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Review

The Application, Accuracy, and Utilization of Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) Systems in Restorative Dentistry

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Abstract

Restorative dentistry is crucial for improving oral health and restoring damaged teeth. Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) systems have revolutionized the field by integrating digital technologies, offering benefits over traditional methods. These systems streamline the restorative workflow, provide accurate restorations with excellent fit and aesthetics, and reduce chairside and laboratory processing times. CAD/CAM applications range from single-tooth restorations to fixed dental prostheses, implant-supported restorations, and orthodontic appliances. The accuracy and precision of CAD/CAM systems are evaluated through various methods, and factors influencing accuracy include scanner type, software algorithms, milling/3D printing technology, and materials used. Strategies to improve accuracy include optimizing scanning techniques and using advanced software algorithms. CAD/CAM systems have significant clinical implications, and their future holds promising advancements in intraoral scanning, CAD software, and CAM technologies. However, challenges such as initial investment, operator skill, and material selection need to be considered.

Keywords: *restorative dentistry, CAD/CAM systems, dental restorations, digital dentistry*

Introduction

Restorative dentistry plays a crucial role in enhancing oral health and restoring damaged teeth to their optimal form and function. It encompasses various procedures to repair and replace damaged or missing teeth, such as crowns, bridges, inlays, onlays, and dental implants. The traditional approach to restorations involves multiple steps, including impressions, laboratory fabrication, and manual adjustments. Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) systems have emerged as a revolutionary technology in dentistry, offering substantial benefits over conventional techniques. CAD/CAM systems revolutionize this process by integrating advanced digital technologies, enabling efficient chairside fabrication of restorations with enhanced accuracy (1).

CAD/CAM systems utilize a systematic workflow that involves digital scanning, virtual design, and computer-controlled milling or 3D printing of restorations (2). The process begins with an intraoral scanner capturing accurate 3D images of the dentition. These digital impressions are then imported into specialized software, allowing dentists to design restorations with precise dimensions, contours, and occlusal relationships. Finally, the digital design is sent to the milling unit or 3D printer, which fabricates the restoration using biocompatible materials.

CAD/CAM systems offer numerous advantages over conventional techniques. Digital scanning eliminates the potential errors associated with traditional impressions, resulting in highly accurate restorations that exhibit excellent marginal fit and occlusal harmony. Further, CAD/CAM systems streamline the restorative workflow, reducing chairside and laboratory processing times (3). Restorations can often be fabricated and placed during a single appointment, enhancing patient convenience. Moreover, CAD/CAM technology enables dentists to customize restorations to the patient's specific needs, ensuring optimal functional and aesthetic outcomes. The ability to match the natural tooth color and translucency enhances the overall appearance. Furthermore, CAD/CAM restorations can be fabricated from a wide range of biocompatible materials, including ceramics, composite resins, and high-performance polymers, ensuring long-term success and patient satisfaction (4). Lastly, CAD/CAM systems provide comprehensive digital records of patient cases, facilitating effective communication among dental professionals and enabling accurate treatment planning and follow-up care (5).

CAD/CAM systems have found widespread application in restorative dentistry, ranging from single-unit crowns to multi-unit fixed dental prostheses (6). The technology is constantly evolving, with ongoing research aimed at expanding its capabilities, such as integrating artificial intelligence algorithms, improving material options, and enhancing intraoral scanning accuracy (7). Future advancements may also involve the integration of CAD/CAM systems with digital smile design and virtual implant planning software, further enhancing treatment outcomes and patient satisfaction.

Review

Restorative dentistry plays a pivotal role in restoring oral health and function by utilizing various procedures, such as crowns, bridges, inlays, onlays, and dental implants (8). Traditionally, these procedures involved multiple steps, including impressions, laboratory fabrication, and manual adjustments. The introduction of CAD/CAM systems has transformed this process by incorporating advanced digital technologies, offering numerous advantages over conventional techniques.

Applications

Single-Tooth Restorations

CAD/CAM systems have significantly impacted the fabrication of single-tooth restorations, such as crowns and veneers (9). Digital intraoral scanning provides accurate and efficient impressions, eliminating the need for conventional impression materials and trays. This leads to improved marginal

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fit and reduced chairside time. The digital data is then used to design the restoration virtually, allowing for precise customization of shape, contour, and occlusal characteristics (10). Once designed, the restoration is milled or 3D printed using biocompatible materials, resulting in high-quality restorations with excellent fit and aesthetics.

Fixed Dental Prostheses

CAD/CAM technology has revolutionized the fabrication of fixed dental prostheses, including bridges. By digitally capturing the intraoral situation, the design and fabrication of multi-unit restorations become more efficient and accurate. The virtual design allows for precise determination of pontic shape, connector design, and occlusal relationships (11, 12). The CAD/CAM systems enable the fabrication of metal frameworks or monolithic restorations using materials like zirconia or lithium disilicate, ensuring excellent strength and esthetics (13). The integration of CAD/CAM systems with 3D printing technology has also opened new avenues for producing metal-free restorations, reducing the reliance on traditional casting techniques.

Implant-Supported Restorations

CAD/CAM systems have simplified the fabrication of implant-supported restorations, offering enhanced precision and aesthetics. In this application, digital impressions of the implant site and opposing dentition are obtained, providing an accurate representation of the patient's oral anatomy (14). Using specialized software, the dentist can virtually plan the implant placement, considering factors such as bone density, proximity to vital structures, and esthetic outcome (15). Once the implant is placed, CAD/CAM technology facilitates the fabrication of custom abutments and implant-supported crowns or bridges. The ability to precisely design and mill these restorations ensures optimal fit and long-term stability.

Orthodontic Appliances

Apart from restorative applications, CAD/CAM systems have also found applications in the field of orthodontics, enabling the fabrication of customized orthodontic appliances, such as clear aligners and retainers (16). Digital impressions are captured using intraoral scanners, eliminating the discomfort associated with traditional impressions. The virtual models allow for accurate and efficient treatment planning, including tooth movement simulations and the design of individualized aligners or retainers. CAD/CAM technology enables the fabrication of a series of aligners or retainers with gradual tooth movements, providing an effective and aesthetically pleasing orthodontic treatment modality (17).

Accuracy

Restorative dentistry relies on the fabrication of dental restorations with high accuracy and precision to ensure proper fit, function, and aesthetics. CAD/CAM systems have emerged as a digital technology that offers the potential for improved accuracy and precision compared to traditional techniques. Accurate digital impressions and precise milling or 3D printing capabilities are key components of CAD/CAM systems that contribute to the overall accuracy and precision of restorations (18).

Evaluation of Accuracy and Precision

The accuracy and precision of CAD/CAM systems can be assessed through various methods, including three-dimensional (3D) comparisons of digital models and physical models, evaluations of marginal fit, occlusal contact analysis, and measurement of internal fit (19). Digital models obtained from intraoral scanners are compared to physical models created from traditional impressions to evaluate accuracy. Marginal fit can be assessed by measuring the gap between the restoration and the tooth preparation (20). Occlusal contact analysis determines the accuracy of the occlusal surfaces, while the measurement of internal fit evaluates the fit of the restoration within the preparation (21).

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Factors Influencing Accuracy and Precision

Several factors can influence the accuracy and precision of CAD/CAM systems in restorative dentistry (22). These factors include the type of intraoral scanner used, the software algorithms for data processing and restoration design, the milling or 3D printing technology, and the materials utilized for fabrication. Intraoral scanner accuracy, image resolution, and scanning technique affect the quality of the digital impressions (23). The software algorithms used for data processing and restoration design can introduce errors if not properly calibrated or if there is a lack of user proficiency (24). The milling or 3D printing technology, including the spindle speed, tool wear, and calibration, can impact the precision of the final restoration (25). Material properties, such as shrinkage or expansion during milling or curing, can also affect the accuracy of the fabricated restoration.

Sources of Errors and Challenges

CAD/CAM systems can be susceptible to sources of errors that may compromise accuracy and precision. Inaccurate digital impressions are one such source of errors that can occur due to various factors, including moisture contamination, movement artifacts, or improper scanning techniques (26). Moisture on the scanning area can interfere with the accuracy of the digital impression, resulting in potential inaccuracies in the final restoration. Movement artifacts can occur if the patient moves during the scanning process, leading to distorted or incomplete digital impressions (27). Additionally, improper scanning techniques, such as inadequate coverage or incorrect angulation, can also impact the accuracy and precision of the digital impressions (28). It is important to follow proper scanning protocols and ensure a dry and stable environment to minimize these potential errors and achieve optimal results with CAD/CAM systems. Data processing errors may arise from interpolation algorithms, noise reduction algorithms, or inadequate image resolution (29). Improper calibration or wear of milling or 3D printing tools can introduce errors during fabrication (30). Material-related issues, such as polymerization shrinkage or inadequate bonding, can affect the fit and longevity of the restorations (31). Additionally, challenges arise when dealing with complex cases, such as multiple-unit restorations or restorations requiring precise occlusal relationships.

Strategies to Improve Accuracy and Precision

Several strategies can be implemented to enhance the accuracy and precision of CAD/CAM systems in restorative dentistry (26). These include optimizing scanning techniques to minimize artifacts and moisture contamination, using high-resolution intraoral scanners, ensuring proper calibration of equipment, and employing advanced software algorithms for data processing and restoration design (23). Regular maintenance and calibration of milling or 3D printing devices are essential to achieve consistent precision. Material selection should consider properties that minimize shrinkage and provide optimal fit and durability. Additionally, continuous education and training for dental professionals in CAD/CAM technology are crucial to ensure proper utilization of the systems and minimize errors.

Clinical Implications

The accuracy and precision of CAD/CAM systems have significant clinical implications in restorative dentistry. Improved accuracy ensures better marginal fit, minimizing the risk of microleakage and secondary caries (25). Precise occlusal contacts contribute to proper function and occlusal stability (23). Accurate internal fit reduces the need for extensive adjustments during restoration seating, improving patient comfort and satisfaction. Additionally, CAD/CAM systems allow for digital records and efficient communication among dental professionals, facilitating treatment planning, and ensuring accurate follow-up care.

Utilization

CAD/CAM systems in restorative dentistry consist of three functional components: data capture, CAD design, and CAM fabrication (32). The data capture process varies among commercially available

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systems, with some using intraoral digital 3-D scanning devices, while others rely on mechanical or optical digitizers for capturing data from models (33). The CAD design software programs allow for the virtual design of dental restorations with varying degrees of user interaction. Once the restoration design is completed, the CAD software generates specific commands for the CAM unit to fabricate the restoration.

CAM in CAD/CAM systems utilizes computer-generated paths to shape dental restorations (34). Subtractive methods involve cutting the restoration from a prefabricated block using burs or diamond tools. However, additive approaches, such as selective laser sintering, are becoming increasingly common, where material is sintered along a path to build a part layer by layer. This additive approach minimizes material waste and allows for the fabrication of complex shapes. Some systems combine additive and subtractive methods to achieve the desired restoration outcome.

The materials used in CAD/CAM systems for restorations include ceramics, metal alloys, and composites (33). Different systems have varying capabilities and limitations regarding material options and restoration types. For example, some systems can produce final restorations with certain materials, while others require additional processing steps for optimal aesthetics. Ceramics like alumina, zirconia, and porcelain-based ceramics are commonly used, and their properties influence the fabrication process (35).

Different business models exist for producing CAD/CAM restorations, including in-office systems where all steps are completed within the dental office, dental laboratory systems where the laboratory fabricates the restorations based on impressions or models sent by the dentist, dental laboratory-production center models where the laboratory collaborates with a production center for more efficient fabrication, and network or open-concept models where multiple laboratories or production centers collaborate to offer a wider range of material choices and pricing strategies (34).

The future of CAD/CAM systems in restorative dentistry holds promising advancements. Intraoral scanning technologies are likely to improve, eliminating the need for traditional impressions. CAD software is expected to incorporate simpler user interfaces and virtual articulators for automatic design of occlusal surfaces (36). CAM technologies may see advancements in high-speed machining, lasers for cutting dental materials, direct shell production, and direct-write assembly techniques (33). These advancements could enhance the speed, precision, and esthetics of CAD/CAM restorations, expanding the range of materials and fabrication approaches available.

As more scanning and fabrication technologies are introduced, open systems and cooperative networks are likely to be utilized to optimize material choices and hardware selection (37). Dental professionals will need to make informed decisions to ensure optimal outcomes based on specific indications and patient needs. The application of new technologies from other industries may lead to unexpected shifts in fabrication approaches and materials options in the field of restorative dentistry (38).

Despite the numerous advantages, CAD/CAM systems face certain limitations and challenges in restorative dentistry (39). These include initial investment, firstly. The cost of acquiring and maintaining CAD/CAM equipment can be a significant barrier for some dental practices, particularly smaller ones. Further, operator skill and training also limit its use as efficient utilization of CAD/CAM systems requires comprehensive training and proficiency in digital workflows and software handling (40). Moreover, material selection is another important consideration. (4) Although CAD/CAM systems offer a wide range of material options, each material has its limitations, and selecting the appropriate material for each clinical situation requires careful consideration (41). Lastly, CAD/CAM systems may face challenges when dealing with complex restorative cases that involve multiple units, extensive anatomical detail, or challenging occlusal relationships (42).

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Conclusion

CAD/CAM systems have revolutionized restorative dentistry with their advanced digital technologies. They offer improved accuracy, customization, streamlined workflow, and a wide range of material options. CAD/CAM systems find applications in single-tooth restorations, fixed dental prostheses, implant-supported restorations, and orthodontic appliances. Evaluating accuracy involves comparing digital models to physical models, assessing marginal fit, occlusal contact, and internal fit. Strategies to enhance accuracy include optimizing scanning techniques and employing advanced software algorithms. Despite their benefits, CAD/CAM systems face limitations and challenges. However, they continue to transform restorative dentistry by providing efficient, precise, and patient-centered dental restorations.

Disclosure

Conflict of interest

There is no conflict of interest

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Data availability

Data that support the findings of this study are embedded within the manuscript.

Author contribution

All authors contributed to conceptualizing, data drafting, collection and final writing of the manuscript.

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