A Review of Computer Aided Design and Computer Aided Technology (CAD/CAM) in Complete Denture Fabrication: Part 2

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ABSTRACT

The field of removable prosthodontics is on the brink of a transformative era, propelled by the continuous evolution of digital technology. Integrating artificial intelligence, machine learning, and 3D printing promises to revolutionise denture fabrication, offering unprecedented customisation and efficiency. As these technologies become more accessible and widely adopted, they are set to establish new benchmarks in quality and patient satisfaction. The future of removable prosthodontics is bright, marked by the seamless integration of these innovations, underpinned by robust research and collaboration among dental professionals. This convergence is poised to deliver superior clinical outcomes, elevate patient satisfaction, and drive continuous advancements in the art and science of denture fabrication.

Introduction

In recent years, digital technology has begun to reshape prosthodontics, mainly by integrating computer-aided design and computer-aided manufacturing (CAD/CAM) systems into the dental workflow. These systems enable clinicians to create digital impressions, which can be manipulated in a virtual environment before being used to fabricate accurately fitting dentures. Adopting CAD/CAM technology has reduced the number of clinical appointments required for denture fabrication, has the potential to minimise errors, and accelerates the production process while maintaining or possibly improving the quality of the final prosthesis.[1] The transition from traditional to digital impression and manufacturing techniques represents a significant shift in prosthodontics that aims to enhance precision, efficiency, and patient satisfaction. However, integrating digital technologies into routine clinical practice is still in its early stages, and long-term studies are needed to assess their impact on treatment outcomes.[2]

Digital denture fabrication is typically divided into several key stages, each contributing to the final product's accuracy and outcome. These stages include:

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Digital impressions

Unlike traditional impression methods that rely on physical moulds, digital impressions are obtained by scanning the patient's edentulous arches. This process is more comfortable for the patient and produces highly accurate digital models.[3] One of the primary challenges in the digital workflow is the accuracy of digital impressions, particularly when capturing the soft tissues of the edentulous arch. While intraoral scanners have improved precision, they still face difficulties accurately capturing mobile and delicate tissues, such as the vestibule, soft palate, and sublingual areas. These are crucial for ensuring the proper fit and retention of dentures.[3]

Inaccurate digital impressions can lead to several complications, including poor peripheral seal and inadequate retention, which can cause discomfort and functional issues for the patient. Although traditional impression techniques using border-moulded trays effectively capture these details, the fully digital workflow often omits these steps, leading to potential inaccuracies in the final prosthesis.[1] To overcome this challenge, further advancements in intraoral scanning technology are needed. Additionally, hybrid approaches that combine digital scanning with traditional impression techniques may offer a viable solution until fully digital methods can match the accuracy of conventional approaches.[4]

Digital Design and Occlusal Plane Determination

Once the digital impressions are captured, they are imported into CAD software, where the denture design takes place. This stage involves several critical tasks, including tooth arrangement, gingival contour customisation, and occlusal plane adjustment using virtual articulators.[5] The fit and retention of digital dentures are crucial factors that directly influence patient comfort and satisfaction. Poorly fitting dentures can cause various issues, from discomfort and pain to difficulties in speaking and eating. Digital workflows, particularly those that incorporate high-precision milling and scanning technologies, have been shown to produce dentures with superior fit and retention compared to traditional methods.[5] However, some challenges remain, mainly when digital workflows omit critical steps such as trial placements or clinical remounts. These omissions can result in occlusal errors only identified after the final denture is delivered, necessitating additional adjustments, time, and costly remakes.[3] An accurate occlusal relationship is essential for the functioning of complete dentures. Inaccuracies in the vertical dimension of occlusion or centric relation can lead to problems such as open bites, excessive wear, discomfort, and dislodgement during chewing. Digital workflows have the potential to enhance the accuracy of occlusal relationships, thanks to the precision of digital design tools and virtual articulators.[1] In addition, systems like *3Shape's Dental Designer* and *Exocad's DentalCAD* offer advanced tools for occlusal analysis, including virtual articulators and facebow

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Process	Description	Advantages
Milling [4]	Milled dentures are carved from pre-polymerised polymethyl methacrylate (PMMA) blocks. This process produces dentures with excellent strength, stability, and longevity. The milling precision ensures that the denture fits the patient's oral cavity with minimal adjustments.	• **Strength:** The milling process creates a dense, homogenous material that is highly resistant to fractures. • **Precision:** The high level of accuracy ensures a close fit to the oral tissues, enhancing comfort and retention.
3D Printing [4]	3D printing allows for greater flexibility in design and customisation. Dentures can be printed layer by layer using materials such as biocompatible resins, which can be customised in colour and texture.	• **Customisation:** Layer printing allows for intricate designs and aesthetic enhancements, such as varying gingival shades • **Efficiency:** 3D printing can significantly reduce the time needed to produce a complete denture, making it a cost-effective option for clinicians and patients.

Table 1: Description of milling and 3D printing, including the advantages of each [4].

transfers, which help ensure that the occlusal relationships are accurately captured and maintained throughout the fabrication process.[3, 5]

Fabrication:

The digital file of the finalised design is then sent to a milling machine or 3D printer to fabricate the denture. Each of these two production methods has certain advantages, as described by Avellino et al. (2024) and depicted in Table 1.[4]

The materials used in digital denture fabrication, particularly those for 3D printing, still face challenges in balancing strength and aesthetics. While milled PMMA offers excellent strength and durability, 3D-printed resins have historically been less robust, leading to concerns about the long-term performance of these dentures, especially in patients with high occlusal loads.[6] 3D printing offers customisation and aesthetic capabilities, making it an attractive option. However, achieving the same level of aesthetic detail and translucency possible with traditional materials or milled PMMA is challenging, mainly when using resin-based printing; therefore, 3D-printed dentures may require additional finishing and characterisation to meet aesthetic standards.[7] Another challenge with 3D printing is the need for post-production processing. After printing, dentures often require additional cleaning, curing, and sometimes surface finishing to ensure they meet clinical standards. These extra steps can add to the overall production time and may introduce variability in the final product depending on the quality and consistency of the post-processing procedures.[6]

Given the distinct advantages of both milling and 3D printing, many dental professionals are now adopting hybrid workflows. For example, a denture base might be milled for strength and stability, while the teeth or aesthetic components are 3D printed for greater customisation and detail. This approach uses the strong points of both methods to produce functional and aesthetically pleasing dentures.[5]

One of the benefits of digital dentures is the reduced number of patient visits required. Traditional denture fabrication typically involves multiple appointments; digital workflows streamline this process, often reducing the treatment time by half or more [1]. This can be seen with systems like AvaDent's Digital Design (MNF) and 3Shape's Dental Design (MNF). As a result, patients can receive their final dentures in a shorter time. The advocates of this process also purport that these dentures require fewer follow-up appointments for adjustments.[3]

Denture materials

The materials used to fabricate digital complete dentures are critical to the prosthesis's overall success. To meet patients' functional and aesthetic demands, these materials must balance strength, durability, aesthetics, and biocompatibility. Table 2 below highlights the primary materials used in denture fabrication, highlighting the associated advantages and disadvantages.

Biocompatibility ensures dental materials are safe for long-term use in contact with oral tissues. Milled Polymethyl Methacrylate (PMMA) has a long history of reliable and well-established biocompatibility. Similarly, 3D-printed resins demonstrate good biocompatibility when processed correctly, although care must be taken to address potential issues such as porosity and surface hygiene.[6, 8]

The Future of Digital Denture Fabrication

Long-term studies on the durability and performance of digital complete dentures are still relatively limited. However, early results suggest that digitally fabricated dentures are comparable to traditional dentures in wear and tear, with many patients reporting satisfactory long-term outcomes. Nevertheless, ongoing monitoring and follow-up are essential to ensure that any issues are promptly addressed and that the dentures continue to perform well over time.[6]

Adopting digital denture technology requires significant equipment, software, and training investment. The high initial costs of purchasing CAD-CAM machines, 3D printers, and intraoral scanners can be a barrier for many dental practices, notably smaller or independent ones.[8] In addition to the financial investment, a steep learning curve is associated with mastering digital workflows.[6]

Artificial intelligence (AI) and machine learning are poised to revolutionise digital denture fabrication by enabling more accurate and efficient workflows. AI algorithms can assist in the design phase by predicting optimal denture shapes based on patient-specific data, automating the identification of undercuts, and even simulating the final fit and function of the denture before it is fabricated.[6]

Machine learning can also improve the accuracy of digital impressions and occlusal records by analysing vast amounts of data from previous cases to refine scanning techniques and prediction models. This could lead to more consistent and reliable outcomes, reducing the need for adjustments and improving patient satisfaction.[5]

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Table 2: Materials used to make complete dentures and the advantages and disadvantages of each

Material/Process	Description	Advantages	Disadvantages
Polymethyl Methacrylate (PMMA)[3]	It is the gold standard for denture bases due to its favourable mechanical properties, ease of manipulation, and aesthetic versatility. In digital denture fabrication, it was used predominantly as pre-polymerised blocks for milling.	• High stability and resistance to polymerisation shrinkage • Precise fit and structural integrity	- Can be time-consuming and generate material waste during milling
Milled PMMA[4]	They are milled from solid blocks of pre-polymerised PMMA, offering high mechanical strength and excellent dimensional stability. Ensures a tight fit against the mucosa, enhancing retention and patient comfort.	• Superior aesthetic outcomes with customisable colour to match gingival tissue • Smooth surface finish for a natural appearance	- Time-consuming process - Generates material waste - Higher production costs
3D-printed Resins[6]	It allows for the creation of dentures through additive manufacturing, layer by layer. It offers flexibility and customisation in design, enabling complex geometries. It is generally more cost-effective due to reduced material waste.	• Cost-effective and efficient production • Customisable for intricate designs and aesthetics	- Historically lower mechanical strength compared to milled PMMA - May require additional finishing for aesthetics - Porosity and surface roughness can lead to hygiene issues
Hybrid Materials[3, 5]	It combines milled PMMA bases with 3D-printed components (e.g., denture teeth) to leverage the strengths of both materials. It offers a balance of strength, stability, and customisation.	• Combines strength and aesthetics • Allows for highly customisable and detailed designs	- May still involve the disadvantages of both milled and 3D-printed processes (e.g., waste, time-consuming production)
Emerging Materials[4, 5]	New materials like modified PEEK are being explored for improved mechanical properties and biocompatibility. PEEK is a high-performance polymer offering strength and flexibility and is a potential alternative to metal frameworks for those with metal allergies.	- PEEK: High strength, flexibility, and biocompatibility - Potential for lighter, more comfortable dentures	- Still in the early research stages - Long-term viability not yet established

CONCLUSION

Digital technology, particularly CAD/CAM systems, has revolutionised prosthodontics by introducing a level of precision and efficiency previously unattainable with traditional prosthesis fabrication methods. Literature suggests that digital impressions and computer-aided design, and manufacturing have improved patient satisfaction through better fit and reduced clinical chair time.[2, 9] However, challenges such as the cost of technology and the need for specialised training underscore the importance of ongoing research and professional development to integrate these tools into routine clinical practice successfully.[10] Digitally aided production of complete dentures could result in a better fit and more durable and aesthetically pleasing prostheses. Additionally, they may benefit from improved strength due to the milling and 3D printing techniques, a more streamlined fabrication process, more time and cost-effectiveness, and enhanced patient satisfaction.[1] The materials used in digital denture fabrication, particularly milled PMMA and 3D-printed resins, play a crucial role in the success of the final prosthesis. Ongoing research into advanced materials, such as modified PEEK and hybrid composites, promises to enhance further the durability, aesthetics, and biocompatibility of digital dentures.[3-6] However, challenges remain in the widespread adoption and standardisation of digital denture technologies, including issues related to the accuracy of digital impressions, occlusal relationships, and material limitations.

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