019).

1.1.4.2 Laser Fluorescence

The DIAGNOdent uses laser fluorescence for caries detection, a technique that relies on the differential refraction of light as it passes through sound tooth structure versus carious tooth structure. As described by Lussi et al. in 2004, a 650 nm light beam, which is in the red spectrum of visible light, is introduced onto the region of interest on the tooth via a tip containing a laser diode. As part of the same tip, there is an optical fiber that collects reflected light and transmits it to a photo diode with a filter to remove the higher-frequency light wavelengths, leaving only the lower-frequency fluorescent light that was emitted by the reaction with the suspected carious lesion. This light is then measured or quantified, hence the name "quantified laser fluorescence." One potential drawback with the DIAGNOdent is the increased incidence of false-positive readings in the presence of stained fissures, plaque and calculus, prophy paste, existing pit and fissure sealants, and existing restorative materials. A review of caries detection technologies published in the *Journal of Dentistry* in 2006 by Pretty that

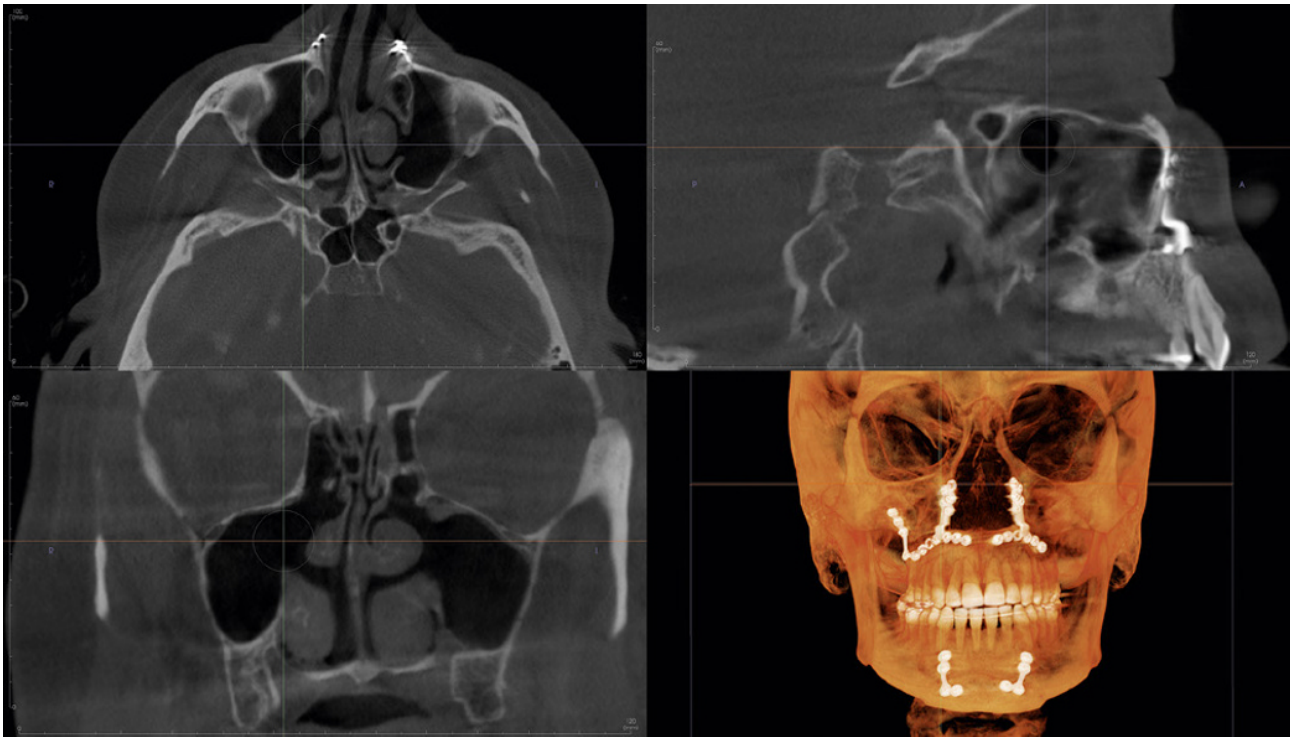


Figure 1.5 MPR images illustrating bilateral antrostomies in a patient with a history of a LeFort I maxillary advancement and genioplasty. The software is In Vivo Dental by Anatomage (Santa Clara, CA, USA), the patient was imaged with a Planmeca ProMax CBCT machine (Helsinki, Finland).

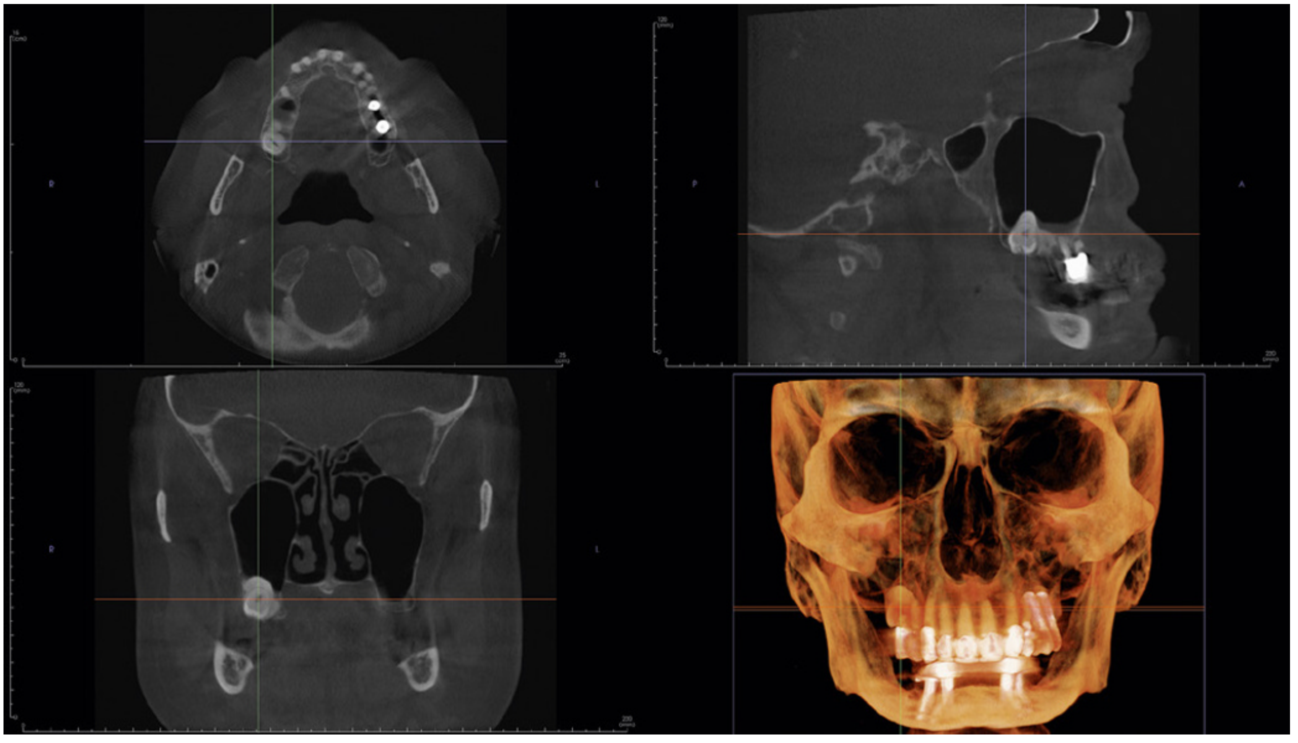


Figure 1.6 MPR images highlighting an impacted maxillary right third molar on a patient with four mandibular implants supporting an attachment retained mandibular RPD. The software is In Vivo Dental by Anatomage; the patient was imaged with a Carestream 9300 CBCT machine (Atlanta, GA).

when the scanner is rotated 90° from the occlusal surface because of the reduced overlap of previously and newly scanned data (Figure 2.5).

The importance of scanning strategies cannot be overstated, and, once again, the importance of understanding the specific scanner used and the scan strategies suggested by the manufacturer is emphasized. If these suggested scan strategies and principles are not followed, there is a much greater chance of incorporating errors into the scan that may or may not be identified. Some examples of suggested scan strategies are shown below (Figure 2.6).

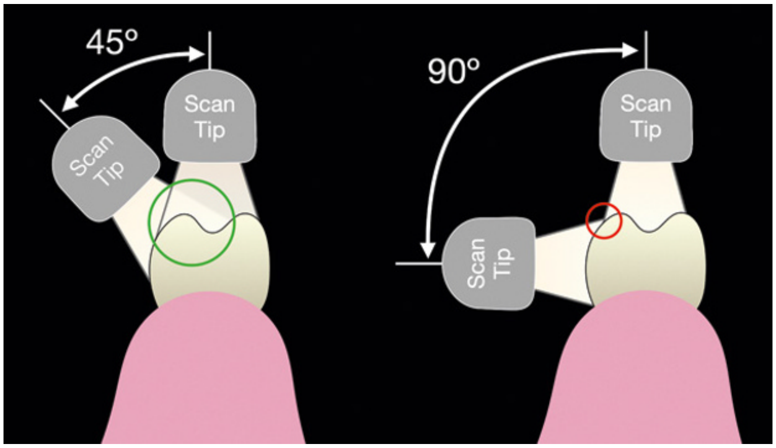


Figure 2.5 When transitioning from occlusal to buccal or lingual surface, it is suggested to rotate the scanner 45° to ensure adequate overlap of scanned data (green circle). If rotation approaches 90°, reduced overlap (red circle) can lead to stitching errors at this location.

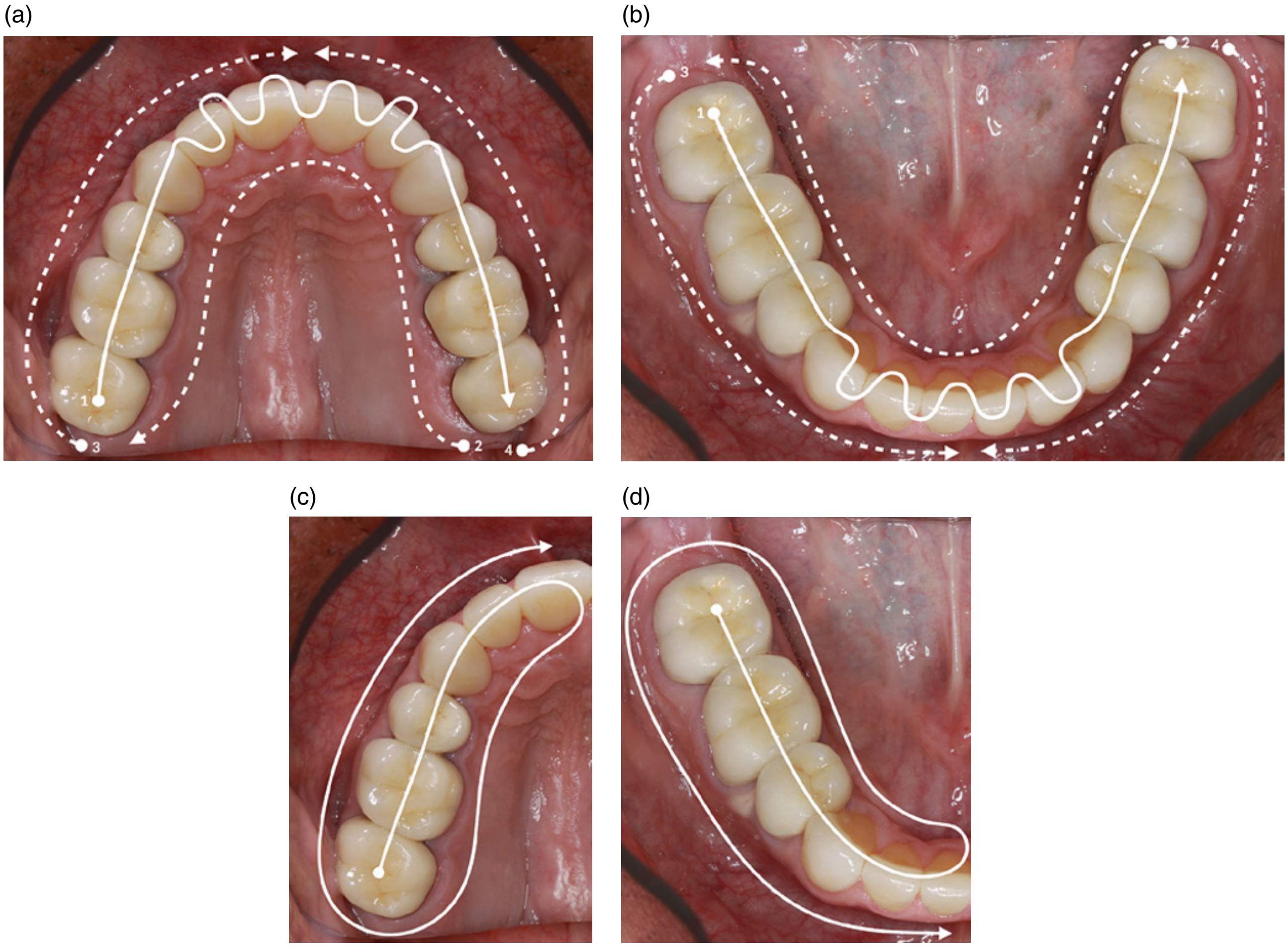


Figure 2.6 (a) Maxillary complete-arch scan strategy; (b) mandibular complete-arch scan strategy; (c) maxillary quadrant scan strategy; (d) mandibular quadrant scan strategy.

Figure 2.8 Intraoral picture of implant scan body

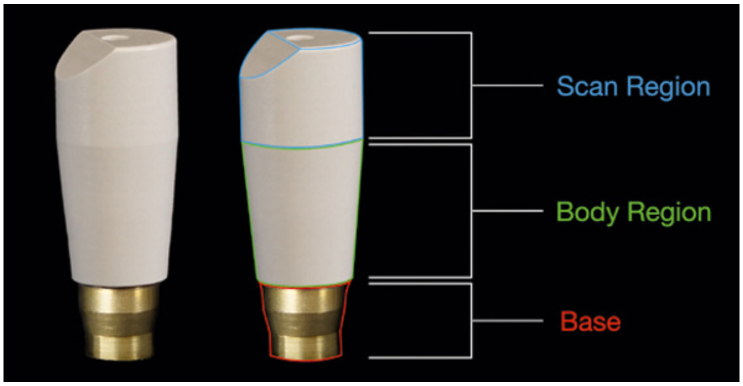


Figure 2.9 Implant scan body regions.

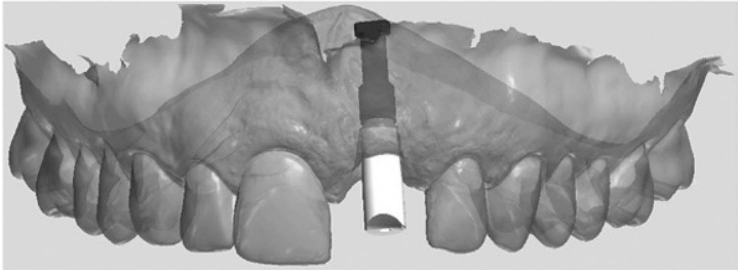


Figure 2.10 Digitized scan body with virtual implant analog.

Some key considerations when selecting a scan body have been described and summarized by Mizumoto and Yilmaz (2018) who conducted a systematic review of implant scan bodies. The most critical consideration when selecting a scan body is to ensure compatibility with the design software used by the laboratory. This compatibility can determine whether a designed restoration can be milled in house with your laboratory or if it must be sent to the implant manufacturer for fabrication. This compatibility must be researched prior to scanning to know the limitations and to select the correct scan body accordingly. Considerations include the scan body material, connection material, reusability, and cost. Scan bodies should be made of a dull, smooth, and opaque surface, allowing the scanner to easily capture its shape (Li et al. 2017; Kurz et al. 2015). The material used at the connection with the implant is another important consideration. Some scan bodies are fabricated entirely of PEEK material including the connection with the implant. Others are fabricated using PEEK for the scan region of the scan body while using metal at the connection. A metal connection provides a more stable and durable interface with the implant. This metal interface will lead to more clinical uses before the scan body needs to be replaced. The exact number of uses for the scan bodies is unknown but factors such as the interface material and sterilization cycles would likely play a role in determining the exact number of uses (Sawyers et al. 2019). With a clear understanding of these factors, the correct scan body can be selected and used to digitally transfer the implant location from the patient's mouth to the computer.

Multiple systematic reviews have been performed to evaluate the accuracy of intraoral scanning of dental implants. These reviews have reported many factors including the distance between scan bodies, depth of the implant, location within the arch, increased torque of the scan body, saliva, fogging of the optics, and using intraoral scan spray. Overall, they concluded that implant scan bodies are complex transfer devices that have many variables that must be understood but offer a valid

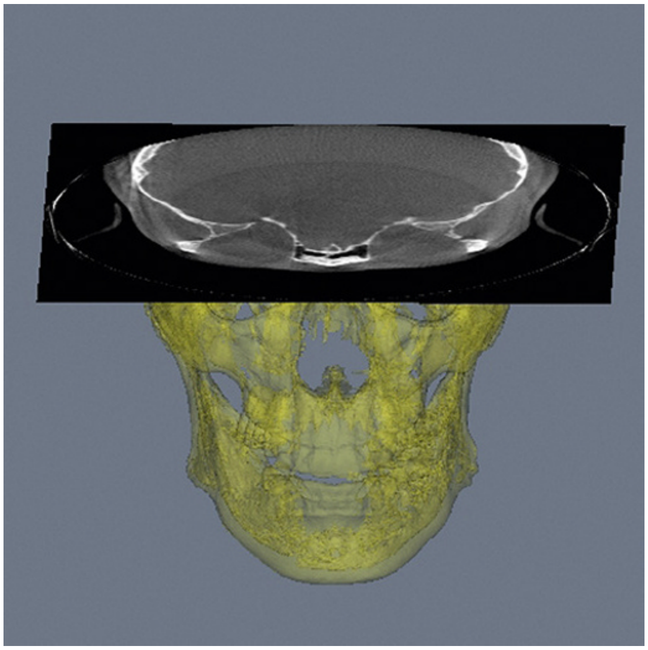


Figure 3.3 Medical images such as a CT scan are a stack of axial slices that can be stacked to build a 3D image.

Figure 3.4 A 5-axis computer numerical control (CNC) milling machines.

Figure 3.5 Example of the irregular organic shapes that are best fabricated using additive manufacturing techniques.

dental profession begin to prevail, there has been a trend toward flexibility between scanners, design software, and manufacturing devices, with more open options (interoperability) available.

System interoperability is dependent on the use of a common file format for the "Scan" step forward in the workflow. This has been achieved in medical imagery with the near universal adoption of the DICOM file format, developed by the National Electrical Manufacturers Association (NEMA) for storage of all medical images. MRI, CT, ultrasound, and other medical imaging systems all use this file format to describe their images. DICOM enables the integration of scanners, servers, workstations, printers, and network hardware from multiple manufacturers into a picture archiving and communication system. The different devices come with DICOM conformance statements that clearly state which DICOM classes they support. DICOM has been widely adopted by hospitals and the Department of Defense Medical Care systems. However, the standard is not widely accepted in dentistry, demonstrated by the proprietary image formats common in some cone beam CT scanners, intraoral scanners, and dental CAD/CAM systems.

Figure 4.3 Post-processing procedures of a vat-polymerized diagnostic cast. (a) additively manufactured diagnostic cast being remove from the building platform; (b) rinsing procedures for cleaning the unpolymerized resin located on the surfaces of the additively manufactured diagnostic cast; (c) diagnostic cast after post-polymerization methods; (d) removing the supportive material from the additively manufactured diagnostic cast.

To maximize the manufacturing accuracy and characteristics of the AM dental devices, it is recommended to follow manufacturing protocol including the optimal printing parameters and post-processing methods for a particular material and printer choice recommended by the manufacturers.

4.3.3 Material Extrusion

Fused deposition modeling (FDM) technology was developed and patented by Scott Crump who founded the Stratasys Company (Crump 1992). Material extrusion or FDM process is an AM procedure in which a thermoplastic material is selectively dispensed through a nozzle, where it is heated and then deposited in a layer. After the completion of the first layer, the extrusion heads move up or the building platform moves down to facilitate the delivery of the subsequent layer of material. The procedure is repetitive until the 3D object is manufactured (ISO:17296-2:2015, ISO:52900).

Figure 5.15 Typical milling tools used for zirconia or PMMA.

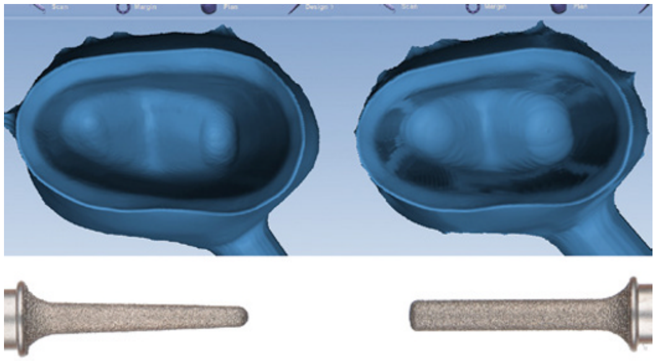


Figure 5.16 Pattern and size of surface adjustments are different depending on the size and shape of milling tools: a smaller milling tool (left, 1 mm round-ended) requires less surface adjustment, but requires a longer milling time and more frequent tool replacement; a larger milling tool (right, 1.7 mm flat-ended) may require shorter milling time and less frequent tool replacement, but it requires more aggressive surface adjustments for tool diameter compensation.

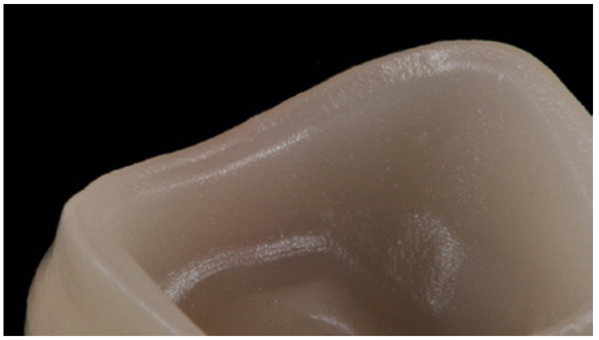


Figure 5.17 Margin overhang due to improper finishing: restoration margins should be manually finished after milling to remove extra material added around the margins.

Figure 5.18 Three-dimensional printed resin model is used to adjust proximal and occlusal contacts; it is especially useful when multiple restorations are planned.

(a) (b)

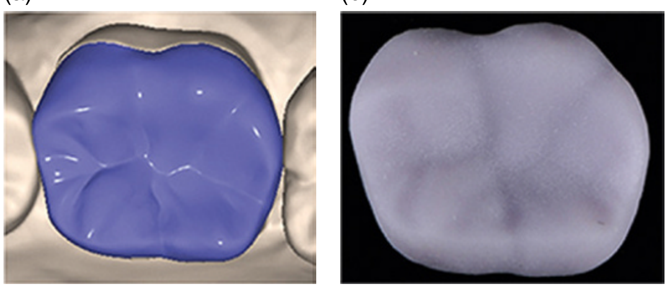


Figure 5.19 (a) Virtual design with detailed anatomy and deep grooves; (b) deep occlusal grooves that are narrower than the milling tool diameter may not be perfectly reproduced.

restorations. Although grinding zirconia for minor occlusal or proximal contact adjustments can be done without compromising its mechanical properties, excessive grinding after sintering should be avoided to preserve the structural integrity of the zirconia restoration (Kosmac et al. 1999, Pereira et al. 2016).

Like most other ceramic restorations, monolithic zirconia restorations can be polished or glazed. Polishing may be preferred to finish occlusal surfaces, especially maxillary occlusal surfaces, as some studies have shown that polished zirconia causes less wear on the opposing teeth compared with glazed zirconia or most other types of ceramic restorations. When coloring liquids are applied before sintering, polishing would not significantly alter the surface color if the infiltration depth were sufficient. However, it is sometimes difficult to achieve ideal color match by just using pre-sinter coloring liquids. If additional color adjustment is necessary, external staining and glazing can be used to correct color and add surface characteristics. While this is a very widely used approach, long-term color stability of post-sinter external staining and glazing on zirconia restorations may not be as great as that of glass-ceramic restorations (Yuan et al. 2018, Sulaiman et al. 2020).

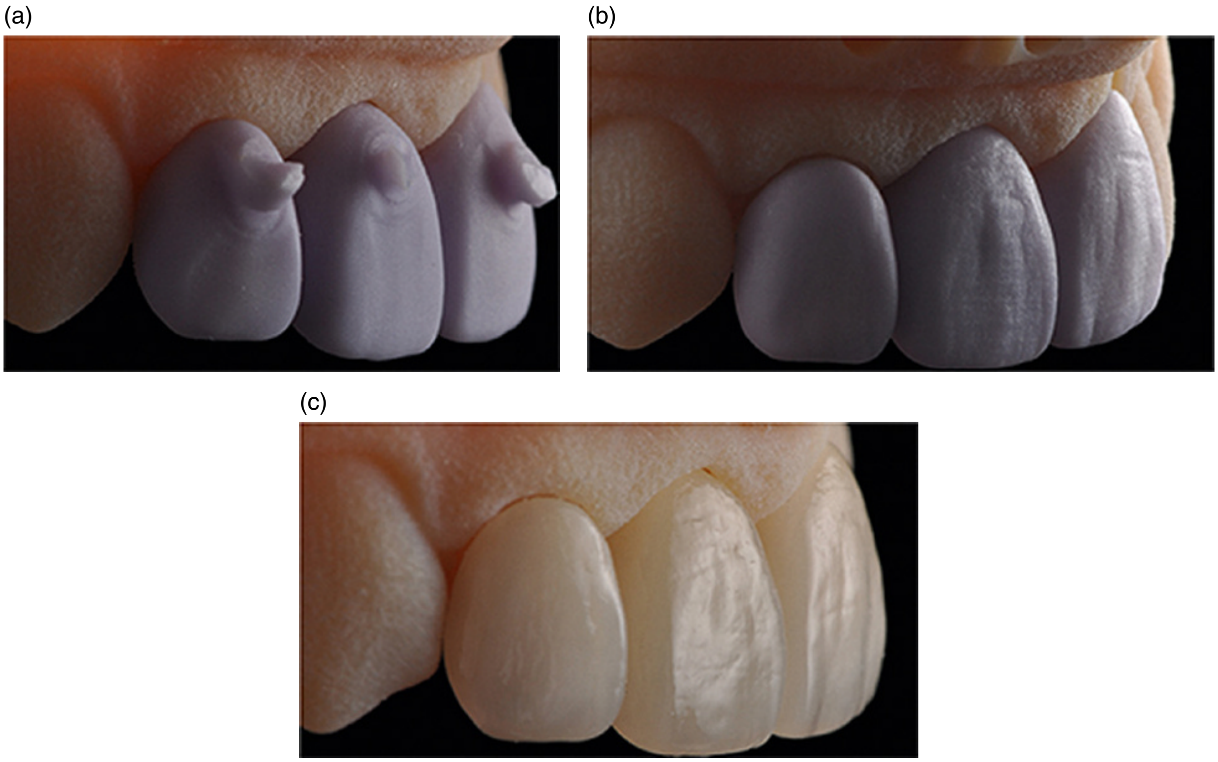


Figure 5.20 (a) Pre-crystallized lithium disilicate glass-ceramic restorations: the milled restorations lack detailed surface anatomy; (b) manually created surface anatomy: gentle grinding with sharp rotary tools can be used; (c) completed restorations.

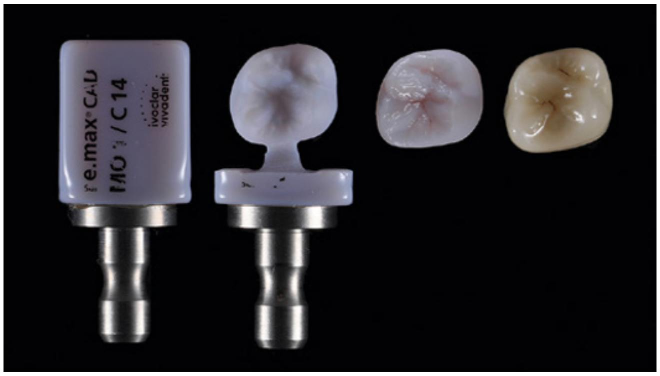


Figure 5.21 Lithium disilicate ceramic block: milled restoration, external stain, and glaze application, fully crystallized restoration (from left to right).

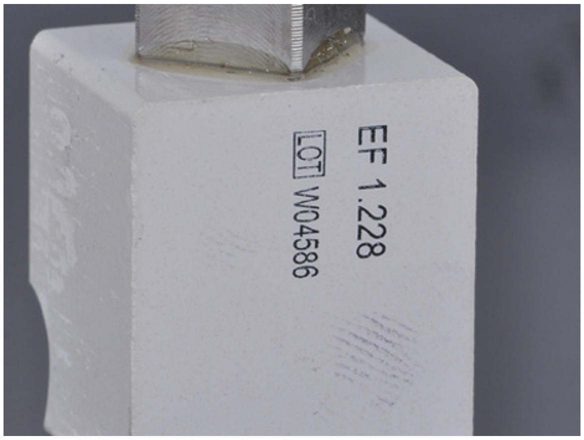


Figure 5.22 Enlargement factor is usually provided by the manufacturer or pre-programmed in the milling system.

Monolithic zirconia restorations have gained popularity due to their excellent mechanical properties combined with recently improved optical properties. Translucency of zirconia can be enhanced by increasing the amount of stabilizers such as yttria. About 4 or 5 mol% yttria partially stabilized zirconia ceramics are often called translucent zirconia ceramics as they show improved translucency compared with 3 mol% yttria partially stabilized zirconia. However, translucent zirconia ceramics should be used with caution because their mechanical properties are not as great as those of opaque 3 mol% zirconia (Zhang et al. 2016, Carrabba et al. 2017). Also, translucency of 4–5 mol% zirconia is still lower than that of highly translucent glass ceramics such as lithium disilicate (Harada et al. 2016, Harianawala et al. 2014).

There are cases that manual ceramic veneering is required to achieve optimal esthetic outcomes. Unlike lithium disilicate ceramic, full veneering of the whole facial side is normally used for zirconia restorations instead of selective