A review on clinical use of CAD/CAM and 3D printed dentures

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Key points

Understand the main advantages of CAD/CAM and 3D printed dentures, as well as the differences between these.

Recognise the challenges and barriers of using digital dentures.

Raise awareness regarding one of the most promising treatments in prosthetic dentistry in the coming years.

Abstract

Aim The aim of this article was to review the current clinical application of computer-aided design/computer-aided manufacturing (CAD/CAM) and three-dimensional (3D) printed dentures in dental clinics.

Methods A systematic approach for searching PubMed, Embase, Scopus, and Web of Science databases. The search was performed using a variety of keywords including clinical use AND 3D printed removable dentures OR clinical use AND CAD/CAM removable dentures OR clinical use AND digital removable dentures. Selection criteria included articles written in English and reporting information on clinical applications of digital dentures between 2010 to January 2022.

Results The findings outlined the main clinical advantages of digital dentures such as saving working time, satisfying clinical results and securing patients' records, and also requirement of additional visits to secure aesthetic patient satisfaction, good retention and ideal vertical dimension. Many studies recommended performing clinical try-in with regards to providing better results. It was also established that 3D printers are less expensive than milling centres and therefore can be afforded by individual dental professionals.

Conclusion Digital dentures are a promising option in treating edentulous patients, especially in remote areas where skilful technicians are rare. However, there are some limitations in their applications.

Introduction

It is speculated that the demand for complete dentures will continuously increase in the next few decades. Efforts to improve the serviceability and technical quality of complete dentures are still ongoing.[1] The introduction of digital technologies has led to significant advancements in the fabrication of partial and complete dentures. Digital manufacturing will change the face of dentistry in the near future in terms of treatment time and simplicity. These new technologies include computer-aided design/computer-aided manufacturing (subtractive manufacturing) and three-dimensional (3D) printing (additive manufacturing).[1,2]

Computer-aided design/computer-aided manufacturing (CAD/CAM) and 3D printing systems launched interesting new stages in prosthodontics, particularly in removable prostheses productions. Some professionals stated that the complicated procedures of denture manufacturing are considered one of the main reasons for the delay in using digital technology for complete dentures compared to other fixed restorations.[3,4] Having said that, the ongoing evolution of digital technologies is expected to overcome the difficulties, and to simplify the fabrication process.[5]

The fabrication of conventional dentures usually includes five clinical sessions. The first and second session are for taking primary and final impressions, then the third session is for taking jaw relation. After that, the fourth and fifth sessions are allocated for the try-in and insertion. Manufacturing conventional dentures requires a lot of work from the dentist and especially from the dental technician. On the other hand, digital dentures need between 2–4 sessions to be completed based on the followed system.[6] Consequently, saving treatment time is one of the key advantages of digital dentures along with digital storing of patients' data. Digital denture manufacturing (four-visits protocol) starts by taking primary impressions, then scanning the impression or the cast. In the second session, final impressions along with jaw relations will be taken. After that, the third and fourth sessions are for try-in and insertion.[5,6] For the two-visits protocol, primary and secondary impressions along with jaw relation will be taken in the first session, then the insertion is in the second session (based on the system). Evidently, the try-in session is omitted from this protocol, although some manufacturers require a separate try-in session for minimising phonic and aesthetic problems.[6]

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The process of fabricating complete dentures with computer-aided technology involves digitisation of the clinical information registered from the patient with light scanning technology, which is a pivotal part of digital manufacturing and digital designing on computer software (CAD). The digital denture construction starts by scanning the impression or cast, then scanning the record blocks and wax rims to transfer all required clinical data to the computer before starting the designing phase.[5] This is followed by an automatised process of manufacturing (CAM), which can be an additive (3D printing) or subtractive (computerised numerical control milling) process.[5,7]

The CAD/CAM digital system is considered as subtractive manufacturing and involves the milling of a complete denture prosthesis from a pre-polymerised manufactured puck. The construction of the puck is achieved under high pressure and temperature, which can result in better hygienic and mechanical properties.[7] The way of puck production is the key factor in giving CAD/CAM restorations superior properties compared to other systems and methods.[7] The CAD/CAM systems have been more in use for fabrication of complete dentures in recent years, whereas previously CAD/CAM was used in constructing many other dental restorations such as onlays, crown and bridges.[8] An important factor that must be considered is the type of milling machine as it plays a vital role in producing a high-quality workpiece.[7]

The type of milling machine can be classified according to how many milling axes it has; this can be three, four and/or five axes. Increasing the number of axes on a milling machine provides a higher ability in production of dentures. For this reason, a five-axes machine may complete a milling task faster than a three-axes device; however, this can be more expensive compared to three and/or four-axes machine. Ultimately, the milling process will ensure the denture's durability and minimise construction flaws.[9] Nevertheless, waste materials and milling burs wearing are considered as key disadvantages of CAD/CAM technology, and are the main drive to improve 3D printing technology (additive manufacturing) as the latter has shown considerable efficiency in minimising wasted materials.[10]

3D printing technology can be described as a method for producing digitally designed objects by connecting materials layer by layer in a successive approach.[10,11] When the computer-aided design is completed, the design will be printed through a big number of sequential layers of liquid or powder material.[10] The thickness and orientation of each layer plays a significant role in the properties of the final model.[11] These layers result in a lack of resolution and make producing an aesthetic restoration quite challenging. 3D printing technologies are developing more intensively in many fields such as industry, life science, medicine and dentistry[11] as this technology has the capacity to produce shapes or models with high accuracy and in a short time.[8] In dentistry, 3D printing has been used to construct micro-prostheses such as onlays and crowns.[12] This method of fabrication of complete removable dentures takes less time and money to make a denture and saves on materials compared to CAD/CAM.[9,13] However, the mechanical and physical properties of materials used with 3D printing technologies are still inferior compared to CAD/CAM technology materials.[13]

Additive manufacturing includes many types such as stereolithography, digital light projection, fused deposition modelling, jet printing and selective laser sintering.[14] Typically, stereolithography uses ultraviolet light to create rigid layers from a sensitive liquid resin by hardening layer by layer until completing the entire model, then the model is rinsed and cured in an ultraviolet oven. Stereolithography can produce resin-based bodies such as dentures and surgical guide plates, along with manufacturing wax patterns, removable denture frameworks, and temporary restorations.[14,15]

Historically, the first attempt to fabricate dentures digitally was in 1994 when Madea reported manufacturing the first removable prosthesis using 3D laser lithography.[16] After that, Kawahata used a CAD/CAM commanding computerised numerical control (CNC) system to produce a duplicated removable prosthesis.[17] Since then, many attempts have been made to construct dentures using digital technologies. Combination between digital design and conventional construction was one of the early attempts to manufacture digital dentures.[8]

Although it seems that digital manufacturing technology has made great changes in the prosthodontics field essentially in producing larger prostheses, this technology is still not fully in use. This is possibly because of the lack of studies and research on this technology, particularly in terms of clinical performance and patient-centred outcomes. The purpose of this study was to review the published papers on clinical uses and performance of CAD/CAM and 3D printed dentures.

Methods

The search included online-published papers and materials in English that were collected from PubMed/Medline, Embase, Scopus and Web of Science. This search was performed by using a variety of keywords including clinical use AND 3D printed removable dentures OR clinical use AND CAD/CAM removable dentures OR clinical use AND digital removable dentures. Selection criteria were any article written in English and reporting on the clinical application of digital dentures in our daily use between 2010 to January 2022.

Study

Two reviewers independently screened the 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 name, year of publication, country, study design, methodologies and related issues of digital dentures. All extracted data were transferred to a specially designed Excel sheet for this purpose. The transferring data process was checked by both reviewers.

After identifying and excluding duplicated papers from the databases, the selected articles' abstracts were reviewed carefully to ensure information followed selected factors for inclusion. Papers were required to be written in a clear way and to demonstrate the clinical use of CAD/CAM or 3D printed dentures, and to be relevant to the clinical performance of digital dentures.

The excluded papers were focused mainly on areas such as: studies on metal framework construction by digital technology, studies on digital fixed dentures and studies with ambiguous information about digital dentures.

Results

Based on the above-mentioned search methodology, 231 papers were identified. After excluding unnecessary sources not matching the agreed selected criteria, the total number of articles decreased to 149. In the second stage of selection, this number declined more, and another 82 records were excluded since they did not meet the inclusion criteria. Overall, 67 studies were considered and included in

our literature review section. The abstracts of the 67 selected papers were carefully analysed, and 20 publications were selected for further evaluation since these 20 papers looked at clinical performance, cost, effectiveness and clinical steps of digital removable dentures.

From what was observed, it could be seen that the vast majority of studies were focused on CAD/CAM dentures, while less research studies were focused on 3D printed dentures. In addition, the number of studies that compared the clinical performance of CAD/CAM dentures with 3D printed dentures were quite limited. Many studies looked at a wider range of CAD/CAM denture properties especially physical and mechanical properties; in addition to what was mentioned, they also demonstrated studies related to clinical performance and cost-effectiveness of these dentures. In contrast, fewer studies addressed 3D printed dentures and even less were conducted on the clinical performance of 3D printed dentures. Furthermore, in these papers the clinical studies of 3D printed dentures were mainly focused on testing temporary/provisional or trail base dentures that were completed using 3D printing technology.

As was described previously, studies on CAD/CAM dentures clearly demonstrated a significant saving in clinical time compared to conventional dentures with their better retention.[2,18] CAD/CAM denture data could be recorded digitally for future reference, with it being more advantageous in patient-centred outcomes. However, the point needs to be emphasised that the studies on constructing 3D printed dentures are still relatively limited and restricted to case reports and proof of concept studies.[19] Nevertheless, the clinical performance of 3D printed dentures was accepted based on patients' opinions.[20]

Many researchers have explored the disadvantages of using digital dentures in terms of clinical uses.[13] These disadvantages include lack of aesthetics and phonics, as well as difficulties in determining centric relation and occlusal vertical dimension mainly due to the lack of experience among dental practitioners.[21,22] The accuracy of impressions was also considered and taken as one of the drawbacks of digital dentures, with relining suggested as a practical solution for this problem.[23] Consequently, the follow-up sessions are more with digital dentures compared to conventional dentures and obviously this adds more to the total cost.[21]

Discussion

Based on the aforementioned information, in spite of the increasing popularity of CAD/CAM and 3D printing technologies, the full utility of these technologies in removable denture manufacturing still requires deeper investigations in many other aspects such as clinical performance and patient satisfaction. Studies of patient-centred outcomes are essential in ensuring the clinical effectiveness and future expectations of digital dentures.

The result of this research showed that most reviewed studies were on CAD/CAM dentures rather than 3D printed dentures. The higher number of research studies on CAD/CAM dentures can be justified by the fact that it is an older technology compared to 3D printing, therefore more studies have been conducted on many aspects of it. There has been a remarkable focus among many researchers on reducing the required sessions to fabricate dentures through developing digital dentures and consequently making this treatment much more affordable.

Advantages of CAD/CAM dentures

Some studies on CAD/CAM dentures showed significantly reduced clinical time compared to conventional dentures, plus better retention and the ability to save digital records for patients. Therefore, in cases where a patient loses or breaks their denture, a replacement of that prosthesis can be achieved easily.[2] The CAD/CAM denture can be finished in a minimum of two visits including manufacturing, while conventional dentures need five sessions to be completed.[20] Moreover, CAD/CAM fabricated dentures seem to have considerably better material properties. This is due to the denture base being milled from poly(methyl methacrylate) (PMMA) pucks which have been polymerised under high pressure and temperature resulting in a highly condensed resin.[9] Consequently, significant improvements in the quality of CAD/CAM complete dentures are expected from the enhanced physical and mechanical properties of the pre-polymerised PMMA pucks.[24] Another explanation for the better properties of preformed PMMA pucks is the high temperature and pressure used to polymerise it, promote longer polymer chain formation and reduce residual monomers. As a result, this prevents shrinkage of the CAD/CAM dentures and improves the physical properties. Additional advantages include the fact that the retention and durability in CAD/CAM fabricated dentures are significantly better than conventional dentures, and construction flaws such as denture porosity are minimised.[9,24]

Advantages of 3D printed dentures

The advantages of 3D printing systems include offering more sustainable techniques by using less denture resin and producing large workpieces (maxillofacial prosthesis) with clear capacity to produce complicated details. Furthermore, 3D printing is less expensive compared to CAD/CAM as there is no need for a commercial specialised centre; therefore, it is affordable for individual dentists or technicians. Having said that, studies on constructing 3D printed dentures are still very limited and constrained to case report studies,[21] although the clinical performances of 3D printed dentures were acceptable.[25] The most common use for 3D printing in denture manufacturing was to prepare trial/temporary dentures and record bases.[22] In addition, it is quite clear throughout the literature that using 3D printed dentures still has a long way to go in terms of considering this treatment as a reliable alternative to conventional complete dentures.[26]

Some researchers started by duplicating an existing denture by using digital technologies as an attempt to reduce the laboratory steps and chair time.[17,26] Kurahashi concluded that the main advantages for duplicating existing dentures by using 3D printing systems were saving on materials and treatment time plus reducing the effect of the human factor.[27] Cristache suggested using modified PMMA-TiO2 nanocomposite material in 3D printed complete dentures, to study the clinical performance of 3D printed dentures over a period of 18 months.[28] 3D printed dentures based on PMMA-TiO2 showed an acceptable clinical performance after 18 months of permanent wearing. Cristache concluded that the main advantages of digital dentures were saving time, records, and obtaining a clinically acceptable denture.[28]

Disadvantages of CAD/CAM and 3D printed dentures

The main clinical disadvantages mentioned in the literature regarding CAD/CAM dentures have been reported in areas such as material waste, high cost, need for immediate reline, problems with OVD, and compromised aesthetics and phonetics.[4,29] It can be seen in this review that some other researchers mentioned more complications with CAD/

CAM dentures such as occlusion and tooth arrangement errors, tooth wear, additional visits, post-insertion adjustments, overall patient dissatisfaction and the need for remake.[4,21] On the other hand, 3D printed dentures have the same clinical disadvantages of CAD/CAM dentures in addition to reduced retention, compromised aesthetics and low strength.[22] The above-mentioned negatives are broadly considered as the main limitations and barriers to CAD/CAM and 3D printed dentures with respect to mainstream denture manufacturing.

When comparing CAD/CAM and 3D printed dentures, Cristache stated that a CAD/CAM denture is more expensive and wastes lots of material, while a 3D printed denture is more affordable and can produce complex details with high accuracy.[28] These results are quite significant since saving materials is widely considered as one of the biggest benefits of 3D printing technologies over CAD/CAM manufacturing technologies. Additionally, saving materials is the main reason for making 3D printing systems more affordable compared to CAD/CAM systems (Table 1).

Retention

As retention is one of the most important features of complete dentures, Al-Helal studied the retention in CAD/CAM dentures and concluded that the retention in CAD/CAM dentures was significantly better than conventional dentures.[18] Further, a milled denture base might be an appropriate choice when obtaining maximum retention is the first priority in difficult cases accompanied with undesirable underlining structures.[18] Kattadiyil compared milled and conventional complete dentures manufactured for the same patient, and found significantly increased retention in milled dentures. This is most likely because CAD/CAM dentures are milled from a pre-polymerised acrylic resin puck, which is produced under high pressure and heat. This leads to a minimal level of polymerisation shrinkage, consequently resulting in better fitting, and thereby improving retention.[2]

In contrast, Saponaro stated that the main drawbacks of CAD/CAM dentures are a lack of denture retention, incorrect centric relation and occlusal vertical dimension. Saponaro admitted that these drawbacks are caused by the difficulty in obtaining a precise impression as well as the lack of experience among dental practitioners. They highlighted that more studies in this area are essential.[4]

Trueness and fitting accuracy

Considering digital denture fitting, Srinivasan compared the trueness of the intaglio surface of complete dentures produced by different techniques: injection moulding, flask-pack-press and CAD/CAM. Srinivasan reported that the three studied techniques showed results accepted clinically.[30,31] Yoshidomea studied the trueness and fitting accuracy in conventional dentures, CAD/CAM dentures and two systems of 3D printed dentures (stereolithography and digital light processing).[32] He concluded that the milled dentures showed better trueness and fitting accuracy compared with 3D printed and conventional dentures. Moreover, 3D printed dentures showed similar trueness and fitting to conventional dentures.[32]

Denture cost

As previously mentioned, the conventional workflow of dentures consists of five sessions followed by post-insertion adjustment sessions as required, whereas the digital workflow includes between 2–4 sessions based on the manufacturer system.[6] For example, the four-session protocol for digital dentures combines the second and third session as the final impression and jaw relation will be taken in one step. Obviously, reducing at least one session would cause a clear reduction in the total cost. However, the cost of materials and equipment are a barrier against adopting these systems and to tackle this problem some researchers suggested using a hybrid system (mix of 3D printing and CAD/CAM).[6] Smith concluded that using the four-session digital protocol is more cost-effective compared to the five-session conventional protocol in terms of material cost, chair time costs, and fewer follow-up visits. Srinivasan concluded that the costs for clinical chairside time, laboratory and the overall costs were significantly lower in the digital denture protocol, even though the materials cost for this protocol was higher.[30,31]

Table 1 A comparison between CAD/CAM and 3D printing systems

System	CAD/CAM	3D printing
Method of manufacturing	Subtractive manufacturing	Additive manufacturing
Materials	Metals, ceramics and resins	Metals, ceramics, resins, and waxes
Material waste	Wastes large quantities of denture base material	Wasting materials are low
Accuracy	Limited capacity to shape complex details such as undercuts	Can build complex geometries and precise details
Cost	High cost	Less cost
Strength	Higher strength	Lower strength
Model size	Small and moderate workpieces	Small, moderate and large workpieces

Patient satisfaction

Regarding patient satisfaction, a number of researchers highlighted that patients were mainly satisfied with their CAD/CAM dentures.[29] The high level of satisfaction can be explained by the better retention and less time needed to construct a CAD/CAM denture.[29] In agreement with that, other researchers concluded that patient satisfaction with dentures fabricated by rapid prototyping was acceptable. These findings can be interpreted by the fact that retention is similar between 3D printed dentures and conventional dentures. Having said that, other researchers stated different results. Ohara evaluated patient satisfaction among patients using conventional dentures and digital dentures (3D printed dentures).[33] Ohara studied patient satisfaction through evaluating their opinions on retention, stability, aesthetics, chewing, pain, phonetics and general comfort. Ohara found that conventional dentures are better than digital dentures in terms of stability, comfort, phonetics and general satisfaction. Furthermore, in terms of quality of life, the conventional dentures are better than digital dentures although digital dentures involved fewer clinical appointments.[33] Ohara stated that 20% of the studied group preferred digital dentures while 80% opted for conventional dentures. Other researchers stated that aesthetics are an important factor to assess patient satisfaction.[33] However, aesthetics in 3D printed dentures are not as good as conventional dentures.[21,22]

It seems that digital dentures require further studies and improvements to ensure efficiency and satisfying results. To consider

digital dentures as a reliable alternative to conventional dentures, further clinical studies with longer follow-up periods are required. In addition, 3D printed dentures have promising potential to streamline denture manufacturing since they are cheaper and require less materials and equipment compared to CAD/CAM dentures. Therefore, conducting further research on digital dentures is essential, particularly on 3D printed dentures.

Conclusion

Digital dentures are increasingly becoming a possible treatment option with high expectations. Digital dentures have shown acceptable clinical performance, improved retention, reduced number of appointments, less dependence on human factor and ability to save patients' records. The main challenges for digital dentures include aesthetics, clinical implications and speech difficulties.

CAD/CAM dentures offer a superior treatment option compared to 3D printed dentures considering the better properties such as trueness, fitting and strength. Having said that, its application is still limited. An understanding of these limitations and finding solutions for them are crucial before adopting digital dentures as an applicable alternative to conventional removable dentures.

Ethics declaration

There are no human participation or personal data in this article, therefore ethical approval is not applicable. The authors declare that they have no conflicts of interest in regards to this manuscript.

Author contributions

Dr Khaled Alhallak (corresponding author): wrote most of the paper, data collection, data analysis and interpretation. Dr Ali Nankali: data collection, revised the manuscript. Dr Eleni Hagi-Pavli: revised the manuscript, provided language and grammatical revision to the manuscript.

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