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Review Article

CAD/CAM Complete Dentures for the Present and for the Future-a Descriptive Review

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Abstract

Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) have started influencing all walks of life within a short period of time. Dentistry has always adapted technological advancements and hence CAD/CAM was integrated to its many facets swiftly. Complete dentures did wait for more time to get adapted to the CAD/CAM process. Traditional dentures required human intervention and most of the dental professionals believed that there is no other option. The multiple steps of CD fabrication demanded high levels of skills and fine-tuned creativity. Naturally CD fabrication required more time which was a deterrent to both professionals and patients.

Impressions, jaw relations, tooth arrangement and processing were all converted to digital format now, either partially or fully. Initially impressions were scanned and digitised but at present attempts are made to use intraoral scanners replacing trays and impression materials. Patient assisted registration of jaw relations still prevail and it is subjected to digitisation. Articulators have become virtual; teeth arrangements done by technologists have become an easy process because computer programmes provide teeth from its library and which can be modified according to the requirement. The laborious process of compression and injection moulding have given way to either milling or 3D printing. Conventional six appointment system gets reduced to two or three appointments with more precision and reproducibility when CAD/CAM is integrated. The contributions of human creativity that adds to the quality of aesthetic dentures still remains unquestioned.

Keywords: Complete Dentures; Digital Dentures; CAD/CAM Dentures; Milled Dentures; 3D Printed Dentures; Additive Manufacturing; Subtractive Manufacturing

Introduction

CAD/CAM is an acronym for Computer Aided (Assisted) Design and Computer Aided (Assisted) Machining. CAD can create a design leading to 2D or 3D models and helps to view the design from more than one perspective. CAD will also allow to perform simulations so that the real time performance can be analysed. Through an intra oral scanner, a 3D model can be made first on the computer screen, then a crown can be designed on it and the occlusal contact can be verified. CAM is done through a software which can control machine tools and transforms the design into a product. CAM has the advantage of implementing automation in the manufacturing process. CAM software generates the tool paths to create a product precisely and optimising the required quantity of material avoiding considerable wastage of materials. CAM software can be integrated with the CAD software so that a streamlined production process can be undertaken [1].

When the chronology of development is considered, CAM superseded CAD. Numerically controlled machines and tools were introduced around the middle of 20th century. CAM software was introduced in 1957 by name PRONTO by Patric Hanratty who is considered as the 'father of CAD/CAM technology (Figure 1). It is popularly believed that nearly seventy percent of all 3-D mechanical CAD/CAM systems available today, can be traced back to Hanratty's original code. Within five years, numerically controlled machines were made available commercially. The precision and versatility of the system has revolutionised production environment. Later CAD and CAM came together and CAM started using CAD drawings and physical objects were created. The era of CAD/CAM was ushered in from this point and no facet of technology could resist the invitation to integrate CAD/CAM technology [2-4].

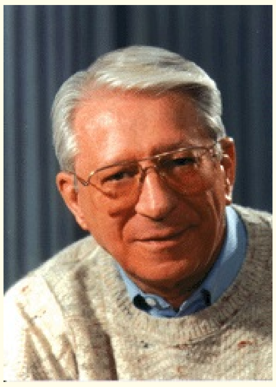

Figure 1: Patrik J Hanratty, father of CAD-CAM.

Francois duret

Development of CAD/CAM dentistry started in the 1980s. Three distinct names were identified who could be considered as the pioneers of CAD/CAM dentistry. Francois Duret is one among them. He along with two co-authors have published an article titled 'CAD CAM in dentistry' which described video imaging, virtual modelling and milling of ceramic crown with CMC machine. Later he developed his own system (Sopha), probably marking the beginning of CAD/CAM dentistry [5].

CEREC

Werner H Mormann, a professor of operative dentistry at the Dental school of Zurich University got interested in the chair side fast paced fabrication of ceramic inlays. Mormann discussed the matter with his friend Marco Brandestini an electrical engineer who was working on ultra sound scanners to study the blood flow. In 1980, the basic concept of CEREC was developed and within eight years the CEREC-1 system was established to make inlays, onlays and veneers. CEREC is the short form of 'computer assisted Ceramic REConstruction'. CEREC-2 (1994) and CEREC-3 (2000) followed with two-dimensional capability software and made different crowns and three-unit bridges. Then Siemens and Sirona associated with dental CAD/CAM development. CEREC-3 of 2003 had three-dimensional software capability and long span bridges could be fabricated. Cerec-3 of 2005 could do virtual occlusal adjustments and the developer was exclusively Sirona (Germany). CEREC Software 5.2 is at present in use [6] (Figure 2).

Figure 2: The CEREC system, milling and scanning.

Procera

Matts Andersson is known for his pioneering efforts in fabricating all ceramic crowns and he developed the Procera system. In the early 1980s, gold has become very expensive and as a replacement Nickel Chromium alloy was used. Its biologic profile was not favourable and many instances of allergic reactions were reported. Andersson tried to fabricate copings with spark erosion and using CAD/CAM, composite veneering was attempted. His search for all ceramic crowns ended up with the Procera system. After the tooth preparation, a die stone model is made and the die is placed on a rotating platform of a contact scanner. The scanner has a sapphire stylus that contacts the die surface at an angle of 45^0. On completing one rotation, 360 recordings will be made and registered in the computer (Figure 3). After one revolution, the stylus will be moved by 200 mm. An average preparation requires fifty thousand recordings to make a digitised image. This will be used in the laboratory to make a duplicate die incorporating expansion to compensate the shrinkage of alumina. After milling, an expanded coping will be made in alumina and which will be sintered to obtain the normal dimensions. Copings are usually made with a thickness of 300 to 400 mm. The prosthesis will be finished with layering of ceramics. Procera when compared to PFM crowns was good at the time of introduction but now better ceramic materials were introduced which could be milled. Equipment availability with superior quality and capability also has affected the popularity of Procera [7-9].

Figure 3: PROCERA system of contact scanning.

PMMA disc used for milling (Puck)

The discs used for milling are usually referred to as PUCK because of the similarity with the hard rubber disc used in ice hockey which is known as PUCK. In a comparison done between PMMA polymerised by conventional compression moulding system and the PMMA disc used for CAD/CAM milling, bio compatibility, mechanical properties and surface roughness were evaluated. There was no difference noticed between the resins in the bio compatibility assays. The CAD/CAM resin showed higher elastic modulus and young's modulus than the compression moulded resin. However, hardness of both the resins was similar. With three point bending test, conventional resins fractured whereas the CAD/CAM resin withstood the bending in majority of samples. Surface roughness was measured with profilometry and the Pucks were on the higher side. The CAD resin dentures can withstand fractures and the denture life will be more without fracture incidents [10] (Figure 4).

Figure 4: PMMA disc and milled denture.

Conventional Vs milled Vs printed dentures

Milling is a process that involves machining and produces required objects. Usually it is a subtractive process, which means that it removes material from a workpiece. A spinning tool is commonly used to make the object by removing material from a block. The object fabricated cannot be smaller than the tool.

3D printing is an additive process to make three dimensional objects layer by layer. Very small objects can be made by printing. Their precision is very high.

Two main protocols are generally followed in the CAD/CAM denture fabrication: subtractive and additive. In the former, a milling machine is used and the denture is made out of a pre-processed PMMA disc. The disc is already polymerised and hence mechanical properties will not deteriorate and maintains the colour. In the additive protocol, the resin is placed on a support, layer by layer and each layer is cured by laser, light or heat. Layering and curing continues until the denture gets its full shape. The process is known as 3D printing or rapid proto typing [11].

A comparison was undertaken to distinguish between milled and printed complete dentures in patients who were wearing conventional dentures by Srinivasan., *et al*. CAD dentures had better satisfaction compared to conventional dentures especially when the retention of the dentures was considered. Between printed and milled dentures, there was no significant difference of satisfaction score.

15 denture wearers were selected for the study and they were given randomly either milled or printed dentures. After the evaluation period, they were crossed over to the other type of CAD dentures for continued observation. At the end, 8 patients liked to continue with milled dentures and 7 with printed dentures. Older individuals and patients with long duration of edentulousness opted for milled dentures.

Clinicians who were evaluating the quality of dentures were of opinion that CAD dentures were better than conventional dentures; however, there was no discernible difference observed between the milled and printed dentures. Chewing efficiency was observed to be better with CAD dentures than conventional dentures [11].

Practice of CD in India and other developing countries

Clinical prosthodontic practice in India centred round the fabrication of complete dentures with conventional techniques of making impressions, registering jaw relations, arranging the teeth either by the dentist or by the technician, obtaining a pre-approval from the patient along with ascertaining the pre-registered relations and the aesthetics and phonation and finally delivering the denture followed by checkup at predetermined intervals. Except for improvements occurred with impression materials, quality changes that were ushered in through denture base resins and acrylic teeth, the fabrication process remained static – compression and injection moulding - for more than eight decades. The five or six day visit schedule for the complete dentures gained acceptance of the patients and dentist too felt quite comfortable with it because of the efficient assistance of the dental technologist. Dental practice got diversified and dentists required multiple skills to cope up with modern practice. Dentists could not spend too much time on complete dentures and the CAD/CAM technology automatically got introduced, reducing the clinical time to almost two or to the maximum three visits [12]. The advantages of adopting CAD/CAM technology are (i) lesser clinical appointments, (ii) absence or reduced processing shrinkage observed commonly with heat cure denture base resins, (iii) improved fit, accuracy, retention and stability (iv) storage of digital data which can be utilised at a later date and (v) facility to make exact duplicates saving considerable time [13].

Popular systems of CAD/CAM dentures

Nadim Baba., *et al*. [12] have listed five CAD/CAM denture fabrication systems which are currently popular

- AvaDent (Global Dental Science),
- Baltic Denture System (Merz Dental GmbH),
- Ceramill Full Denture System (Amann Girrbach AG),
- DENTCA/Whole You (DENTCA, Inc; Whole You, Inc), and
- Wieland Digital Denture (Ivoclar Vivadent, Inc).

AvaDent

In this system, the denture is milled from a disc that provides both the denture base and the teeth. Both single layer (XCL 1) and multilayer (XCL 2) teeth can be incorporated by this system. Multi layered teeth are more aesthetic. Avadent has also a facility to mill both the denture base and the teeth separately and which can be bonded at a later stage. Denture appointments can be completed either with two days or with three days. In the latter, a try in denture will be obtained so that aesthetics, functional relations and phonation can be evaluated.

The preferred option in AvaDent is to make a definitive impression along with jaw relation records. If the patient is a denture wearer, it can be duplicated and used as a tray to do border moulding and final impression. Good fit denture trays available in the market appear like dentures made in thermoplastic resins. These are modifiable and can be adapted to the ridges for better fit. On cooling it becomes hard and it can be trimmed according to the occlusal plane. Both impressions and jaw relations can be integrated with these trays (Figure 5).

Figure 5: Good fit impression trays which look like dummy dentures.

Another method is to use anatomical measurement device (AMD trays) which has upper and lower trays. The upper tray has a central bearing point and the lower tray has a tracing platform. The central bearing point can be adjusted to the desired vertical dimension. Gothic arch tracing can be done and at the arrow point a depression is made which the patient can locate with the stylus and maintain the centric position. The upper tray has a lip support adjustment flange. The AMD tray is relined with heavy body or putty consistency silicone impression material with borders moulded. It can be relined with light body and bite registration can be done with an appropriate paste. The lab requires an accurate final impression and the AMD trays with registered bite. The tray has a provision to adjust the lip support, do gothic arch tracing, mark the occlusal plane and selecting appropriate tooth sizes from templates (Figure 5a,6).

Figure 5a: AMD trays

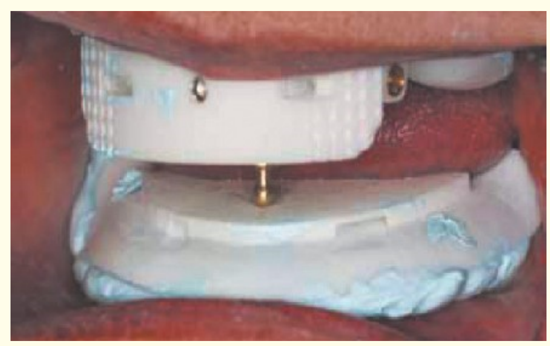

Figure 6: AMD trays with tracing unit

The lab, scans the final impression and the registered AMD trays, superimposes them and virtually designs the complete dentures and which will be sent to the clinician for assessment. If the clinician is not comfortable with the virtual image, milled trial dentures can be asked for. Milled denture base with recesses for teeth is a better option for trial denture. The teeth can be fixed with wax and the trial can be completed. Once the trial denture is approved for aesthetics, phonation and accuracy of centric relation and vertical dimension, it can be sent back to the lab for final milling. The final denture can be subjected to occlusal adjustment if necessary. This stage is similar to that of the conventional dentures [12].

Baltic Denture System (Merz Dental GmbH), Ceramill Full Denture System (Amann Girrbach AG) and Wieland Digital Denture (Ivoclar Vivadent, Inc) are three popular CAD denture systems, the operational basics are almost similar to Avadent system. These three systems utilise milling with advanced five axis CNC machine. Specialised adjustable trays which can incorporate border moulding, jaw relations and aesthetic positioning of teeth are used. Face bow and their modified versions are incorporated in these systems. Pre polymerised PMMA discs are used for milling denture bases or monolithic discs are used for making dentures with integrated teeth. Denture delivery stage for all these systems is similar to that of conventional (analogue) dentures.

DENTCA/Whole You

DENTCA and Whole you are two sister concerns; the former is concentrating exclusively on designing (CAD) and the latter on manufacturing (CAM). The fabrication process is additive (3D printing or Rapid prototyping or 3D laser lithography). Dentures are printed by two techniques. In one method a trial denture is printed and tried in the patient and required modifications are incorporated. This trial denture is then processed similar to conventional dentures using specifically printed denture flasks. In an alternate method, the final denture base is printed and denture teeth are attached to it.

DENTCA impression trays are available in four different sizes. The posterior portion of the trays can be detached; similarly, the handles also. Impressions are taken with PVS heavy body/putty and light body. The impression is sliced with a sharp blade and the posterior part is detached along with the tray. This will reduce the interference during the tracing which will follow the impression. The posterior segment can be reassembled before scanning. Tracing table is attached to the upper tray and a stylus to the lower tray. The stylus acts as a vertical stop also while registering the centric relation. Then an EZ-tracer sheet, which has a built-in adhesive, is attached to the upper tray and the patient is requested to make preferably the gothic arch tracing. The arrow point/centric is marked with a depression so that the stylus can be engaged when the patient is directed to do so. Bite registration is done with a paste. Lip length and midline can also be ascertained. All these can be sent to the lab for scanning and virtually arranging the teeth. Denture can be printed and sent to the clinician [12-16] (Figure 7-11).

Figure 7: Dentca components.

Figure 8: Dentca-maxillary tray, the posterior part can be removed.

Figure 9: Dentca- mandibular tray.

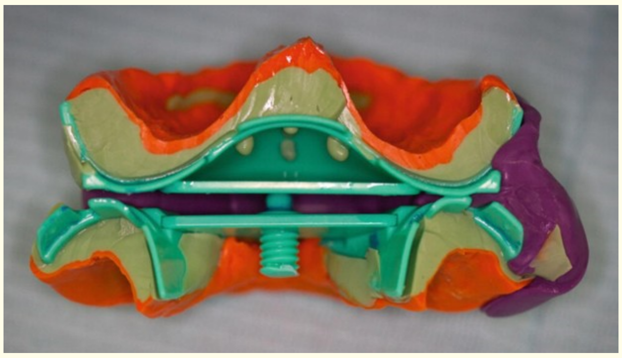

Figure 10: On completed impressions, tracing unit attached for bite registration.

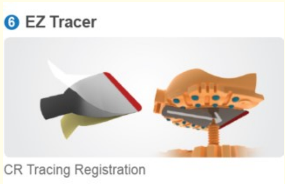

Figure 11: EZ tracing sheet attached.

3D printing in Dentistry

More than one tenth of additive manufacturing is undertaken for the health sector. It is estimated that by the turn of this decade, it will get the status of ten billion industry. Numerous technologies are used in 3D printing viz. Fusion Deposition Modelling (FDM), Photo polymerisation and Metal additive manufacturing.

In fusion deposition modelling, thermo-plastic filaments commonly made of Poly Lactic Acid (PLA) and Acrylonitrile Butadiene Styrene

(ABS) are used. The parts made through this process is of low cost but accuracy and biocompatibility are questionable. This is mainly used for making models for Ortho aligners, retention plates and whitening trays. Recently introduced Poly ether ether ketone (PEEK) is a solution to the problem of biocompatibility and can be used for removable partial dental prosthesis. PEEK has an advantage that it is a 'taste-neutral' material.

Photo polymerisation is the most popular additive manufacturing process used in dentistry. Stereolithography (SLA) and Digital Light Processing (DLP) produce objects through a chemical reaction. In SLA, laser is used for curing the resin and in DLP, visible light source is used. Complex shapes can be made with accuracy. DLP resins are known as Liqcreate resins which can be cured by light having wavelength of 385nm to 420nm. Laser or light cures the resin layer by layer. Surgical guides, provisional prostheses and patterns for castings can be made with appropriate photosensitive resins (Figure 12).

Figure 12: 3D printed denture base with supports.

Metal additive manufacturing is used in the fabrication of metallic components of prostheses or appliances used for dentistry. Selective laser melting (SLM) and selective laser sintering (SLS) are utilised. SLM fuses materials in the powder form by heating up to the melting point whereas in SLS the heating is done fifteen percent less than the melting point. Metal copings are successfully fabricated by SLS and conventional castings are almost replaced [17].

Advantages of 3D printing

3D printing has caused a major shakeup in the organisation of the clinical practice. Materials which were once considered as unreplaceable, face more or less complete elimination now. In CAD dentures, impression materials, casts and articulators have become almost virtual. The work speed has reduced from days to hours. Very soon CAD dentures can become profitable when the clinics install required equipment. Patients will also get the benefit because of the reduction in clinical time and facility to order for a duplicate denture without undergoing the entire process.

One of the commonly used printers for CD is Solfex 170 DLP Printer (W2P Engineering, Vienna, Austria) which prints layer by layer, each layer having a thickness of 50μm. For printing both the dentures, it takes 7hours and 50minutes. Different brands of printers may have different layer thicknesses and duration of printing (Figure 13).

Figure 13: 3D printer used for dental purposes.

Additive technologies are known for their low energy consumption and environmental friendliness. Usually biodegradable and recyclable materials are used but material manufacturers should reveal more details of the materials presently used. Introduction of any new system will demand a learning curve on the part of the clinicians and their assistants and it should not be considered as a disadvantage.

Milled dentures and 3D printed dentures were compared by Christopher Herpel., *et al.* and found that milled dentures showed trueness of 65 ± 6μm and precision of 48 ± 5μm. Whereas, printed dentures showed trueness of 82 ± 8μm and precision of 56 ± 8μm. In a multi centric study, the authors have observed that the printed trial dentures were within clinically acceptable limits. Srinivasan., *et al.* have pointed out that printed dentures are superior to conventional compression moulded dentures in trueness. However, no significant difference was observed between printed dentures and milled dentures [18-20].

Favourable properties of CAD dentures

The PMMA discs used for milling dentures are processed under controlled conditions and better mechanical properties are expected. Toughness and flexural strength of milled denture is better than printed denture and the compression moulded conventional acrylic denture. However, hardness of milled dentures and printed dentures was almost similar. When colour stability is considered, pink coloured resins used for milled dentures were superior to that used for printed dentures [21,22].

Workflow for CAD dentures

In the initial stages of any new technique, the work protocol will be dictated by the manufacturer of the system. The insistence of the manufacturer is mainly to ensure quality and partly to keep monopoly in the market. Operators who get exposed to a system first, are most unlikely to leave it in their life time. The economic factors will also compel them to stick to that system. After a decade or two, manufacturer independent protocols may evolve and Murali Srinivasan., *et al*. have listed a protocol for CAD/CAM complete dentures.

First visit

Alginate impression is taken using stock tray and cast is made in dental stone. If the patient is a denture wearer, the distance from the border to the occlusal plane is measured with a calliper or Gutowsky gauge (Figure 14). Upper lip length is measured using Papillameter (Avadent). Custom made acrylic tray is made with incorporated occlusion rim. If the patient is not a denture wearer, conventional check bite technique can be used. Tray handle can be integrated with the occlusion rim.

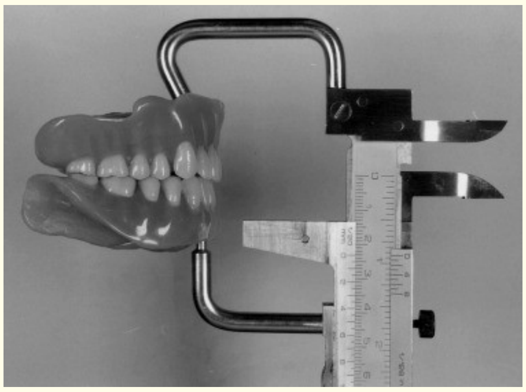

Figure 14: Gutosky Gauge denture related distances.

Second visit

The tray is tried in the mouth for extensions, occlusion rims adjusted for soft tissue profile and occlusal plane determination. The handles are also adjusted to the height. Border moulding is done with medium viscosity Polyether impression material (Authors of this article recommend silicone putty modified with Vaseline). The definitive impression is completed with low viscosity poly ether impression material (authors of this article would suggest light body silicone impression material) [23,23a]

Labial soft tissue support (fullness), occlusal plane orientation, vertical dimension establishment and recording of tentative jaw relation are done. Centric relation is further verified with gothic arch tracing. In young patients check bite registration is sufficient. Midline and canine lines are marked and centric relation is registered with bite registration material (Jet bite). Teeth selection is done and relevant photographs taken.

The combined impression- jaw relation block is scanned and stored in standard tessellation language (STL). This is done either in the clinic if it has the facility or in the lab. The scanned data is imported to the design software (AvaDent design) and the borders are aligned. This is followed by the virtual tooth arrangement and subjected to digital preview. Once approved, the data is transferred to the CAM software for milling.

Third visit

The finished denture is inspected for manufacturing defects if any and delivered. Final occlusal adjustments may have to be done if required [23a].

Intra oral scanning and CAD/CAM complete dentures

CAD CD requires conventional impressions which are scanned and incorporated in the designing process. Use of intra oral scanning started in the 1980s. This was initially used in the fabrication of fixed dental prosthesis but later adapted to complete dentures. A few cases were reported by Goodacre., *et al*. in 2018. Intra oral camera (Trios 3, 3Shape A/G) was used to scan both maxillary and mandibular residual ridges. No contrast medium was used because, they found that there is no particular improvement in the quality of scanning. Scanning of maxillary ridge was satisfactory. While scanning soft tissues were adequately stretched to get an accurate border extension. Branemark retractors were used for soft tissue management. The sequence of scanning for maxilla was as follows: crest of the ridge, palate and the vestibule (Figure 15, 16)). Mandibular ridge scanning was not satisfactory because of the difficulty in tongue retraction. In mandibular ridges, trial denture was made by milling/ printing and it was border moulded and lining impression was made. Other steps were similar to that followed in CAD/CAM dentures [24]. Retention values of maxillary bases fabricated from conventional border moulded impressions and intra oral scanning (milled and printed bases) were compared by Najla Chebib., *et al*. They have found that maxillary bases made by conventional border moulded impressions showed better retention than those made through intra oral scanning (both milled and printed). At present we have to accept the fact that intra oral scanning has limitations in ensuring retention of maxillary complete dentures. Till we find an advanced scanning system which can copy functional borders, integration of conventional impressions with the digital format will remain as the successful option in fabricating digital complete dentures [25].

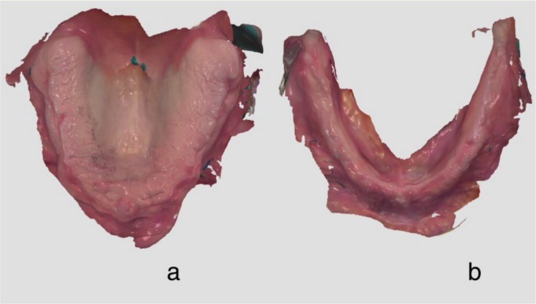

Figure 15: Scanned images of residual ridges.

Figure 16: Branemark retractor.

Discussion

Fabrication of complete dentures always involved human skill and time. In the 20th century, prosthodontic practice centred around complete dentures and professionals never thought or even dreamt of a situation of reduced work burden related to dentures. Because of the work load and limited returns, an element of disinterest crept into the profession and dentists would try to avoid complete denture practice. In some of the Asian countries, there is an attempt to make complete dentures, an exclusive postgraduate subject. Introduction of CAD/CAM has ushed in a new ray of hope and interest in the fabrication of complete dentures. CAD/CAM has equipped the Prosthodontists with powerful tools to design and fabricate prostheses with accuracy and considerable reduction in the processing time. We are going to witness in the near future seamless digital workflows which would enable dentists to deliver quality treatment with ease and precision. Once, more developments and progress are achieved, CAD/CAM dentures may become a standard practice and we can brand it as a revolution which would kindle research and find solutions that would benefit the future generations of professionals and patients.

Conclusions

CAD/CAM is a valuable tool that can enhance the existing fabrication process used in the making of complete dentures. The greatest advantage is the precision factor and the speed with which it can be achieved. Making an exact copy of a denture is a difficult task with conventional techniques. Digital fabrication has made it simple. Any number of copy dentures can be fabricated which will definitely look alike. If a denture is lost in an accident, the stored data in the computer can be retrieved and a denture can be fabricated without replicating the long processes.

The question that may arise in this context is that will the CAD/CAM ever replace the dentist and the conventional clinical and laboratory processes? It is not a likelihood in the near future. The professional expertise acquired through long years of experience which can judge the clinical situation and modify the treatment plan may not find a replacement in digitisation. Only future can tell precisely whether digital decision making will be put into practise or not. Will a machine ever duplicate the warmth in doctor-patient relationship?

Author Contributions

Conceptualization -K. Chandrasekharan Nair, Pradeep Dathan; Review of articles - K. Chandrasekharan Nair, Viswanath Gurumurthy; Ashish K Soman, Sreeba S B, Initial draft preparation - K. Chandrasekharan Nair; Review and editing - K. Chandrasekharan Nair, Pradeep Dathan, Viswanath Gurumurthy; Supervision - K. Chandrasekharan Nair.

All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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Figure 1. https://halloffame.tech.uci.edu/inductee/hanratty-patrick/

Figure 2. https://www.dentsmileint.com/blog/zero-error-in-one-session-with-the-digital-dentistry:-cerec/

Figure 3. http://www.excel-dental.com/product/6/

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Figure 7-10. https://hiossen.eu/magic-line/

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