



Evaluation of Next-Generation Complete Denture Manufacturing

Material, Biological, and Clinical Outcomes

Farah Nabeel Mohammed Tahir AlKhayyat, Shaymaa Majid Abdulhamed, Nagham Bahjat Kamil

College of Dentistry, Mustansiriyah University, Baghdad, Iraq

Abstract

This study aimed to comprehensively evaluate the next-generation complete denture manufacturing systems that include the material engineering properties, printing procedures, and their effects on the mechanical properties, surface properties, and biological behaviors. An in vitro experimental study was conducted. The conventional heat-polymerized polymethyl methacrylate (PMMA), CAD/CAM-milled polymethyl methacrylate (PMMA), and additively manufactured denture resins were used in making full dentures. The characterization of the materials was carried out with respect to mechanical (flexural strength and fracture resistance), surface (surface roughness and microscopic morphology), and physicochemical (stability) tests. Biological performance was measured by the analysis of protein adsorption as well as microbial adhesion. Statistical analysis was performed to determine significant differences between manufacturing techniques. Computer-aided design and computer-aided machining (CAD/CAM) dentures showed significantly ($p < 0.05$) increased flexural strength (112.7 ± 7.5 MPa) and fracture resistance (1560 ± 110 N) compared to the conventional PMMA denture. CAD/CAM fabricated dentures had significantly lower surface roughness (0.28 ± 0.05 μm) than PMMA. Furthermore, there was a decrease in protein adsorption and bacterial adhesion in CAD/CAM dentures, indicating improved biological compatibility. The next-generation complete denture manufacturing systems are improved to the conventional fabrication techniques, in terms of material properties, surface finish and biological responses. The combination of new material engineering with digital manufacturing is a new trend towards more predictable and reliable performance, better durability and potentially better clinical outcome in complete denture restoration.

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Email: farahnabel@uomustansiriyah.edu.iq

Introduction

Edentulism remains a common oral health problem, particularly among elderly patients, and is associated with functional, esthetic, and psychosocial consequences. Although implant-supported prostheses are increasingly used, complete dentures remain an important treatment option because they are affordable, non-invasive, and widely applicable in fully edentulous patients.

The traditional form of full denture manufacturing has been highly relying on the traditional heat-polymerized polymethyl methacrylate (PMMA) polymers which is being subjected to compression molding process. Despite the clinical success of these classic workflows of decades, they have been attributed to some inherent weaknesses, like shrinkage of the polymerization, creation of pores, size errors, and operator-dependent variability. These disadvantages may influence the adhesion of dentures, mechanical

retention, and clinical prognosis over time, leading to patient satisfaction and prostheses retention [1]. Recent advances in digital dentistry have introduced CAD/CAM milling and additive manufacturing as alternatives to conventional denture processing. These techniques allow the fabrication of denture bases from pre-polymerized or digitally cured resin materials, which may improve material homogeneity, dimensional accuracy, and reproducibility.

Besides mechanical and dimensional factors, the biological behavior of complete denture materials have also been in the focus of the investigation in the contemporary world. Outcomes of surface modification as a by-product of production process are crucial in protein adsorption, microbial adhesion, and biofilm formation, which are directly involved in the pathology development of denture-related pathologies, denture stomatitis. It has been argued that digitally made denture bases have a smoother surface and are less prone to colonization by bacteria than the traditional PMMA processing, possibly providing a biological advantage associated with the digital processing [2].

Although reports have been done on the isolated evaluation of specific aspects of digital denture production process including the accuracy of fit or mechanical performance, there is a myriad of gaps in literature regarding the behavior of detailed analytical studies that perceive the material engineering, manufacture methodology, biological functions, and clinical outcomes as a unit of analysis. It is necessary to bridge this gap to have a clear picture of the impact of the advanced complete denture manufacturing on patient-centered care and evidence-based practice in the discipline of prosthodontics [3].

Previous studies have mainly evaluated isolated outcomes such as denture fit, mechanical strength, or surface roughness. However, fewer studies have combined mechanical, surface, and biological assessments within one experimental design. Therefore, the present study aimed to compare conventional heat-polymerized PMMA, CAD/CAM-milled PMMA, and additively manufactured denture resins in terms of mechanical performance, surface properties, and biological interactions.

Materials and Methods

Study Design

This study was conducted as an integrated in vitro study which would assess the impact of different denture fabrication techniques on material, biological and clinical outcomes. Three methods of fabrication were explored, including traditional heat-polymerized polymethyl methacrylate (PMMA), CAD/CAM-milled PMMA and additively manufactured denture base resins.

Denture Fabrication Groups

Full denture bases were made and separated into three experimental groups based upon the production method:

- Group I: PMMA dentures made traditionally by heat-polymerizing the material through the compression molding process.
- Group II: CAD/CAM-milled dentures made of pre-polymerized PMMA

blocks with the help of a computer-aided production system.

- Group III: Additively manufactured dentures made with a photopolymerizable denture base resin that would be processed through a 3D printing system.

All the specimens were prepared according to the instructions of manufacturers and the standard laboratory protocols to reduce the influence of the operator.

A total of 30 specimens were fabricated for each experimental group. Rectangular specimens measuring 65 × 10 × 3 mm were prepared according to ISO 20795-1 standards.

Mechanical Testing

Flexural strength and fracture resistance were the tests done to assess the mechanical properties of the denture base materials.

A three-point bending test on a universal testing machine was used to measure flexural strength as per the ISO standards on denture base polymers. The samples were continuously loaded under a fixed crosshead rate until fractured.

Fracture resistance was measured in applying compressive force until final failure. The highest magnitude of fracture was noted in Newtons (N).

Surface Characterization

Surface roughness (Ra) was determined, and surface morphology was analyzed as surface properties of denture base materials.

A digital profilometer was used to measure the surface roughness. Each of the specimens was read several times, and the average was obtained. Besides, scanning electron microscopy (SEM) was used to examine microscopic surface morphology to determine surface defects, porosity, and structural irregularities.

Biological Evaluation

Protein adsorption and microbial adhesion analysis was used to evaluate the biological performance of denture base materials.

Protein adsorption was assessed through the exposure of denture specimens to artificial saliva which has salivary proteins and then spectrophotometric determination of adsorbed proteins was done.

Microbial adhesion was determined using the common oral microorganisms related to the formation of denture biofilm. Microbial colonies that were adhered to denture surfaces were then counted by means of colony-forming unit (CFU) testing after incubation.

Statistical Analysis

The statistical software was used to analyze all the collected data. Each variable was computed as descriptive statistics of means and standard deviations.

One-way analysis of variance (ANOVA) was done with post-hoc tests being used where necessary to compare the three

manufacturing techniques. The level of statistical significance was taken to be $p < 0.05$.

Results

Results are summarized in Figure 1 and Tables 1, 2, and 3.

Mechanical Performance of Complete Denture Base Materials

Significant differences in mechanical performance were observed among the three manufacturing techniques. CAD/CAM-milled PMMA showed the highest flexural strength and fracture resistance, followed by additively manufactured resin and conventional heat-polymerized PMMA.

Surface Properties of Full Denture Bases

Significant differences in surface properties were observed among the manufacturing techniques. Higher values of surface roughness of the traditionally manufactured dentures were accompanied by surface irregularities and porosities even though the polishing was standard. In contrast, CAD/CAM-milled dentures demonstrated smoother and more homogeneous surfaces with fewer structural irregularities. Additive produced dentures showed intermediate values of surface roughness, and surface features of layers, which were partially removed following finishing and polishing. These findings indicate that in the final conditions of complete denture base surfaces, manufacturing technique plays a very crucial role in determining the final conditions.

Interactions of Biology and Surfaces

Biological evaluation demonstrated that manufacturing technique directly influenced protein adsorption and microbial adhesion. CAD/CAM-milled denture bases showed the lowest levels of protein adsorption and microbial colonization, whereas conventional PMMA demonstrated the highest values. Additively manufactured dentures showed intermediate biological behavior. These findings suggest that smoother denture surfaces may reduce microbial accumulation and improve biological compatibility.

Discussion

The findings of the present in vitro study demonstrate that digital denture manufacturing techniques, particularly CAD/CAM milling, significantly enhance the mechanical performance of denture base materials compared to conventional heat-polymerized PMMA. The CAD/CAM-milled specimens, with improved flexural strength and fracture toughness, may be attributed to the industrial polymerization of pre-polymerized resin blocks leading to improved homogeneity of materials and less porosity. These enhancements are fundamental in reducing the generation and propagation of cracks under masticatory forces and thus contribute to

denture base stability. Similar findings regarding the improvement in mechanical properties of CAD/CAM fabricated denture materials have been reported before [4]. The tested methods also exhibited significant variations in surface properties. Dentures manufactured by CAD/CAM milling had lower surface roughness than conventional PMMA denture base materials, demonstrating the accuracy and precision of subtractive manufacturing. In comparison, conventional processing techniques can create surface imperfections and porosities resulting from shrinkage and manual handling. Given that the surface roughness plays a critical role in bacterial attachment and plaque formation, better surface properties of CAD/CAM denture bases may positively affect their biological behavior. These results agree with other studies that reported better surface properties of CAD/CAM denture bases [2,5].

The biological assessment adds to the body of literature promoting the use of digital denture fabrication. The observed reduction in protein adhesion and microbial adhesion in CAD/CAM specimens can be attributed to their more smooth and uniform surfaces. Reduced microbial adherence is especially important in avoiding denture-related oral diseases like denture stomatitis, where biofilm formation is a key factor. Other studies have also shown decreased biofilm accumulation on digital denture materials compared to conventional resins, further confirming the advantages of digital denture technologies [6,7].

Additive manufacturing showed moderate results with regards to mechanical, surface, and microbiological characteristics. Although disposable dentures made through 3D printing systems have benefits with respect to design and material waste, the layered structure may lead to anisotropy in mechanical properties and to surface imperfections, which might influence the mechanical stability and the initial bacterial adhesion. This agrees with earlier reports, which showed that additive manufacturing technologies, despite being promising, need to be improved in terms of material types and post-processing methods to achieve comparable properties to CAD/CAM-milled dentures [7,8].

In summary, this study underscores the importance of processing technologies in the performance of denture base materials. The combination of enhanced material engineering and digital production techniques offers a more uniform manufacturing process, which leads to enhanced mechanical properties, surface incompatibilities and biological

effects. While the current study was performed in a laboratory setting, the outcomes of this study indicate great prospects for digital denture manufacturing in prosthodontics. However, such results need to be confirmed through long-term studies for a better understanding of the clinical performance and the long-term stability [3,9].

Study Limitations

This study has several limitations. First, the experiment was conducted under controlled laboratory conditions, which may not fully reproduce the complexity of the oral environment. Second, thermocycling and long-term aging simulation were not performed. Third, only selected denture base materials and fabrication systems were evaluated. Therefore, future studies should include long-term clinical evaluation, broader material comparisons, and aging protocols to confirm these findings.

Future Research Directions

The future research needs to be conducted based on long-term clinical trials on the durability of digitally fabricated dentures, wear resistance, and biological performance of such dentures in various patient groups. Additional research is also necessary to determine the effects of various 3D printing technology, resin formulations, and subsequently post-processing instructions on the mechanical and biological characteristics of denture base materials. Also, to develop the performance of complete denture therapy and its personalization, it is recommended that further investigations should be conducted on the adoption of innovative biomaterials and antimicrobial surface modifications, along with the artificial intelligence-enhanced digital workflows. These new developments can help in improving predictable, long-lasting and patient-centered forms of prosthodontics in the digital era of dentistry.

Conclusion

Within the limitations of this in vitro study, CAD/CAM-milled PMMA and additively manufactured denture resins showed improved mechanical, surface, and biological performance compared with conventional heat-polymerized PMMA.

In general, the implementation of modern material engineering, combined with digital manufacturing, is an important contribution to the overall denture therapy, which provides greater predictability and longevity and, more importantly, a biologically preferable prosthodontic solution to edentulous patients.

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Mustansiriyah University, College of Dentistry.

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Table 1. The mechanical characteristics of total denture base materials produced using different manufacturing procedures.

Manufacturing technique	Flexural strength (MPa)	Fracture resistance (N)
Conventional PMMA	85.4 ± 6.8	1,120 ± 95
CAD/CAM-milled PMMA	112.7 ± 7.5	1,560 ± 110
Additive manufacturing	98.9 ± 6.2	1,340 ± 105

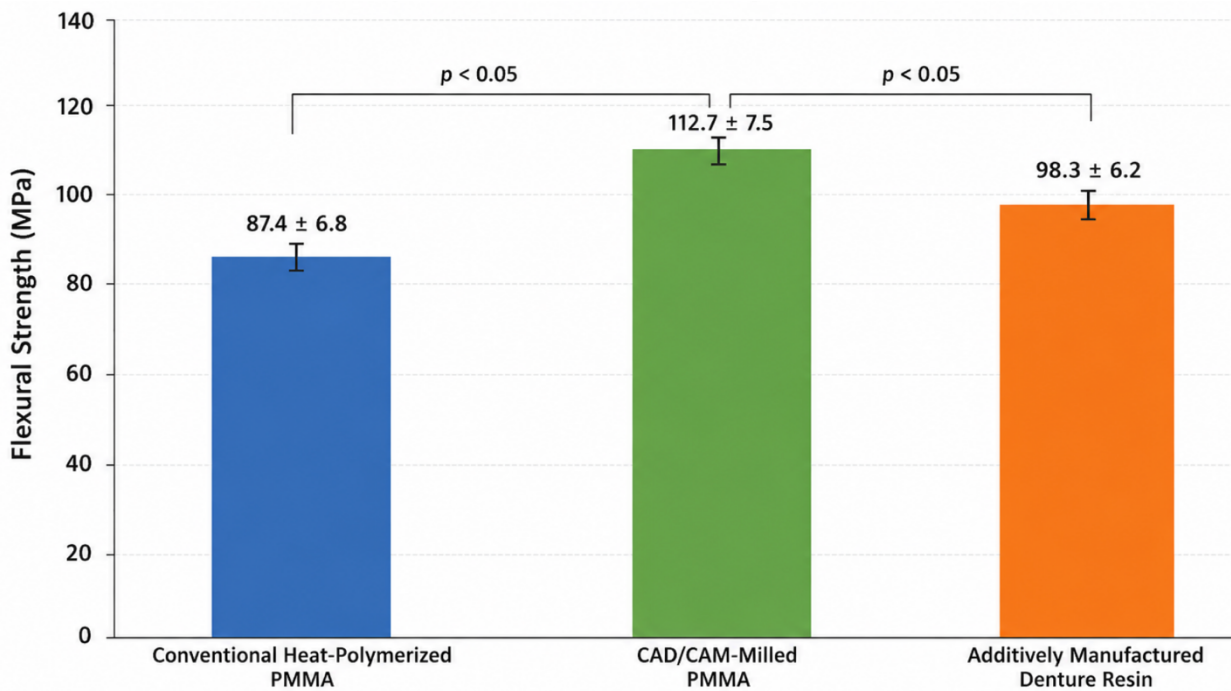


Figure 1. Flexural strength of complete denture resins fabricated by different manufacturing techniques.

Table 2. Numbers of surface roughness (Ra) of full denture base materials.

Manufacturing technique	Surface roughness Ra (μm)
Conventional PMMA	0.62 ± 0.08
CAD/CAM-milled PMMA	0.28 ± 0.05
Additive manufacturing	0.41 ± 0.07

Table 3. Wholesale denture base material biologic interaction parameters.

Manufacturing technique	Protein adsorption ($\mu\text{g}/\text{cm}^2$)	Microbial adhesion (CFU/ mm^2)
Conventional PMMA	4.8 ± 0.6	$3.2 \times 10^3 \pm 0.4 \times 10^3$
CAD/CAM-milled PMMA	2.1 ± 0.4	$1.1 \times 10^3 \pm 0.3 \times 10^3$
Additive manufacturing	3.3 ± 0.5	$2.0 \times 10^3 \pm 0.5 \times 10^3$