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RESEARCH ARTICLE

THE ERA OF DIGITAL COMPLETE DENTURES: A LITERATURE REVIEW

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ABSTRACT

Introduction: Removable complete dentures have entered the digital era in the past decade, revolutionizing the field of prosthodontics. Digital workflows are constantly evolving with the maturity of digital technologies. Aim: The aim of the current review is to summarize the current knowledge and current advancements in the field of digital complete dentures. The article reviews techniques for recording edentulous ridges, steps and different methods of recording maxillo-mandibular relationships. It gives a description of the digital designing of the prostheses and touches upon various available manufacturing technologies. It can be inferred that the main advantages of digital complete dentures over conventional are the reduced clinical time and the number of visits, digital archiving, higher retention, superior mechanical and physical properties in CAD/CAM dentures, leading to favorable clinical and patient-centered outcomes. Milled dentures have been studied longer compared to 3D printed ones in the currently available literature. The restricted number of clinical studies limit current indications of 3D printing to fabrication of custom trays, record bases, trial/interim/immediate dentures but not definitive prostheses. **Conclusion:** The digital workflow is applicable and versatile to all fields of dentistry. Though digital technology has shown to have clear advantages, careful planning has to be considered prior to its implementation. Digital dentures are a promising option to simplify complete denture fabrication.

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INTRODUCTION

Although preservation of existing natural teeth is the goal of modern Dentistry, with progressing age, individuals are more likely to experience tooth loss. Longer life expectancy in addition to this has inevitably led to progressively increasing demand for rehabilitation options.(1) Removable Complete Denture (CD) is the most common and most accepted rehabilitation option for completely edentulous patients worldwide. (2) It is anticipated that demand for CDs will invariably rise in the following decades. Efforts to further improve overall quality and patient satisfaction is still in progress.(3) Protocol for fabrication of complete dentures using a traditional workflow involves multiple steps. These include, registering the supporting tissues and peripheral musculature by means of two sets of impressions, recording the maxillomandibular relationships, teeth selection, tooth arrangement, try in and finally fabrication of the denture followed by its insertion. Thus, it necessitates a succession of clinical and laboratory steps which further requires handling by multiple operators and is thus consequently prone to errors (2).

Since its introduction in the 1980s, digital dentistry has revolutionized multiple aspects of dental practice. Its introduction in complete denture prosthodontics being no exception. Edentulous ridges and maxillomandibular relationships can now be recorded using intraoral scanners, CDs can now be designed using multiple commercially available softwares, and the traditional laboratory steps can be substituted by milling (subtractive manufacturing) or 3D printing (additive manufacturing). Nowadays, fabrication of CDs using digital methods has attracted a lot of attention in the field leading to further improvements in design and quality. This newer technology is promising faster and better results. The objective of this article is to briefly introduce digital complete dentures, the steps involved in the fabrication of the same and its current advances.

HISTORY: As mentioned earlier, digital dentistry has revolutionized various fields of dentistry since its introduction in the 1980s. In 1994, the 1st attempt to fabricate a digital denture was made. Maeda *et al*, a group of Japanese Investigators were the first to publish a scientific report in

English on the concept of using computer-aided technology to fabricate complete dentures from photo polymerized composite resin material with rapid prototyping technology. Later in 1997, another Japanese group, Kawahata *et al*, worked on the concept of digitally duplicating existing dentures and milling them by using a CNC milling machine.(4) However, Digital denture construction, was pioneered by Goodacre *et al*. in 2012.(5)(6)Since then, several investigators have volunteered and bestowed improvements in the field ranging from complete digitization of maxillomandibular relationships, digital teeth arrangements with help of softwares to using CBCT to scan and fabricate complete dentures.(4)

FABRICATION PROCEDURE

DIGITAL IMPRESSIONS: A digital scanner is a non-contact measuring device that records and reconstructs three-dimensional (3D) surfaces or volumes. (7) It consists of an optical acquisition system in association with a 3D reconstruction software. Intra oral scanners (IOS) are portable and are used to record intraorally, while extra-oral scanners (EOS) are used in the laboratories to digitize impressions/models. Aesthetic lines, facial landmarks or extraoral defects during construction of maxillofacial prosthesis can be recorded using face scanners. Preliminary non-compressive digital scanning of edentulous ridges can be achieved with intraoral scanners. Scanning of edentulous ridges presents few recording challenges, which include a) lack of anatomical landmarks b) difficulty in recording the functional borders c) difficulty in recording the posterior palatal seal.(2)Placement of composite markers /use of a dermal marker on the mucosa will aid in impression making while recording areas without anatomical landmarks such as palate or edentulous ridge(8). Jung *et al*. proposed digital scanning can match the conventionally registered functional borders.(9)Mobilizing of soft tissues with a finger or a mirror to record their position was also proposed by some authors. As far as the posterior palatal seal is concerned, the anterior and posterior vibrating line on the soft palate can be defined with the help of indelible pencil or small spots of light-polymerised gingival barrier material before scanning. The accuracy of intraoral digital scans is found to be similar to that of the conventional materials for maxillary arch; however, for the mandible, confirmation is still desired.(2)This preliminary impression can then be used for fabrication of custom tray for conventional secondary impressions if needed. Some examples of IOS include, TRIOS 3/TRIOS4, 3Shape A/S, iTero Element, CEREC Primescan, iTero 2,iTero 5D Element etc.

RECORDING OF MAXILLOMANDIBULAR RELATIONSHIP: Most often, conventional steps for recording maxillomandibular relationship is followed by fabrication of base plates either by conventional manner or by 3D printing.(2)George Kouveliotis *et al*, mentioned use of handle free edentulous stock trays. Following Intraoral reline of the Stock trays using elastomeric impression materials like medium viscosity polyvinyl siloxane to improve their retention, occlusal rims can be attached and maxillomandibular relations can be conventionally determined. These records are then scanned by an extraoral lab scanner to join the digital workflow.(10)(1) In case of immediate complete denture fabrication, intraoral scanners can be used to scan the bite prior to extraction of posteriors, thus maintaining the maxillomandibular relationship digitally post extraction aiding in denture fabrication. (11) In Ivoclar-Vivadent workflow, maxillo-mandibular relationship is recorded in two steps. First, preliminary impressions are recorded conventionally and a preliminary jaw relation is recorded with a specific device(centric tray). This later is scanned in the laboratory using an EOS and then positioned on a virtual articulator. This follows digital designing of occlusal rims close to the clinical situation, simplifying the final recording.(12)Weiwei Li *et al*, designed an in house headgear that maintained the mandibular position during scanning, thus completely digitizing the step.(13)In another original research by Weiwei Li *et al*, a jaw movement tracking system was devised which determined the mandibular trajectory of motion, thus establishing another method of completely digitizing the record of maxillomandibular relationship.(14)(15)

COMPUTER ASSISTED DESIGNING OF THE DENTURE: Multiple commercially available CAD soft wares allow designing of complete dentures and offer a variety of virtual tools and adjustment options. These include tooth selection, tooth arrangement and occlusal adjustments with the help of virtual articulators which allow both static and dynamic occlusal analysis(1)Teeth libraries of different brands and shapes are included in these softwares. It is also possible to personalize and customize the shape and position of teeth according to the operator's choice. Finally, papilla widths, canine eminences, marginal curves can also be modified. The CAD files are then ready for the production of the dentures for try-in and functional evaluation. After designing these CAD files can also be used for fabrication of surgical templates for implant surgeries or can be used as transitional dentures in patients with TMJ problems (2) (12)examples of CAD software include 3Shape Dental System®, Dental Wings®, Exocad®, Ceramic D-Flow®, Lucy®, 3Shape Digital Denture®, Modifier.(2) Designing of complete denture via CAD softwares allows customizations according to patient requirements and yet saves an appreciable amount of time in comparison to conventional methods.

COMPUTER ASSISTED MANUFACTURING OF THE DENTURE: Considering the manufacturing part for digital CD production, currently two principal methods are known, one is additive and the other is subtractive.(1)Polymer poly methyl methacrylate (PMMA) is so far the most commonly used material for fabrication of conventional CDs. Relative ease of processing and repair, esthetic characteristics and biocompatibility has led to its increased use and acceptability by the patients. Nonetheless, PMMA has multiple disadvantages including high polymerization shrinkage, susceptibility to microbial colonization, allergic reactions mostly due to leaching of the monomer, degradation of the mechanical properties over time and low wear resistance.(5) In the conventional process, strict control of temperature, pressure and polymerisation time is required to minimize the polymerization shrinkage and get the desired material properties. However, these traditional protocols are operator dependent and hence prone to errors and inconsistent results. Fabrication of CDs via digital method, reduces these sources of errors. These shortcomings of conventional techniques have inspired development of novel materials and manufacturing techniques, both additive and subtractive. (2)(5)

COMPUTER-ASSISTED MILLING OF COMPLETE DENTURE: It is a subtractive method which involves shaping of the denture from pre polymerised resin discs. The denture base is milled as one unit having the sockets for placement of

separately milled teeth set. The two are later bonded using commercially available bonding systems. Most commonly used bonding system is IvoBase CAD Bond; Ivoclar Vivadent AG (Autopolymerizing PMMA based 2- component bonding system).Positioning of the milled teeth set is facilitated by a transfer key.(10)(1)Newer discs with shell geometry incorporate both gingival and tooth coloured PMMA in a single block. These blocks incorporate papilla architecture between the two colors giving a natural transition between the two parts when milled.(11). The reversal of the shaping and polymerisation steps reduces the polymerization shrinkage to a great degree and shifts the polymerisation quality control in manufacturer's hands. The most important clinical outcome is the excellent fit of the denture with increased comfort and improved retention. Material composition can also be optimized in order to achieve desired mechanical properties like flexural strength, fracture resistance and biocompatibility. Inspite of the fact that milling is widely used, it has economic and environmental costs, since a large part of the disc is not used and gets wasted.(2)

COMPUTER-ASSISTED PRINTING OF COMPLETE DENTURE

3D printing is an additive process which comes across very promising. It includes shaping of the dental prosthesis by successive addition of material, layer by layer. Satisfying precision is achieved with Stereolithography (SLA) or digital light processing (DLP) with resin layers ranging from 20 to 150 µm. It is compatible for the manufacture of both the denture base and the teeth. Commercially available systems include Dentca CAD-CAM (DENTCA Inc), Pala (Kulzer) digital denture, Next-Dent B.V, Envisiontec Inc.(2)Similar to the procedure of milling, the denture base is printed separately with compartments to bond the separately printed dental arch. Commercially available teeth can also be used. Due to the lack of clinical evidence regarding denture adaptation, mechanical properties and biocompatibility, 3D printing is not commonly used for fabrication of final CDs. However single unit printed dentures can be used for clinical evaluation of esthetics, phonetics and function simulating the step of try in prior to final denture fabrication by process of milling. Several studies have inferred that the accuracy of the printed CDs is lower than that of milled ones, but still remain clinically acceptable. However the additional advantages includes less wastage of material, lesser cost, requirement of less sophisticated and complex equipment compared to milling.(2)(16)(17)

DISCUSSION

Comparison of conventional v/s digital Complete Dentures: Several Studies have shown that digital (milled) CDs in comparison to conventional CDs offer better retention, similar to better adaptation, equal biocompatibility and improved mechanical properties.(18) Kattadiyil compared milled and conventional complete dentures manufactured for the same patient, and found significantly increased retention in milled dentures. (19)(3) High level of patient satisfaction has been demonstrated with Digital CDs owing to better retention and less number of clinical appointments (20)(21)(22). In a questionnaire based study by Saponaro *et al* it was revealed that 70% of experienced CD patients found their new digital CDs 'to be better' than their previous set of CDs.(23) However on the contrary, a patient satisfaction study by Ohara concluded that 20% of the studied group preferred digital dentures while 80% opted for conventional dentures.(24) Researchers have also mentioned duplicating an existing denture via digital technology as an attempt to reduce the laboratory steps and chair time.(3)The ability to save digital records for future reference as in the case of denture breakage or misplacement adds on to the advantage of digital dentures. This allows denture duplication without the need to carry out any of the clinical steps again.(21) Furthermore, digital (milled) dentures are found to have significantly better material properties. The reasons being, a)denture base milled from prepolymerized PMMA pucks resulting in a highly condensed resin.(25) b)Longer polymer chains and reduced residual monomers as a result of fabrication under high pressure and temperature.(25)(3) This prevents polymerization shrinkage of the digital dentures which is seen to a large extent in conventional dentures and thus improving the physical properties and denture adaptation, further improving denture retention(3)(21) Construction flaws such as denture porosities are additionally minimised.(20)

Disadvantages of digital CDs include difficulties in determining CR and VD without the use of conventional methods. One of the drawbacks of digital dentures also includes accuracy of digital impressions. Greatest misfit of the intaglio surface of the digital CDs was shown in the posterior palatal seal area, the border seal area, and areas displaying undercuts. Relining is often suggested as a solution to these problems.(26)(27) Other problems encountered specially with milled dentures include material wastage and high cost(3) Apart from these, Milling or 3D printing render monochrome shades to the bases and prosthetic teeth, and may require additional laboratory staining procedures.(2) However, it was concluded by Srinivasan that the costs for clinical chairside time, laboratory costs and the overall costs were significantly lower in digital protocol, even though the materials cost was higher.(28)(29)

Comparison of milled v/s 3D printed Complete Dentures:, The CAD-CAM milled CDs are found to be superior in comparison to the 3D printed CDs in terms of trueness of the intaglio surfaces(18)(30)3D printed dentures in comparison to milled dentures have found to have lesser retention, compromised aesthetics and low strength. 3D printed polymers often require clinical reline to achieve acceptable retention. Additionally, long term color stability and esthetics are also proven to be inferior 3D printed polymers compared to milled ones.(5)

Yoshidoma compared the trueness and fitting accuracy in conventional dentures, CAD/CAM dentures and two systems of 3D printed dentures (stereolithography and digital light processing).It was concluded that compared to 3D printed and conventional dentures, the milled dentures show better trueness and fitting accuracy. Conventional and 3D printed dentures showed similar fitting accuracy and trueness.(31). One of the major benefits of 3D printing technology over milling is less material wastage as it is an additive method. Cristache mentioned that compared to 3D printed dentures, milled dentures are more expensive and waste a lot of material. He further stated that 3D printed dentures are more affordable, bring about less material wastage and are also capable of producing complex details.(16) For individual dentists/technicians 3D printing is a more convenient and affordable option compared to CAD/CAM as the latter

demands the need of commercial specialized centers. Studies on fabrication of CDs via 3D printing are limited and constrained to case reports, however certain studies have shown that the clinical performances of 3D printed dentures are in clinically accepted ranges rendering acceptable patient satisfaction.(17)(5)As of today, 3D printing is commonly used to print record bases and denture prototypes. Denture prototypes can be used as trial dentures, to confirm teeth arrangement and to assess other parameters prior to milling of the final denture. This gives an option of try in, in a more economical way.(27)(10)Though 3D printed dentures have promising potential in denture manufacturing considering they require lesser materials and simpler equipment compared to milling, further clinical studies are needed to prove their clinical efficacy.

CONCLUSION

The introduction of digital technology in the field of complete dentures has led to significant advancements. Over the years, Digital CDs have shown acceptable clinical performance, reduced number of appointments, improved retention, less dependence on human factors and ability to save patient's records especially in cases that might require denture duplication in future. With the current evolution of imaging, biomaterials, CAD/CAM and printing technologies, the future prospects for digital complete dentures are promising. Currently milled complete dentures offer a superior treatment option in comparison to 3D printed dentures considering the better properties such as trueness of fit, strength, mechanical properties etc. 3D printed technology is a promising modality having the potential to modernize and simplify the denture fabrication techniques, materials and workflows, nonetheless more clinical studies to prove its efficacy in the field are needed.

Conflicts of Interests: None

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