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LITERATURE REVIEW

DIGITAL COMPLETE DENTURES: AN UPDATED COMPREHENSIVE REVIEW

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Abstract

Background: Digital technologies are widely used today to fabricate prosthodontic restorations, including complete dentures. The aim of this review was to provide information about the technologies for fabricating digitally manufactured complete dentures, the materials used, the digital methods for obtaining impressions, and the digital design of prostheses. Additionally, it discusses the procedures for creating complete removable dentures using both conventional and digital methods, examining their advantages and disadvantages, along with the unique features of various digital technologies. Standardizing treatment stages with digital dentures enhances fabrication speed, data consistency, and patient comfort.

Materials and Methods: All study types reporting on complete dentures manufactured by digital (milled/3D-printed) and conventional processes were included. Studies reporting on fixed dentures and partial removable dentures were excluded. The search was conducted in Pubmed/MEDLINE, Cochrane, Scopus, Embase, Google Scholar, and Science Direct, and only English-language papers were included.

Results: A total of 1,082 studies were initially identified through the search across mentioned databases. Ultimately, 24 studies met the inclusion criteria and were included in this review. These studies provided comparative data on the fabrication of complete dentures through digital (milled and 3D-printed) and conventional processes, offering insights into their clinical applications, materials, workflows, and outcomes.

Conclusion: Digital complete dentures offer significant advantages in terms of efficiency, precision, and patient satisfaction, positioning them as a viable alternative to conventional dentures. However, further advancements in technology and research are required to address existing limitations, particularly in clinical trial phases and cost-effectiveness.

Keywords: *Complete denture, Computer engineered complete denture, CAD/CAM Complete dentures, Computer-aided engineering complete dentures, Digital complete dentures.*

INTRODUCTION

Complete dentures restore the entire dentition and the adjacent structures of the maxilla and mandible. The fabrication of complete dentures through digital techniques marked the beginning of a new era in removable prosthodontics. However, in the past, the fabrication of complete dentures using digital workflows seemed impossible. While the conventional procedures for manufacturing complete dentures are well-defined and successfully applied, the standardization and simplification of these processes have driven interest in digitally fabricated removable dentures.[1]

According to the Glossary of Digital Dental Terms, a digital denture is a complete removable structure produced through automated methods using computer-aided design / computer-aided manufacturing (CAD/CAM) and computer-aided engineering (CAE) systems, replacing traditional processes. A denture is considered digital when its final appearance is shaped through automated processing, eliminating the errors and drawbacks associated with the standard procedures of conventional denture fabrication.[2]

Various protocols for fabricating complete dentures using digital techniques have been proposed. However, digital workflows demonstrate inherent challenges. The primary issue lies in the precise recording of the alveolar ridges, palate shape and size, as well as the functional width and depth of the denture borders, including the posterior palatal seal area. Another challenge involves determining the vertical dimension, recording intermaxillary relationships, and meeting esthetic demands. This information dictates the contour of the denture's cameo surface, the space required for artificial teeth, and the planning of functional and esthetic arrangements.[3,4]

The digitization procedure of the intaglio surface of the denture is still evolving and largely depends on the applied system. Generally, there are two approaches: one involves intraoral scanners to scan supporting tissues directly, while the other uses conventional impressions made with elastomeric materials or gypsum models that are scanned indirectly in a dental laboratory.[5]

The accuracy of intraoral scanners is comparable to that of traditional impressions. However, the applied scanning process significantly influences the final outcome. It is reported that intraoral scanners capture mucostatic impressions of edentulous jaws but are still incapable of reproducing functional movements.[6,7] In some cases, this limitation is not considered significant from a retention perspective, as retention is presumed to develop through close adaptation between the denture base and the underlying tissues. Challenges in direct intraoral scanning of edentulous jaws, particularly the mandible, include mobile tissues, smooth mucosa covered with saliva, excessive salivation, movements of cheeks and tongue, difficulty of frenula management, and the absence of stable reference points. Authors identify potential limitations such as short denture flanges, compromised border seal, reduced retention and stability, and inadequate lip and cheek support.[8] Attempts are being made to combine intraoral scanning with digital relining processes to fabricate fully digital dentures with functional borders. Intraoral scanning offers advantages over traditional impressions, including patient comfort (no gag reflex, less time-consuming, fewer visits) and simplification of laboratory work (model preparation and transportation). Moreover, intraoral scans are spatially accurate.[9]

The goal of obtaining an impression from an edentulous jaw is to replicate the tissues in a healthy state without excessive pressure and to ensure perfect internal and external border seals. This allows the denture base to achieve support, retention, and stability. Various materials and methods are used, each requiring specific materials. Although certain clinical cases justify a multi-step impression process, evidence suggests that a two-step process is not superior to a single-step approach. Therefore, dentists may choose an impression method that conveniently and effectively meets the requirements for an ideal impression.[10,11] Following the final impression, traditional procedures involve fabricating hard bases with occlusal wax rims, allowing step-by-step recording of centric relation. This step can be performed during the impression-taking phase to improve efficiency.

Combining traditional impressions with intraoral scans enables to obtain decompressive impressions from mobile tissues. This approach scans mobile or overgrown tissues through a window in the impression tray while stable tissues are replicated with a conventional impression. The two impressions are then merged.[12] Significant efforts are being made to integrate intraoral and facial scan data, but digital denture technology still struggles with recording the interrelationships of jaws. Consequently, occlusal wax rim recordings are scanned and combined with other obtained data. Once the digital models of the maxilla and mandible, along with scanned jaws' interrelationships, are combined, the denture surfaces can be designed.[13,14]

Jaw movements and interrelationships can be reproduced using advanced CAD software, which incorporates virtual articulators. Efforts are underway to develop fully digital approaches to assess the lower jaw's position concerning the upper jaw using different image combinations. Additionally, work focuses on simplifying the workflow, including image acquisition through mobile phone applications. Combining these images with cone-beam computed tomography (CBCT) data has great potential for accurately reproducing the movements of the mandible and condyles.[15-17]

Considering the different concepts of digital removable dentures and the lack of comprehensive comparative analysis between conventional and digital fabrication methods in the literature, we aim to analyze the technologies, biomaterials, and denture design methods for complete digital dentures. Furthermore, we presented fabrication procedures, advantages, disadvantages, and characteristics of both conventional and digital fabrication methods.

MATERIALS AND METHODS

Inclusion criteria: Studies reporting on complete dentures manufactured by digital (milled/3D-printed) and conventional processes. All study designs were considered.

Exclusion criteria: Studies reporting on fixed dentures and partial removable dentures.

Search strategy: Articles on complete dentures, both digital and conventional, were searched using the keywords "complete denture", "computer engineered complete denture", "CAD/CAM complete dentures", "computer-aided engineering complete dentures", and "digital complete dentures" in Pubmed/MEDLINE, Cochrane, Scopus, Embase, Google Scholar, and Science Direct. Further search criteria included being published in English literature. Then, relevant articles were selected, included, and critically analyzed in this review.

RESULTS

A total of 1,082 studies were initially identified through the search across PubMed/MEDLINE, Cochrane, Scopus, Embase, Google Scholar, and Science Direct databases using the keywords "complete denture," "computer-engineered complete denture," "CAD/CAM complete dentures," "computer-aided engineering complete dentures," and "digital complete dentures." Ultimately, 24 studies met the inclusion criteria and were included in this review. These studies provided comparative data on the fabrication of complete dentures through digital (milled and 3D-printed) and conventional processes, offering insights into their clinical applications, materials, workflows, and outcomes (Figure 1).

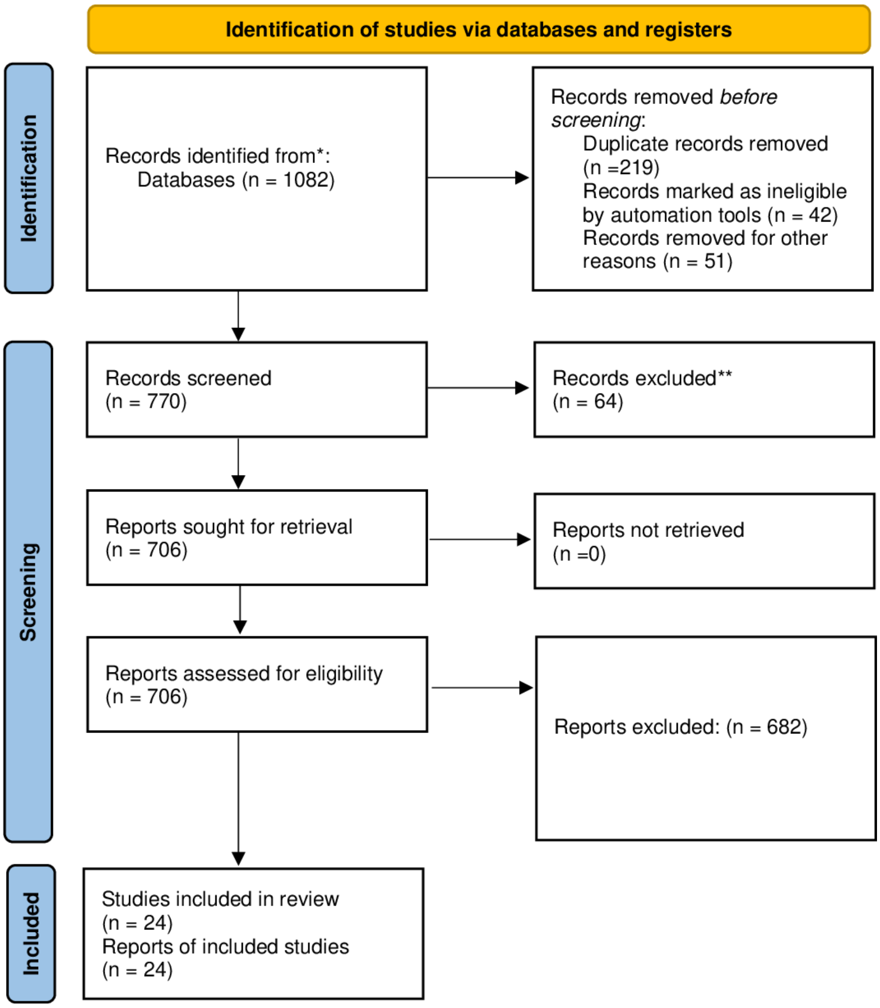

Figure 1. *PRISMA flow diagram showing the identification, screening, eligibility and inclusion process of the studies*

ANALYSIS OF THE GENERAL SITUATION

Currently, with implants being widely used in various clinical scenarios, the question arises whether treatment with complete dentures is still relevant or indicated for edentulous patients. Despite significant debates in the literature, the answer is “yes”. Given the global economic situation, for many edentulous patients, complete dentures remain a desirable treatment option. However, certain medical and practical considerations must also be taken into account: a) In many cases, the cost-to-profit ratio of dentures is unattractive for dentists, b) Continuing education in this field is minimal or nearly absent, c) The clinical and laboratory phases of fabricating complete removable dentures are labor-intensive, d) Most fabrication stages depend heavily on the experience of the dentist and dental technician, often lacking a strong scientific foundation, e) Anatomically complex cases are challenging to treat successfully, f) The patient's reaction to the final denture outcome is unpredictable.[18,19]

Moreover, fabricating complete dentures requires a detailed analysis of the patient’s general and dental history, precise diagnosis, and treatment planning. It also demands profound knowledge and understanding of clinical and laboratory procedures, as well as effective communication with the patient, who has unique characteristics and perceptions. Often, these factors conflict with the opinions, knowledge, and potential (and sometimes even resources) of the professional team (dentist and dental technician). Such a complex interplay of factors often discourages dentists from providing treatment with complete dentures despite the high demand from patients.[20,21]

Patients may refuse implants due to anxiety about surgery, fear of potential pain, high costs, or the long treatment duration. Furthermore, a patient's general health condition may contraindicate implant placement, such as uncontrolled diabetes, immunodeficiency, intravenous bisphosphonate therapy, heavy smoking, alcohol abuse, or psychiatric, neurological, and behavioral disorders. In such cases, complete dentures may serve as an alternative treatment option. This is where the potential of digital dentures lies.[22,23]

Tooth loss due to caries, periodontitis, trauma, or iatrogenic factors leads to numerous oral and maxillofacial disturbances. Tooth loss contributes to malnutrition, early morbidity, and decreased quality of life, while prosthetic treatment for edentulous patients improves their quality of life and reduces morbidity. Treating edentulous patients with complete removable dentures only partially restores missing tissues, esthetics, function, phonetics, and patient satisfaction. Thus, treating edentulous patients with complete removable dentures remains a complex and demanding task. Additionally, establishing good relationships with the patient is often more critical for achieving satisfaction than creating a technically perfect denture.[24]

While upper jaw complete dentures often meet patient expectations, challenges are more common with lower jaw dentures, which frequently lack sufficient retention and stability, leading to discomfort and pain. In such cases, and especially for maladaptive patients, the use of implants to fabricate removable or fixed prostheses significantly enhances oral function and quality of life.[4]

EPIDEMIOLOGY OF EDENTULISM AND LONGEVITY OF COMPLETE REMOVABLE DENTURES

Edentulism, the final stage of chronic periodontal diseases, is less prevalent in developed countries. However, it is strongly associated with age and socio-economic factors. It is particularly more common among the elderly and socio-economically compromised populations, making it a significant health issue requiring prosthetic treatment. Evidence regarding the longevity of dentures is limited. Recent studies indicate that the average replacement period for dentures is approximately 10 years, with maxillary (upper jaw) dentures showing greater durability than mandibular (lower jaw) dentures.[25,26]

DIGITAL DENTURES FABRICATION METHODS

Digital denture systems are classified based on their fabrication process (subtractive/milling or additive/printing) or the procedural approach (number of visits required). Many systems combine analog and digital phases. Conventional complete dentures (compression or injection-molded) exhibit spatial changes inherent to the material and fabrication process (polymerization shrinkage, thermal expansion, and contraction). These changes can affect the precision of the denture base and occlusion (premature contacts, changes in vertical occlusal dimension).[27] In contrast, denture bases fabricated using CAD/CAM methods demonstrate minimal spatial changes. Currently, digital dentures can be fabricated through both additive and subtractive methods. Milled complete dentures are used as final restorations, while printed dentures are still primarily considered temporary.[28] Both CAM technologies provide clinically acceptable results and are faster than traditional methods.

Additive Manufacturing (3D Printing)

Additive manufacturing, also known as rapid prototyping, builds 3D objects layer by layer. Printed dentures typically involve a pink resin base to which teeth or tooth arches of matching color are attached using a special light-curable liquid resin, followed by light polymerization [29]. However, residual unpolymerized photoreactive resin in printed dentures can negatively affect the mucosa or skin (Table 1).

Table 1. *Additive manufacturing methods, advantages, and factors influencing final product quality*

Common Additive Methods	Advantages	Factors Influencing Final Product Quality
Stereolithography Digital Light Processing (DLP) MultiJet/PolyJet Printing	Short production time Fewer patient visits High-quality printing of complex geometries Precise reproduction of small details No material waste	Laser intensity Printer and software calibration Material properties Printing direction and angle Number and thickness of layers Bond between layers Post-polymerization conditions

Subtractive Manufacturing (Milling)

Subtractive manufacturing creates 3D objects by milling a standard block of material according to a pre-designed digital model. In prosthetic dentistry, this method is implemented via CAD/CAM technology and is widely used for fabricating partial and complete crowns, removable dentures, implant abutments, and maxillofacial prostheses.[30,31] Pre-polymerized PMMA disks are milled to produce homogeneous objects with excellent biocompatibility. Advanced milling strategies allow for detailed and precise reproduction of tissue and external surfaces.[32] Studies show that the tissue surface of milled dentures is more accurate than that of printed ones.[33,34]

Applications and Indications

Digital complete dentures are suitable for the following scenarios including a) Single-arch final complete dentures, b) Complete dentures for both maxilla and mandible, c) Immediate dentures and temporary dentures, d) Diagnostic evaluation of tooth arrangement in implant-supported fixed and removable prostheses, e) Surgical or radiographic guides for implant placement.[35]

Fabrication Process

Avadent Digital Dental Solutions offers either a milled/printed denture base to which teeth (standard or milled) are attached or a monolithic denture (Avadent Clinical Protocols). For the two-visit fabrication process, it is preferable for existing dentures to be in acceptable condition (fit, arch alignment, occlusal plane, esthetics, and centric relation). Recently, various procedures have been described to collect the necessary clinical information. Among these, the three-visit procedure has gained the widest acceptance. In this process, during the second visit, a milled/printed preliminary denture or a milled/printed base with wax-mounted teeth is tested in the oral cavity.[36]

In cases where a) The patient has no previous dentures, b) The existing denture information is insufficient, c) The new dentures require significant changes compared to the previous ones, or d) The clinical situation is complex, it is advisable to use the conventional fabrication method.

Maintenance Recommendations

The denture should be cleaned daily with liquid soap and a soft toothbrush before sleep.

Additionally, peroxide-based cleaning tablets should be used weekly to reduce *Candida albicans* levels and prevent denture stomatitis.

Material Selection

Polymethyl methacrylate (PMMA) is the most widely used material for fabricating complete dentures due to its esthetics, low water absorption and solubility, sufficient strength, ease of maintenance, and straightforward fabrication process. However, PMMA has certain drawbacks, such as porosity, residual monomer content, the presence of potential allergens, prolonged processing time, brittleness, and uneven thickness.[37]

Pre-polymerized standard PMMA disks, fabricated under high pressure and temperature, possess high density, resulting in dentures with superior mechanical and physical properties. The high pressure and temperature during polymerization promote the formation of long polymer chains and minimize residual monomer content.[38] This process prevents shrinkage and enhances physical properties.[39,40] Milling spatially stable, pre-polymerized PMMA blocks offers certain advantages over conventionally heat-cured PMMA:

a. Enhanced Mechanical Properties:
   - Greater flexural strength, fracture resistance, and elastic modulus allow for the fabrication of thinner denture bases if needed.[41]

b. Improved Surface Characteristics:
   - Increased surface hardness reduces vulnerability to wear and damage.[32]
   - Smoother, more hydrophilic surfaces with greater wettability, depending on milling quality and tools used, make CAD/CAM denture surfaces less prone to microbial colonization. Polished milled surfaces exhibit superior properties compared to 3D-printed and conventionally fabricated surfaces. This reduces plaque and calculus accumulation and facilitates easier cleaning.[32]
   - The smooth surface combined with higher material density and reduced porosity enhances stain resistance and decreases susceptibility to discoloration. Research indicates that conventional acrylic resins are more prone to discoloration at the tooth-denture base interface under exposure to substances like coffee and red wine.[42,43] CAD/CAM milled samples show less pigment uptake compared to conventionally fabricated samples.

c. Lower Monomer Content:
   - CAD/CAM blocks contain significantly less monomer and exhibit nearly uniform monomer release, similar to that of heat-polymerized dentures. However, factors like the adhesive material for securing denture teeth and the thickness of pre-polymerized blocks, which may hinder monomer evaporation from the interior, require further consideration.[44]

d. Biocompatibility:
   - While digital denture biocompatibility requires further investigation, CAD/CAM PMMA and conventional heat-cured PMMA have demonstrated nearly equivalent biocompatibility. Digital fabrication eliminates the modeling and polymerization process, along with monomer-related risks, minimizing potential adverse effects.[45,46]

e. Better Fit and Reproducibility:
   - CAD/CAM milled dentures show superior adaptation and reproducibility compared to conventionally fabricated dentures. Some studies indicate that injection-molded and CAD/CAM methods exhibit similar adaptation to the denture-bearing area. Other research highlights that milled denture bases offer greater accuracy than 3D-printed and conventionally fabricated bases for both maxillary and mandibular dentures. However, contradictory findings also exist.[47,48] While milling remains the benchmark for precision, 3D printing achieves clinically acceptable results.

f. Reproducibility and Efficiency:
   - Milling and printing methods show lower reproducibility compared to injection molding. However, CAD/CAM milled monolithic techniques optimize the balance between precision and reproducibility.[49]

FIT AND RETENTION

The retention of a digitally fabricated complete denture base, milled from pre-polymerized PMMA, is superior to that of conventional heat-polymerized resin bases due to the absence of polymerization shrinkage.[50,51] However, the use of denture adhesives reduces the retention of milled bases, likely due to compromised adaptation.[52] Digital dentures offer a better fit to the denture-bearing area, clinically greater retention, and fewer traumatic contact points compared to conventionally fabricated dentures. Milled digital complete dentures demonstrate higher retention, stability, and fit, as well as greater spatial stability, compared to conventional dentures. The greatest mismatch between digital denture bases and the denture-bearing area is observed at the border seal region, including the posterior palatal seal area. These dentures often require relining after some time to enhance retention and compensate for the physiological resorption of bone.[2,47,48,53,54]

SURFACE QUALITY OF THE DENTURE

CAD/CAM monolithic removable dentures

provide the highest precision and reproducibility. A smooth surface is crucial in any restorative treatment to prevent the accumulation of microorganisms, which is essential for achieving aesthetic results, patient adaptation, and clinical success. Eliminating surface porosity and irregularities on the denture base is vital to reducing *Candida* adhesion to the polymer surface. Denture stomatitis, an inflammatory condition of the mucosa beneath the prosthesis, is often associated with *Candida* colonization and biofilm formation. The smooth surfaces of digital dentures inhibit *Candida* accumulation and facilitate cleaning [55]. Digital removable dentures are less porous, and polymerization shrinkage is absent, reducing the incidence of denture stomatitis. Even with proper finishing and polishing, conventional complete dentures promote more *Candida* adhesion compared to CAD/CAM polymers. As a result, digital dentures contribute to better hygiene and lower rates of prosthetic stomatitis.[56-59]

TIME EFFICIENCY IN DENTURE FABRICATION

Digital complete dentures present an alternative to conventional removable dentures due to their shorter treatment duration and fewer clinical and follow-up visits for adjustments and repairs. For conventional dentures, adjustments are typically made 24 hours after placement, requiring an average of three visits. In contrast, digital dentures are more time-efficient and practical for edentulous patients. Thanks to digital clinical data and laboratory software, the laboratory stages are completed faster, resulting in a standardized, high-quality final product [34]. For the dental technician, the process shifts from manual tooth arrangement in wax to digital design on a screen and from manually crafted dentures to digitally guided production. This approach is more standardized, manageable, straightforward, faster, and predictable, streamlining the fabrication process.[2,4]

PATIENT SATISFACTION

Achieving patient satisfaction relies heavily on the personal experience of the fabrication process and proper patient selection. Evaluating 3D digital data on a screen, as opposed to using conventional models, can be challenging and prone to misinterpretation, making effective communication between the dentist and dental technician essential. Certain technical and clinical stages remain complex (e.g., attaching denture teeth). Dissatisfaction with retention, aesthetics, and other complaints is often linked to shortcomings during the trial phase. Selecting the right procedure can help avoid many issues.[4]

Patients are generally satisfied with digital removable dentures, primarily due to their improved retention and shorter fabrication times [1]. However, some studies indicate higher satisfaction with conventional dentures in terms of stability, comfort, aesthetics, and phonetics. Additionally, patients report greater quality-of-life improvements with conventional dentures. The retention of milled, pre-polymerized denture bases is comparable to that of conventional bases. Some observations showed equal levels of satisfaction with both digital and conventional dentures.[2]

Since digital dentures lack a clinical trial phase, it is impossible to evaluate aesthetics and phonetics beforehand, which might otherwise lead to greater patient satisfaction. In contrast, conventional dentures include a wax try-in phase, allowing adjustments to tooth arrangement and customization to refine facial contours.[60]

Patients often prefer digital dentures for greater retention, shorter treatment times, and overall convenience. However, in two-visit fabrication protocols, issues such as reduced retention, incorrect occlusal vertical dimension, and misaligned centric relations are noted. As such, this approach is more suited for elderly or medically compromised edentulous patients. Although fewer visits reduce costs, the high material cost of digital dentures makes them more expensive overall. It is evident that advancements in technology can address the potential shortcomings of digitally fabricated dentures.[1,4]

ADDITIONAL CONSIDERATIONS

The aesthetics of digital dentures are somewhat inferior due to the lack of a trial phase during fabrication. However, chlorhexidine rinses have minimal impact on color retention. Many techniques use white plastic, requiring external staining of the denture.[61] Aesthetic features such as retention, tooth size, vertical dimension, horizontal relations, and patient appearance can still be improved during digital trials, although these evaluations are more complex in digital workflows.[2]

Comparative studies have also examined the distribution of occlusal forces in conventional versus digital dentures. A bilaterally balanced occlusal scheme ensures better force distribution, which is critical given the connection between occlusal force imbalance and temporomandibular joint (TMJ) disorders. Uneven occlusal contacts can lead to TMJ pathology. Digital dentures face challenges in determining the occlusal vertical dimension, the position of maxillary incisal edges, and proper lip support.[62,63]

Despite these limitations, digital dentures provide significant advantages, such as fabrication ease and short production times. The ability to store digital data allows replacing lost or damaged dentures without additional clinical visits. This is especially beneficial for elderly patients or during pandemics (e.g., COVID-19) when fewer visits reduce the risk of infection spread. Digital fabrication generally requires two clinical visits, saving both clinical and laboratory time. Studies also indicate improved quality of life for patients with digital dentures.[2]

CONCLUSION

Digital complete dentures represent a modern solution to edentulism, combining technological precision with clinical efficiency. Milled dentures offer superior retention, biocompatibility, and surface quality compared to conventional and printed dentures. Digital workflows streamline fabrication and reduce patient visits, making them particularly suitable for medically compromised or elderly patients. Despite these benefits, challenges such as high material costs, absence of trial phases, and limitations in assessing esthetics and occlusion remain. Future advancements in digital technology and materials are essential to overcome these hurdles and fully integrate digital dentures into routine clinical practice.

DECLARATIONS

Conflicts of interest and financial disclosures

The author declares that he has no conflict percent and there was no external source of funding for the research in question.

Ethical approval

Not Applicable.

Informed consent

Not Applicable.

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AUTHOR CONTRIBUTIONS

Conceptualization, A.H., S.G. and A.Z.; methodology, A.H.; software, S.G.; validation, A.H.; formal analysis, A.H. and S.G.; investigation, S.G. and A.Z.; resources, A.Z.; data curation, S.G. and A.Z.; writing—original draft preparation, S.G. and A.Z.; writing—review and editing, A.H.; visualization, S.G., A.Z. and A.H.; supervision, A.H.; project administration, A.H. All authors have read and agreed to the published version of the manuscript.

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