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Crafting precision: A comprehensive narrative review on the impact of CADCAM technology in operative dentistry

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Abstract
Introduction: Integrating CAD/CAM (Computer-Aided Design/Computer-Aided Manufacturing) technology has significantly transformed operative dentistry.
Methods: English language articles were searched in various databases such as Pubmed, Scopus, Science Direct, and Google Scholar. The keywords used for searching were "CADCAM", "Operative dentistry" and "Recent Advancements."
Conclusion: The present review spotlights the history, components of CAD CAM, and its application in operative dentistry with an emphasis on tooth preparation guidelines and digital workflows for various types of restorations, and the precision offered by CAD/CAM technology followed by its advantages and disadvantages.

Keywords: CAD/CAM, operative dentistry, recent advancements

Introduction

Computer-aided design/computer-aided manufacturing (CAD/CAM) has gained prominence in dentistry, evolving from creating impressions to final restorations, encompassing various dental prostheses. [1] The processes involve converting non-digital data to digital, editing, and reconverting it into a physical form, often utilizing 3D printing or milling in a "digital workflow." [2] CAD/CAM technology enhances traditional restorative methods, streamlining design, manufacturing, and cost-efficiency. Despite its benefits, chairside procedures can be time-consuming and more expensive than traditional methods. CAD/CAM dentistry employs both subtractive and additive processes, offering flexibility for dental labs and dentists. [3] It consists of three main components: a data acquisition unit, software for virtual restoration creation, and an automated milling machine. Beyond the core processes, CAD/CAM technology allows additional procedures, enhancing restoration quality. Dentists and labs recognize its productivity and cost-saving benefits. Staying informed on evolving CAD/CAM advancements is crucial for practitioners navigating this dynamic field.

CAD/CAM technology has revolutionized restorative dentistry by providing digital solutions for designing and fabricating dental restorations. This involves using computer software to create a virtual design, which is then translated into a physical object using milling or 3D printing technologies.

This narrative review explores recent insights into recent CAD/CAM technology integrated into Glass Ceramic, Zirconia, Inlays, Onlays and Veneers tailored for dentistry. **This information aids dentists in making informed decisions about utilizing these technologies effectively in their practices.**

History of CAD/CAM

The history of CAD/CAM (computer-aided design/computer-aided manufacturing) in dentistry traces back to the 1970s, marked by the exploration of its potential to achieve precise and customized dental restorations. Early attempts focused on digitally capturing tooth surfaces and employing computer-assisted milling for fabrication. The concept of numerically controlled machines (NC machines) preceded CAD, with advancements in machining techniques and programming languages like APT contributing to automation. CAD software emerged in the 1960s, evolving through the decades with the introduction of 3D modeling and companies like Autodesk. [4]

In dentistry, pioneers like Dr. Duret contributed to the development of dental CAD/CAM systems, leading to the first commercially available system, CEREC, in the 1980s. Over the years, advancements in data acquisition, computing power, and milling systems have improved precision and fit in dental restorations, meeting stringent standards set by organizations like the American Dental Association. Today, CAD/CAM technology has converged, offering integrated software for both design and manufacturing across various industries.

Components of CAD/CAM

CAD/CAM systems revolutionize dental restoration by incorporating three main components: a data acquisition unit, design software, and a milling device. [5]

1. **Data Acquisition Unit**
- **Intraoral Scanners:** These devices capture highly detailed images of the patient's teeth and gums directly within the mouth. The use of intraoral scanners eliminates the need for traditional impression materials, making the process more comfortable for the patient and providing immediate digital data for further processing.

- **Extraoral scanners:** In cases where intraoral scanners are not used, traditional impression materials can be employed. These impressions are then scanned using a laboratory extraoral scanner to convert the physical mold into a digital format. This step ensures that even traditional methods can be integrated into the digital workflow.

2. **Design Software**
- **Virtual Design of Restorations:** The design software allows clinicians and dental technicians to create a virtual model of the dental restoration. This software offers tools for precise customization, ensuring that the restoration fits perfectly with the patient's anatomy and occlusion.

- **Customization and Visualization Tools:** Advanced features in the software enable the manipulation of the virtual model, including adjusting the shape, size, and contour of the restoration. The visualization tools provide a realistic preview of the final product, allowing for any necessary adjustments before fabrication. These tools are crucial for achieving optimal esthetics and functionality.

3. **Milling Device**
- **Fabrication of Physical Restorations:** The milling device takes the virtual design and converts it into a physical restoration. This is done by either subtractive or additive manufacturing processes.

- **Subtractive Manufacturing:** In this process, the milling device carves the restoration out of a solid block of restorative material, such as ceramic, composite, or metal. This method is known for its precision and is commonly used for creating crowns, bridges, and other restorations.

- **Additive Manufacturing:** Also known as 3D printing, this process builds the restoration layer by layer from various materials, including resins and metals. Additive manufacturing is particularly useful for creating complex geometries and customized dental appliances.

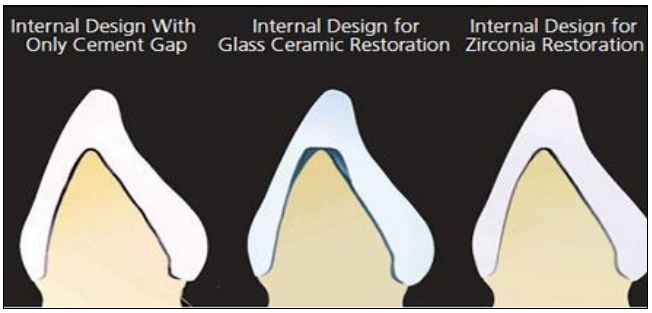
By integrating these components, CAD/CAM systems streamline the process of creating dental restorations. They provide clinicians and technicians with efficient tools for achieving precision and customization, ultimately enhancing the quality and functionality of dental prostheses. This technology not only improves the patient experience by reducing the number of visits and time spent in the chair but also allows for the production of highly accurate and durable restorations. [6]

CAD/CAM in Operative Dentistry

Intraoral Scanning and Tooth Preparation

Achieving successful intraoral scanning for CAD-CAM prostheses requires careful consideration of tooth preparations. Specific tooth preparation guidelines for chairside glass ceramic and zirconia restorations are outlined, addressing issues such as overmilling and dimensional changes during the manufacturing process.

Glass Ceramic Restorations



When using CAD/CAM technology for ceramic restorations, precise tooth preparation is crucial. Anterior teeth necessitate a reduction of 2 mm incisally, 1.5 mm facially, and 1 mm lingually. Posterior teeth require a 2 mm occlusal and 1.5 mm axial reduction. Maintain a uniform 1 mm chamfer margin around the tooth, ensure smooth prepared walls, round internal line angles, and eliminate undercuts. Additional refinements for CAD/CAM restorations are vital for compatibility with the chosen milling unit. Incisors, being taller and narrower, are at higher risk, requiring an extra 1 mm incisal edge thickness for accurate reproduction. Adjustments for posterior teeth involve creating flatter and broader cusps (1 mm thickness) to counter CAD/CAM milling limitations and prevent excessive material loss. If preparing boxes or grooves, eliminate sharp corners to avoid overmilling,

Fig 1. An anterior restoration showcasing an optimal, consistent cement gap and glass ceramic and zirconia drill compensations.

ensuring a smooth transition from axial wall to groove.

Standard bur dimensions are typically 1.8 mm in diameter for the cylinder-pointed bur on the external surface and 1 mm or 1.3 mm for the step bur on the internal surface. Overmilling occurs when the internal surface points are narrower (<1 mm) than these bur sizes, causing excessive reduction, material thinning, and potential restoration failure.

Zirconia Restorations

In contrast to glass ceramics, zirconia restorations exhibit minimal impact from overmilling. The article discusses the advantages of milling zirconia in an enlarged dimensional state, compensating for sintering-induced shrinkage and allowing for more anatomically shaped preparations.

An anterior restoration in Figure 1 demonstrates an optimal cement gap, showcasing effective drill compensation for both glass ceramic and zirconia restorations. Milling zirconia in an enlarged state, owing to the material's partial sintering and subsequent 25% to 30% volumetric shrinkage during sintering, results in a reduced milling tool diameter by the same percentage. This process minimizes tool wear and the need for extensive drill compensation. Ultra-translucent zirconia emerges as an excellent choice for anterior teeth, especially with delicate incisal edges, offering

flexibility in preparation. For monolithic zirconia in posterior teeth, the minimal impact of overmilling allows for anatomically shaped preparations without the need to extensively consider dimensional changes during milling and sintering, setting it apart from glass ceramics. [2, 4]

Inlay Restoration

The preparation of occlusal cavities and approximal boxes in ceramic restorations emphasizes addressing specific defects over creating parallel-walled surfaces and sharp transitions to the cavity floor. Utilizing diamond burs with rounded transitions facilitates the creation of concave shapes, promoting the desired "round" transition. Adhesive bonding negates the previous necessity for parallelism in "box walls," focusing instead on micromechanical adhesion to enamel and dentin. Studies suggest that ceramic inlay fracture risk increases with a cavity angle increase of 5 to 10 or 20 degrees, emphasizing an optimal included angle of approximately 6 to 10 degrees. [2]

Diamond instruments for preparation should feature conical geometry, with a recommended minimum thickness of 1.5 mm in the fissure region. Failure to meet these criteria may necessitate shortening cusps or cavity walls, potentially opting for a partial crown instead of a ceramic inlay. Rounded transitions are crucial not only in preparation shape but also in cavity wall contours, aligning with both traditional and CAD/CAM milling methods. Approaches to the approximal region involve creating diverging, box-shaped preparations with well-defined margins, avoiding acute angles and following a non-traditional "extension for prevention" concept. Extending the preparation in the approximal region supports material removal, glycerin gel application, and facilitates conventional or optical impression techniques.

Handling larger defects involves filling them with adhesive buildup fillings, allowing subsequent adjustments for optimal ceramic restoration thickness. Rounding off edges and corners during this process contributes to durability and prevents contamination. Attention to ceramic restoration margins is crucial, avoiding thin, tapered margins and steering clear of acute-angled bevels, particularly in the approximal area. These considerations collectively contribute to successful ceramic restoration outcomes. Tooth preparation guidelines for inlay restorations are explored, focusing on addressing specific defects rather than creating parallel-walled surfaces. [7]

Onlay Restoration

In situations where the required minimum wall thicknesses are not met, addressing dubious cases involves shortening affected cavity walls or cusps. Shortening cusps becomes necessary when the minimum thickness of approximately 1.5 mm of tooth structure is not maintained, especially if the preparation extends occlusally up to the cusp tip or if dynamic occlusal contacts raise concerns about flexural loading on the residual tooth structure. When dealing with defects extending beyond the enamel into the dentin, common in the replacement of amalgam restorations, proper isolation with a rubber dam during adhesive bonding mitigates concerns about a limited dentin margin. The use of an adhesive buildup filling is recommended for preparing ceramic partial crowns, particularly for deep defects, preventing unnecessary tooth structure removal and ensuring uniform material thickness in the final restoration. This approach also enhances energy density for light polymerization, crucial for effective bonding.

In scenarios where both cusps need shortening, achieving a comparatively "round" preparation is essential. This represents a departure from classical preparation techniques for metal restorations and traditional luting cement. While the recommended preparation shape proves optimal for adhesive bonding of ceramic restorations, it also serves well for provisional restorations. However, concerns about tooth surface contamination arise, prompting the need for a compromise in occlusal box design. This design should allow for sufficient macroretention to secure provisional restorations while ensuring the secure placement of the final restoration in its intended position. With adhesive bonding, the use of a parallel-walled isthmus to enhance retention is unnecessary, avoiding undesirable tooth structure loss and facilitating stress-free insertion. Oval grinding instruments, originally designed for shaping palatal surfaces, prove useful in preparation for their versatility and effectiveness. The guidelines for onlay restoration include considerations for minimum thickness, dealing with defects, and the use of adhesive buildup fillings. The importance of maintaining thickness and proper light polymerization for optimal results should be stressed. [7]

Veneers

In the realm of advanced dentistry, a comprehensive approach begins with a detailed clinical examination, paving the way for a digital smile design (DSD) that meticulously determines the optimal proportions of anterior teeth. The journey unfolds with the replication of this design into a diagnostic wax-up, facilitating the assessment of enamel loss through meticulous evaluation of wax distribution on the cast model. Leveraging cutting-edge technology, the wax-up is further transformed into a 3D resin model using a model scanner, specifically the dental wings 3 series. The practical application of this intricate process extends to the creation of a mock-up using bisacrylic material.

The subsequent phase ventures into tooth preparations guided by the mock-up, ensuring controlled and precise reduction with the aid of a specialized diamond bur kit, such as the Ceramic Laminate Veneers Kit. This process involves creating orientation grooves with a specific bur (868B.314.018, Komet) to facilitate vestibular reduction, meticulously marked with a graphite pencil. Further steps include the use of a tapered-shaped bur (6850.314.016, Komet) for vestibular reduction until all marked grooves are removed. The culmination of these preparations involves incisal grooves of 1.5 mm depth, proximal preparation with an 8850.315.016 tapered diamond bur, and the final touch with a diamond disc (952.180 + 310.204, Komet) for the elimination of the contact point.

The journey through intraoral scanning unveils crucial considerations, where factors like mouth opening, scanning device size, and adjacent oral structures significantly influence scan quality. Prudent examination of the margin line, undercut verification, and adequate preparation assessment are paramount post-scanning. Gingival retraction maneuvers, such as cord packing or laser techniques, become pivotal for subgingival margins. Controlling saliva and blood is imperative, emphasizing the need for dry oral conditions during scanning. Thorough attention to these factors ensures precise intraoral scans of dental arches and preparations, marking a significant stride in modern dental practices. [9]

Digital Workflow for Restorations

The digital workflow for restorations and prostheses initiates by importing essential data such as intraoral scans, digital bite registration, and additional images into CAD software. This comprehensive process involves the selection of the tooth for the crown, along with adjacent and antagonist teeth, while specifying the material and relevant parameters. The subsequent digital waxing procedure encompasses aligning arch scans, bite registration, and meticulous manual adjustments to preparation margins. This step-by-step approach includes defining the insertion axis and cement gap thickness, with the added flexibility of choosing crown shapes from libraries. Users are empowered to make precise adjustments to dimensions, positioning, and surface smoothness of the digital crown. Rigorous final checks ensure proper alignment and appearance, culminating in the export of the digital crown design as an STL file. The resulting design is then seamlessly integrated into the fabrication phase, with options for milling or 3D printing, marking the culmination of a streamlined and efficient digital workflow.

The digital workflow for restorations begins with importing intraoral scans and other relevant data into CAD software. A step-by-step guide is provided, outlining the process of creating a digital wax pattern for a single crown using commercial dental CAD software. [10]

Step-by-Step Procedure Using Commercial Dental CAD Software:

- Start the CAD software program.
- Enter patient information.
- Choose the tooth that will receive the single crown.
- Select adjacent and opposing teeth.
- Choose "Anatomic crown."
- Pick the material for the crown.
- Select any additional parameters if necessary.
- Click "OK."
- Click "Design" to open the Dental CAD software program.
- In the file browser that opens, select the STL file for the intraoral scan of the main arch.
- Select the STL file for the opposing arch.
- Use the mouse to position the main arch scan in an occlusal view, ensuring all margins of the preparation are visible, then set this view as the orientation axis.
- Click "Next."
- Click "Antagonist" (top left of the screen) to display the opposing arch. If a digital bite registration is needed to articulate the main and opposing models, import the STL file of the bite registration by selecting "Expert mode" → Tools → Add/remove meshes.
- Align the virtual mesh of the bite registration with the models by selecting common points on both meshes.
- Click "Align" and choose the best fit option to superimpose the meshes properly.
- Switch back to "Wizard" mode.
- Allow the software to automatically detect the preparation margin by clicking on two points at the edge of the preparation margin. This will enable automatic detection of the finish line.
- Switch to "Manual" mode to make fine adjustments to the preparation margins.
- Use the magic lantern tool (found in the "Tools" menu) to change the light direction in the 3D space. This helps determine the optimal preparation margin location with higher precision. After adjusting the margin, proceed to the next step.
- Check and confirm the insertion axis of the crown. If the axis orientation is not satisfactory, retentive parts will appear in red. Ensure the preparation margins are visible and there are no retentive areas.
- Click "Next."
- Select the desired parameters for the crown's intaglio surface, such as the cement gap thickness.
- Click "Next." A new mesh for the minimum thickness will be created, which varies depending on the material. The software will also generate a crown shape to be positioned onto the preparation.
- Choose a crown shape from the library or switch to "Expert" mode for a full drop-down menu of available libraries.
- Digitally adjust the crown dimensions and orientation, considering the positions of the opposing and adjacent teeth.
- Once the optimal position is established, click "Next." The crown shape will automatically adapt to the previously outlined preparation margins.
- Use the brushes to adjust and smooth the crown surface.
- Perform a final check to ensure the crown position is satisfactory.
- Click "Next" to export and save the digital crown design as an STL file. The crown is now ready for fabrication.

Advantages and Disadvantages of CAD/CAM

The advantages of CAD/CAM technology in dentistry are noteworthy. Firstly, it eliminates the need for traditional impression procedures, enabling the direct transfer of treatment details. This not only improves precision but also enhances patient comfort. The technology reduces or eliminates the need for temporary restorations or repeat visits for permanent restorations, resulting in significant time and cost savings for both the dental practice and the patient. Additionally, CAD/CAM provides high levels of strength and aesthetics with modern materials like ceramics and zirconia, meeting both functional and aesthetic expectations. The convenience of one-appointment dentistry is a significant advantage, enhancing office productivity and patient satisfaction. Furthermore, it contributes to environmental sustainability by reducing the use of disposable supplies and laboratory fees. The ability to maintain control over the fabrication and seating of restorations ensures precision and customization, and specific systems like CEREC, Procera, CERCON, and LAVA offer additional benefits tailored to various applications. [11]

However, there are notable disadvantages to using CAD/CAM technology in dentistry. There is a learning curve during the implementation phase, potentially leading to a temporary loss of office productivity. The initial cost of equipment and potential resistance from the dental team can be challenging. Some clinicians may lack confidence or willingness to adapt to a computerized system, and integrating the technology into existing practices may pose difficulties for some dentists. Despite these challenges, the advantages of CAD/CAM outweigh the disadvantages, making it a successful and beneficial treatment option in dentistry.

The limitations of CAD/CAM technology, such as line-of-sight constraints, absence of certain materials, and accuracy issues in full arch digital impressions, are being actively addressed. Potential future advancements, including ultrasound impressions for non-invasive and accurate

impressions, laser milling, and direct inject printing for new material choices, offer promising solutions. These innovations have the potential to overcome current limitations and further advance the field of digital dentistry. Overall, the continuous evolution of CAD/CAM technology in dentistry showcases its adaptability and potential for ongoing improvements. [12, 13]

Conclusion

In summary, this narrative review underscores the pivotal role of CAD/CAM technology as a beacon of precision and efficiency in contemporary dentistry, ushering in a new era of innovation for tooth preparation and restoration design. The digital workflows, akin to an avant-garde tapestry, provide clinicians with sophisticated tools, orchestrating a harmonious symphony of meticulous craftsmanship and technological prowess in operative dentistry. As the vanguard of Artificial Intelligence (AI) and Virtual Reality (VR) advances, the future promises a metamorphosis in the application of CAD/CAM, potentially overcoming current challenges faced by endodontists in terms of time, cost-effectiveness, and precision. The horizon beckons with possibilities, unveiling a panorama where technological ingenuity and dental finesse take center stage, elevating the artistry of dentistry to unprecedented heights. Despite being in their early stages of development, CAD/CAM systems in dentistry have shown continuous improvements, expanded capabilities, increased user-friendliness, and enhanced computing power. The introduction of higher-resolution scanners and ongoing advancements in technology are expected to further refine CAD/CAM systems, contributing to the field's evolution and benefiting dentistry as a whole. Patient satisfaction remains high, driven by the accessibility, affordability, and natural feel of CAD/CAM restorations, with notable improvements in efficiency and aesthetics. The overall trajectory of CAD/CAM technology in dentistry is promising, with ongoing advancements and improvements anticipated in the future which might be a boon for the budding endodontists.

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