

# 3D Printing Technologies for Removable Dentures Manufacturing: A Review of Potentials and Challenges

## Keywords

Rapid Manufacturing  
3D Printing  
Additive Manufacturing  
Dentures  
Digitally Designed

## Authors

Khaled R. Alhallak\*  
(DDS, MSc)

Ali Nankali§  
(Dr. Stom., CMS, PhD, FHEA)

## Address for Correspondence

Khaled R. Alhallak\*

Email: ddshallak@hotmail.com

\* Institute of Dentistry, Office 2, Barts and The London, School of Medicine and Dentistry, Queen Mary University of London, Turner Street, London, E12AD

§ Prosthodontics, Centre of Teaching and Innovation (Adult Oral Health), Clinical Senior Lecturer, Barts and The London, School of Medicine and Dentistry, New Road, London, E11BB

## ABSTRACT

The aim of this review is to investigate the use of 3D printing technologies for removable denture fabrication with a focus on the advantages, potentials, disadvantages and barriers. Methods: An electronic search of the English language literature from 1970 to March 2020 was carried out in databases such as PubMed/MEDLINE, Embase, Scopus, and Web of Science databases with applying the inclusion and exclusion criteria. The search was performed using a variety of keywords including 3D printing, rapid prototyping, additive manufacturing, dentures/complete dentures. Results: A total of 412 publications were retrieved. After applying the inclusion criteria and excluding the studies on CAD/CAM, studies on 3D printed crown and bridge and studies on 3D printed metal framework, 18 articles were identified for reading and analyzing in details. The results have outlined the main 3D printing advantages such as saving working time, satisfying clinical results and securing patients records. The detected disadvantages were the strength, esthetics and material biocompatibility. Conclusion: Denture fabrication by 3D printing technology is becoming more common in dental clinics. However, there is still a lack of information about biocompatibility and clinical performance of 3D printed dentures and further studies are essential.

## INTRODUCTION

Three dimension (3D) printing technology which is also known as additive manufacturing can be described as a method for producing of digitally design objects by connecting materials, incrementally, in successive approach.<sup>1</sup> 3D printing technologies are developing rapidly in fields such as industry, life science, medicine and dentistry.<sup>2</sup> In dentistry, CAD/CAM and 3D printing have been used to construct a variety of restorations such as inlays, onlays and crowns.<sup>3</sup> In prosthodontics, it can fabricate wax patterns then print to form a final prosthesis by using a variety of materials such as resins and ceramics. The fabrication of complete removable dentures by 3D printing has become possible considering the less time and cost needed to make a denture compared with CAD/CAM. Also, saving materials is another ability along with no need of any commercial specialized center as CAD/CAM system needs.<sup>4-7</sup>

Additive manufacturing includes many types such as stereolithography (SLA), digital light projection (DLP), fused deposition modelling (FDM), jet printing and selective laser sintering SLS.<sup>8</sup> Stereolithography can produce resin-based bodies such as dentures and surgical guide plates, along with

Received: 09.09.2020

Accepted: 07.04.2021

doi: 10.1922/EJPRD\_2208Alhallak06

manufacturing wax patterns, removable denture frameworks, and temporary restorations.<sup>8,9</sup> On the other hand, selective laser melting can be used with metal alloys such as chrome-cobalt and palladium chrome.<sup>2,10</sup>

Additive manufacturing has been used for creating 3D complex models in medicine since the 1990s.<sup>7</sup> Earlier, 3D printing used for industrial purposes depended on the CAD/CAM technology to create a physical model from three dimensional data.<sup>11</sup>

In 1994, Maeda reported the manufacture of the first removable prosthesis by using 3D laser lithography.<sup>12</sup> After that, Kawahata used CAD/CAM with a computerized numerical control (CNC) to produce a duplicated removable prosthesis.<sup>13</sup> The manufacturing process was sophisticated and time consuming, while the combination between the digital design and the conventional manufacturing was applicable.<sup>14,15</sup>

Although it seems that the digital manufacturing technology has made great changes in the prosthodontics field, essentially in producing large prosthesis, this technology is not widely in use. Some professionals stated that the main reason of the delay in 3D printing popularity is the lack of information regarding many properties and aspects of this technology. In this review, many published articles on denture manufacturing using 3D printing have been systematically reviewed to outline what scientists have achieved so far. Also, this review will focus on exploring the negative aspects of this existing technology and investigating the pluses and future potential of this technology.

## METHODS

### SEARCH STRATEGY

The search was only for online published papers in English and the data was collected from PubMed/MEDLINE, Embase, Scopus and Web of Science.

This search was performed by using variety of keywords including 3D printing, rapid prototyping, additive manufacturing, dentures, complete dentures, partial dentures with no limitations on year of publication up to the end of March 2020. The main focus for this review was to investigate the potentials, advantages, disadvantages, challenges and barriers of using 3D printing in denture manufacturing.

### DATA EXTRACTION

Two reviewers independently screened titles and abstracts of the identified papers to secure the accuracy and scientific value of the review. Data extraction from individual studies included information on author's name, year of publication, country, study design, methodologies and related issues of using 3D printing in denture manufacturing such as advantages, disadvantages, challenges, potentials and barriers. All extracted data were transferred to an excel sheet for this purpose. The transferring of data process were double checked by the two reviewers.

## INCLUSION AND EXCLUSION CRITERIA

The inclusion and exclusion criteria are a crucial part of the review to outline the scope of study and to narrow down the large number of available papers within the different databases.

After removing all duplicated papers from the database, the title and abstract of each publication was reviewed to determine eligibility for inclusion.

The inclusion criteria were:

- Relevance: papers were required to report the potentials, advantages, disadvantages, challenges, barriers and the other related issues of using 3D printing in dentures' manufacturing.
- Language: only papers written in English were included in the review.

The exclusion criteria were:

- studies on CAD/CAM.
- Studies on 3D printing in crown and bridge manufacturing.
- Studies on metal framework construction by 3D printing.

All the above-mentioned studies were excluded from this review. In addition to, studies with ambiguous information regarding 3D printing and dentures. Articles not written in English, letters, editorials and congress abstracts were also omitted.

## RESULTS

Based on the search methodology used in this study, the electronic database search revealed 412 titles in the English literature. After removing duplicated information, the total number of articles decreased to 278. In the next stage, a total of 157 records were removed as they did not fulfil inclusion criteria. Overall, 121 studies were included in our literature review section. The abstracts for the 121 paper were read and 18 publications were selected for reading and analyzing in more detail. These 18 papers have shown various 3D printing techniques, advantages, and disadvantages of 3D printing for removable denture fabrication. Moreover, the restrictions and future challenges of 3D printing technologies in denture manufacturing were highlighted in some studies.

The result of this review showed a limited number of researches on using 3D printing technology for denture manufacturing. Most of these studies focussed on the applicability of fabricating dentures by using 3D printing and evaluating the clinical performance of 3D printed dentures.<sup>1,4,16</sup> There was a remarkable focus among many researchers on reducing the required sessions to fabricate dentures and consequently making this treatment much more cost-effective.<sup>4</sup> The first attempt to construct 3D printed dentures has taken place in the last decade, in this attempt, the primary impression and jaw relations were taken by the traditional technique then the design would be prepared and the denture would be fabricated by printing the

denture base and the denture teeth separately. In the last stage the denture teeth were bonded on the denture base to complete the denture.<sup>4,16</sup> Regardless, the studies on constructing 3D printed dentures are still very limited and constrained with case reports and proof of concept studies.

Some studies started by duplicating an existing denture by using 3D printing technologies.<sup>16</sup> The main aim for them was to reduce the laboratory steps and chair time when fabricating dentures for patients with existing dentures.<sup>16,17</sup> Kurahashi concluded that the main advantages for duplicating existing dentures by using 3D printing systems were saving material and treatment time and reducing the effect of the human factor.<sup>18</sup> Cristache suggested using modified PMMA-TiO<sub>2</sub> nanocomposite material to obtain 3D printed complete dentures. The author stated that the 3D printed dentures based on PMMA-TiO<sub>2</sub> nanomaterial that have been investigated showed acceptable clinical performance after 18 months of wear.<sup>19</sup>

Inokoshi compared clinically between the Rapid Prototyping (RP) and conventional methods in manufacturing a trial complete denture. The author found superiority of the conventional method compared with the RP method in terms of stability, esthetics and treatment time, whilst the patient's satisfaction between the two methods was relatively parallel.<sup>4</sup> Pereyra concluded that the patient satisfaction with dentures fabricated by rapid prototyping was higher compared with conventional dentures.<sup>20</sup>

In addition to the clinical performance and workflow of 3D printed dentures, there were some studies on the mechanical properties, accuracy and trueness of those dentures considering the vital role of these properties on having retentive and successful denture, which is the top priority for the vast majority of denture users.<sup>1,21-23</sup> Some researchers concluded that the mechanical properties of 3D printed dentures such as accuracy and fracture resistance are better than conventional dentures.<sup>21-24</sup> In contrast, other scientists such as Prpić stated that conventional and CAD/CAM dentures showed better mechanical properties than 3D printed dentures.<sup>25</sup> Kalberer compared between the CAD/CAM and RP fabricated dentures regarding the trueness of intaglio surface, he found a superiority for CAD/CAM compared with RP. Kalberer suggested that there was a lack of information in regards to some biocompatible properties of the new manufacturing systems.<sup>1</sup> Table 1 shows the key advantages and disadvantages of 3D printed dentures.

Some scientists suggested a combination of denture base materials and some fillers such as modified titanium dioxide in order to improve the antibacterial and mechanical properties of materials suitable for 3D printing systems.<sup>26</sup> However, further mechanical and biocompatibility investigations are still required in order to improve the properties and clinical outcome for using these combinations.<sup>26-28</sup>

Additionally, it can be concluded that, 3D printing technology could have a positive impact on dental education, patient care, research, and public health worldwide. Yet, there was a

**Table 1. Table on advantages and disadvantages of 3D printed dentures**

3D printed dentures	
Advantages and potentials	Disadvantages and barriers
Less working time	Lack of strength
Saving patients' data	Biocompatibility
Reducing materials used	Esthetics
Build complex geometries and precise details	Clinical complications
Fabricating small, moderate and large workpieces	Need relining
Less cost compared with CAD/CAM dentures	Poor retention
Employing less human power	

limitation in the available data on the clinical performance essential for 3D printing materials. More appropriate evidence are required to ascertain the safety and long-term performance of such dentures. Clinical trials with true clinical endpoints are necessary to validate this technology, specifically for the toxicological properties of materials that are used. Table 2 summarizes the included papers in this review and their main conclusions.

## DISCUSSION

From the reviewed literature, it can be concluded that 3D printing technology appeared in industry more than three decades ago and became only widely available in dentistry in the last few years.<sup>7,11</sup> The widespread prevalence over the previous few years was noticeable through the rapid increase of the 3D printing market, from less than \$300 million in 2012 to \$2.5 billion in 2013 and to almost \$16 billion in 2018, with an expectation of a continuing growing trend.<sup>29</sup>

From the current review, it can be stated that studies are mostly focused on the applicability of printing dentures, some mechanical properties along with their clinical evaluations.<sup>4,20-22</sup> Many scientists reviewed and highlighted the advantages and disadvantages of 3D printing systems.<sup>1,7</sup>

In the published papers, 3D printing technology appeared as a very promising technology with several advantages. However, as this technology is recently becoming popular in the dental industry, more appropriate research and investigations are needed to justify its place in dentistry.

The advantages of 3D printed dentures included less treatment time, saving patient data, using variety of materials, employing less human power and offering the sustainability of the technique by using less denture resin. Furthermore, 3D

**Table 2.** Table of the included published papers on 3D printed dentures

Authors	Year	Topic	Conclusion
Kalberer et al <sup>1</sup>	2019	Mechanical properties of CAD/CAM and 3D printed dentures	The CAD-CAM complete dentures were better than to the 3D dentures in trueness of the intaglio surfaces. Further research is required on the biomechanical and clinical aspects.
Inokoshi et al <sup>2</sup>	2012	Clinical evaluation of 3D printed trial dentures.	Esthetics and stability were better in the conventional method than with the 3D printing method.
Clark et al <sup>6</sup>	2019	Digital replicated denture: A case report	Digital replicated denture can streamline the process of dentures' manufacturing for patients with old dentures.
Takeda et al <sup>7</sup>	2020	Digital replicated denture: A case report	This method allows for the predictable fabrication of accurate dentures in less time and with increased quality.
Kurahashi et al <sup>8</sup>	2017	Duplication of complete dentures using 3D printing.	The advantages of this procedure include, wasting less material, less human power involved, reducing treatment time.
Cristache et al <sup>9</sup>	2019	Clinical performance of digital dentures.	The 3D printed dentures based on PMMA-TiO <sub>2</sub> showed acceptable clinical outcomes after 18 months of permanent use.
Tasaka et al <sup>21</sup>	2019	Mechanical properties of 3D printed dentures.	The denture base manufactured using additive manufacturing showed more accurate and better retentive force than the conventional denture base.
Chung et al <sup>22</sup>	2018	Mechanical properties of 3D printed dentures.	3D printing using resin materials provides acceptable fracture resistance for artificial tooth use.
Lee et al <sup>23</sup>	2019	Mechanical properties of denture base prepared by different techniques.	The overall accuracy of the denture base is higher in milling and RP method than the injection molding method.
Cha et al <sup>24</sup>	2019	Mechanical properties of 3D printed dentures.	3D-printed denture tooth by using resin materials provides adequate wear resistance for denture tooth use.
Prpić et al <sup>25</sup>	2020	Mechanical properties of denture base prepared by different techniques.	CAD/CAM materials showed better mechanical properties than heat-polymerized and 3D-printed acrylics.
Chen et al <sup>26</sup>	2019	3D printed dentures: testing improved polymers.	The addition of 1% of TiO <sub>2</sub> would be an effective amount to enhance both mechanical and antibacterial properties for 3D Printing PMMA composite resin.
Totu et al <sup>27</sup>	2017	3D printed dentures: testing improved polymers.	Substantial improvements have been noticed in polymer characteristics when adding 0.4wt% of TiO <sub>2</sub> nanoparticles.
Park et al <sup>33</sup>	2018	Digital dentures: A dental technique	This technique (combining 3D-printed metal and resin for digitally fabricated dentures) provides new possibilities for making a variety of digital dentures.
You et al <sup>35</sup>	2020	Clinical performance of 3D printed dentures.	It is more suitable to set the layer thickness to 100 µm rather than 50 µm in regards to clinical outcomes.
Cristache et al <sup>36</sup>	2020	Clinical performance of digital dentures.	The proposed workflow with the improved material used is a suitable treatment choice for completely edentulous patients.
Unkovskiy et al <sup>37</sup>	2019	Digital dentures: a case report	The use of intraoral scanning may allow for manufacturing of complete dentures with functional borders within a fully digital workflow.
Choi et al <sup>38</sup>	2019	Mechanical properties of 3D printed dentures.	Teeth bonded to CAD/CAM and 3D printed DBRs showed significantly lower bond strength than heat-cured DBRs.

printing is less expensive compared to CAD/CAM, therefore such affordability attracts more individuals to this technology. A further advantage is to manufacture large workpieces such as maxillofacial prostheses with the ability to produce a very precise and complex detail.<sup>1,7,8,17</sup>

In contrast, the disadvantages of 3D printed dentures were inferior mechanical strength, compromised esthetics, and complications in some clinical stages such as determining vertical occlusion and try-in and color stability. Moreover, the safe use of these dentures for patients still needs more studies regarding the toxic effects on the human body.<sup>1,25</sup> The cytotoxic effects of 3D printed prosthesis are not restricted on the patients but they even extend to workers who are in contact with 3D printing machinery such as dentists, nurses and physicians who are obviously subjected to this risk. Even, waste collection companies can be involved with this risk.<sup>29</sup> The toxic effects of 3D printed dentures are still not well studied and further studies to determine the level of these risks are vital.<sup>29-31</sup> This point was also raised by Kalberer, who stated that there is a lack of information in regards to some biocompatible properties of the new manufacturing systems, therefore he recommended carrying out a further study to evaluate the biocompatibility of dentures prepared by 3D printing systems.<sup>1</sup>

In addition to studying the cytotoxicity of 3D printed dentures on patients and dental practitioners, there are suggestions to investigate practical methods to mitigate the toxic effects of those dentures.<sup>29</sup> Detoxification methods are significant factors in regards to improving the properties of 3D printing technologies and overcoming the toxicity of the materials used with these technologies.<sup>30,32</sup> Oskui found that the exposure to ultraviolet light reduced the toxicity in stereolithography samples but this treatment was not able to entirely eliminate the cytotoxicity from those samples. Oskui recommended using the exposure to ultraviolet light to minimize the cytotoxicity. Moreover, the author suggested carrying out further studies regarding detoxification methods.<sup>29</sup> Additionally, further studies on the mechanical properties of materials used with those systems and long-term clinical evaluation of 3D printed dentures are required.

Considering the above-mentioned arguments, it is quite apparent that 3D printing technology is a promising technology with high potential of significant improving in many dental treatments in the near future.<sup>33,35-38</sup> These potentials include achieving variety of dental treatments in a considerable short time and affordable cost particularly compared with CAD/CAM technologies. Even more, saving materials and decreasing the dependency on existing skilled practitioners. On the other hand, the challenges and barriers for using 3D printing technologies in denture manufacturing includes strength, poor esthetic results, biocompatible properties, accuracy and complications of some clinical steps. It is highly probable that patients with 3D printed prostheses would need more follow up sessions than conventional denture wearers considering the poor esthetic results and the need for denture relining.

Consequently, there are several aspects that need to be researched in terms of achieving the best outcomes and avoiding the flaws. On top of these aspects, the biocompatibility of the used materials is also a key consideration. Further, the improvement of mechanical properties requires more research and also the need for carrying out long-term clinical studies to evaluate the effectiveness of 3D printed dentures compared with conventional processing methods.

## CONCLUSION

According to the current literature review, and within the limitations of this study, 3D printing techniques are growing rapidly in our daily dental practice. 3D printed denture fabrication will become more common in dental clinics. The main studies related to 3D printed dentures were focused on the applicability and mechanical properties of the end products rather than their biocompatibility and clinical efficiency.

The advantages for 3D printed dentures in literature are saving working time, recording the patients' data and reducing materials used. The detected disadvantages were: some strength characteristics, biocompatibility and esthetics.

## REFERENCES

1. Kalberer, N., Mehl, A., Schimmel, M., Müller, F. and Srinivasan, M. CAD-CAM milled versus rapidly prototyped (3D-printed) complete dentures: An *in vitro* evaluation of trueness. *J Prosthet Dent.* 2019; **121**:637-643.
2. Van Noort, R. The future of dental devices is digital. *Dent Mater.* 2012; **28**:3-12.
3. Miyazaki, T., Hotta, Y., Kunii, J., Kuriyama, S. and Tamaki, Y. A review of dental CAD/CAM: Current status and future perspectives from 20 years of experience. *Dent Mater J.* 2009; **28**:44-56.
4. Inokoshi, M., Kanazawa, M. and Minakuchi, S. Evaluation of a complete denture trial method applying rapid prototyping. *Dent Mater J.* 2012; **31**:40-46.
5. Abduo, J., Lyons, K. and Bennamoun, M. Trends in Computer-Aided Manufacturing in Prosthodontics: A Review of the Available Streams. *Int J Dent.* Volume 2014; **2014**:783948.
6. Kanazawa, M., Inokoshi, M., Minakuchi, S. and Ohbayashi, N. Trial of a CAD/CAM system for fabricating complete dentures. *Dent Mater J.* 2011; **30**:93-96.
7. Sun, J. and Zhang, F.Q. The application of rapid prototyping in prosthodontics. *J Prosthodont.* 2012; **21**:641-644.
8. Hazeveld, A., Huddleston Slater, J.J. and Ren, Y. Accuracy and reproducibility of dental replica models reconstructed by different rapid prototyping techniques. *Am J Orthod Dentofacial Orthop.* 2014; **145**:108-115.
9. Chang, C.C., Lee, M.Y. and Wang, S.H. Digital denture manufacturing- an integrated technologies of abrasive computer tomography, CNC machining and rapid prototyping. *Int J Adv Manuf Technol.* 2006; **31**: 41-49.
10. Srinivasan, M., Gjengedal, H., Cattani-Lorente, M., Moussa, M., Durual, S., Schimmel, M. and Müller, F. CAD/CAM milled complete removable dental prostheses: An *in vitro* evaluation of biocompatibility, mechanical properties, and surface roughness. *Dent Mater J.* 2018; **37**:526-533.

11. Di Giacomo, G.A., Cury, P.R., de Araujo, N.S., Sendyk, W.R. and Sendyk, C.L. Clinical application of stereolithographic surgical guides for implant placement: Preliminary results. *J Periodontol.* 2005; **76**:503-507.
12. Maeda, Y., Minoura, M., Tsutsumi, S., Okada, M. and Nokubi, T. A CAD/CAM system for removable denture. Part I: Fabrication of complete dentures. *Int J Prosthodont.* 1995; **7**:17-21.
13. Kawahata, N., Ono, H., Nishi, Y., Hamano, T. and Nagaoka, E. Trial of duplication procedure for complete dentures by CAD/CAM. *J Oral Rehabil.* 1997; **24**:540-548.
14. Williams, R.J., Bibb, R. and Rafik, T. A technique for fabricating patterns for removable partial denture frameworks using digitized casts and electronic surveying. *J Prosthet Dent.* 2004; **91**:85-88.
15. Eggbeer, D., Bibb, R. and Williams, R. The computer-aided design and rapid prototyping fabrication of removable partial denture frameworks. *Proc Inst Mech Eng H.* 2005; **219**:195-202.
16. Clark, W.A., Duqum, I. and Kowalski, B.J. The digitally replicated denture technique: a case report. *J Esthet Restor Dent.* 2019; **31**:20-25.
17. Takeda, Y., Lau, J., Nouh, H. and Hirayama, H. A 3D printing replication technique for fabricating digital dentures. *J Prosthet Dent.* 2020; **124**:251-256.
18. Kurahashi, K., Matsuda, T., Goto, T., Ishida, Y., Ito, T. and Ichikawa, T. Duplication of complete dentures using general-purpose handheld optical scanner and 3-dimensional printer: Introduction and clinical considerations. *J Prosthodont Res.* 2017; **61**:81-86.
19. Cristache, C.M., Totu, E.E., Grosu, A.R., Ene, O., Beuran, I.A. and Burlibasa, M. Nanocomposite for rapid prototyped complete denture eighteen months follow-up on clinical performance. *Rev Chim.* 2019; **70**:387-392.
20. Pereyra, N.M., Marano, J., Subramanian, G., Quek, S. and Leff, D. Comparison of patient satisfaction in the fabrication of conventional dentures vs. DENTCA (CAD/CAM) dentures: a case report. *J N J Dent Assoc.* 2015; **8**:26-33.
21. Tasaka, A., Matsunaga, S., Odaka, K, et al. Accuracy and retention of denture base fabricated by heat curing and additive manufacturing. *J Prosthodont Res.* 2019; **63**:85-89.
22. Chung, Y.J., Park, J.M., Kim, T.H., Ahn, J.S., Cha, H.S. and Lee, J.H. 3D Printing of Resin Material for Denture Artificial Teeth: Chipping and Indirect Tensile Fracture Resistance. *Materials (Basel).* 2018; **11**:1798.
23. Lee, S., Hong, S.J., Paek, J., Pae, A., Kwon, K.R. and Noh, K. Comparing accuracy of denture bases fabricated by injection molding, CAD/CAM milling, and rapid prototyping method. *J Adv Prosthodont.* 2019; **11**:55-64.
24. Cha, H.S., Park, J.M., Kim, T.H. and Lee, J.H. Wear resistance of 3D-printed denture tooth resin opposing zirconia and metal antagonists. *J Prosthet Dent.* 2019; **124**:387-394.
25. Prpić, V., Schauperl, Z., Čatić, A., Dulčić, N. and Čimić, S. Comparison of Mechanical Properties of 3D-Printed, CAD/CAM, and Conventional Denture Base Materials. *J Prosthodont.* 2020; 10.1111/jopr.13175.
26. Chen, S.G., Yang, J., Jia, Y.G., Lu, B. and Ren, L. TiO<sub>2</sub> and PEEK Reinforced 3D Printing PMMA Composite Resin for Dental Denture Base Applications. *Nanomaterials (Basel).* 2019; **9**:1049.
27. Totu, E.E., Nechifor, A.C., Nechifor, G., Aboul-Enein, H.Y. and Cristache, C.M. Poly(methyl methacrylate) with TiO<sub>2</sub> nanoparticles inclusion for stereolithographic complete denture manufacturing - the future in dental care for elderly edentulous patients?. *J Dent.* 2017; **59**:68-77.
28. Shakeri, F., Nodehi, A., Atai, M. PMMA/double-modified organoclay nanocomposites as fillers for denture base materials with improved mechanical properties. *J Mech Behav Biomed Mater.* 2019; **90**:11-19.
29. Oskui, S.M., Diamante, G., Liao, C., Shi, W., Gan, J., Schlenk, D. and Grover, W. Assessing and Reducing the Toxicity of 3D-Printed Parts. *Environmental Science & Technology Letters.* 2016; **3**:1-6.
30. Macdonald, N.P., Zhu, F., Hall, C.J., et al. Assessment of biocompatibility of 3D printed photopolymers using zebrafish embryo toxicity assays. *Lab Chip.* 2016; **16**:291-297
31. Puškar, T., Trifković, B., Koprivica, D., Kojić, V., Jevremović, A., Mirković, S. and Eggbeer, D. *In vitro* cytotoxicity assessment of 3D printed polymer based epoxy resin intended for use in dentistry. *Military-medical and pharmaceutical.* 2017; **76**:127-132.
32. Alifui-Segbaya, F., Bowman, J., White, A. R., Varma, S., Lieschke, G. J. and George, R. Toxicological assessment of additively manufactured methacrylates for medical devices in dentistry. *Acta Biomaterialia.* 2018; **78**: 64-77.
33. Park, J.M., Ahn, J.S., Cha, H.S. and Lee, J.H. Wear Resistance of 3D Printing Resin Material Opposing Zirconia and Metal Antagonists. *Materials (Basel).* 2018; **11**:1043.
34. Bilgin, M.S., Erdem, A., Aglarci, O.S. and Dilber, E. Fabricating complete dentures with CAD/CAM and RP technologies. *J Prosthodont.* 2015; **24**: 576-579.
35. You, S.M., You, S.G., Kang, S.Y., Bae, S.Y. and Kim, J.H. Evaluation of the accuracy (trueness and precision) of a maxillary trial denture according to the layer thickness: An *in vitro* study. *J Prosthet Dent.* 2021; **125**:139-145.
36. Cristache, C.M., Totu, E.E., Iorgulescu, G., Pantazi, A., Dorobantu, D., Nechifor, A.C., et al. Eighteen months follow-up with patient-centered outcomes assessment of complete dentures manufactured using a hybrid nanocomposite and additive CAD/CAM protocol. *J Clin Med.* 2020; **9**:324.
37. Unkovskiy, A., Wahl, E., Zander, A.T., Huettig, F. and Spintzyk, S. Intraoral scanning to fabricate complete dentures with functional borders: a proof-of-concept case report. *BMC Oral Health.* 2019; **19**:46.
38. Choi, J.J.E., Uy, C.E., Plaksina, P., Ramani, R.S., Ganjigatti, R. and Waddell, J.N. Bond strength of denture teeth to heat-cured, CAD/CAM and 3D printed denture acrylics. *J Prosthodont.* 2019; **4**:5