3D printing dental prosthesis using photo curable biomaterial with better resolution & reproducibility

Hrithik Pawar[1], Sidhant Kumar[2], Lakshay[3]

[1,2,3]*Dept. of Electronics & Com. Engineering, Delhi Technological University, Delhi, India*

---***---

Abstract - *Dental treatment involves making of dentures and installing by dentists using flask investment method, which requires measurements of gum impression, jaw position, bite pattern, and also the affected area. This whole complex process needs significant amount of skills, time and multiple appointments. Our research overcomes the mentioned shortcomings using 3D printing system to make dental prosthesis while reducing labor. The system helps dentists make dental apparatus without multiple visits, reducing cost, time and number of patient visits required to perform dental procedures. Our research involves development of 3d printing system, photocurable biomaterial for 3d printing dental prosthesis, and curing of the dental prosthesis parts, with better resolution and reproducibility than current systems.*

Key Words: 3D Printing, Dental Prosthesis, Photocurable Material, Dentistry, Robotics

1. INTRODUCTION

Dental prosthesis or dentures have been used since last few decades for treatment of edentulism [1]. There is lack of innovation in the traditional prosthesis technology.

There are two main fabrication methods in digital dentistry for making dental prosthesis : subtractive and additive [2]. In subtractive method, dental prosthesis is made by milling prepolymerized resin blank. This milled denture is bonded to base subsequently. Such systems include Zirkonzahn Denture System (Zirkonzahn, Italy), Ivoclar Digital Denture (Ivoclar Vivadent, Liechtenstein), Vita Vionic (Vita Zahnfabrik, Germany) and AvaDent Digital Dentures Bonded Teeth (AvaDent, USA). The main problems with subtractive method is high material wastage and unaesthetic teeth. In additive manufacturing method, the dental prosthesis is made layer by layer, so zero material wastage and aesthetic teeth. Current additive systems include FotoDenta denture (Dentamid, Germany) and Dentca 3D Printed Denture (Dentca, USA) [3]. The limited resolution, reproducibility and technical constraints have been obstacle to adoption of the current 3d printing system [4].

In our research, we are aiming to develop 3D printing system using photocurable biomaterial to 3d print dental prosthesis with better resolution and reproducibility, which will revolutionize the digital dentistry industry.

2. 3D PRINTING SYSTEM

Additive manufacturing is method of producing objects layer by layer, reducing waste produced. There are two methods which can be used to print dental prosthesis, one is fused deposition modeling and digital light processing method, as we will describe in next sections.

2.1 Fused Deposition Modeling (FDM) system

This section of the paper relates to a cartridge for a 3D printer. The cartridge has a nozzle or is designed such that a predefined nozzle is formed. The cartridge contains a dental composite material. The composite material comprises a curable, particularly photocurable matrix, and only fillers with a maximum particle size of <5 um[12]. In the uncured state, the dental composite has a viscosity in the range from 1-10,000 Pa*s, preferably from 10-2,000 Pa*s, especially preferably 50-800 Pa*s, in particular.

In this manner, blockage of the nozzle during the 3D printing is primarily ruled out, enabling continuous 3D printing. Pausing or stoppage of the printing process to free the nozzle from blockages is thus not necessary. The cartridge, according to this section of the paper, enables efficient and speedy 3D printing of dental prosthesis parts. According to this paper, the cartridge allows inexpensive printing by a dentist (chair-side) within a short time so that a patient can be treated entirely in one consultation[13].

The cartridge can have a size ratio of the nozzle diameter to the greatest particle size of the composite material of 10:1, preferably 30:1, especially preferably 50:1. Here the diameter can range from 50 to 300 um, preferably 100 to 250 um, especially preferably 150 to 200 um. Through the appropriately selected ratio of cartridge nozzle diameter to the greatest particle size of the composite material, blockage and hence stoppage or interruption of the 3D printing is prevented.

Furthermore, the cartridge can be designed to contain a quantity of a composite material that essentially suffices for one use (single dose). This has the advantage that a new and clean nozzle is used for each new construction task and each material component. In this manner, the process stability is improved. Cleaning after the conclusion of the construction task is not necessary. Accordingly, no composite material residues collect in areas that could cure because of the ambient light and could interfere with the printing process in the following task.

The cartridge can hold material ranging from 0.5g to 4 grams, adequate for one sitting. In the production of dental parts by 3D printing, the quantity of material required is usually smaller[14].

The cartridge and tank can be made of different materials and used in different ways. Therefore, construction materials can be selected from a group of metal, plastic, and metal and plastic composites. Preferred metals are stainless steel, aluminum, or titanium. These have the required strength and durability, do not react with composite materials, cannot be illuminated, and can be brought immediately to the desired geometric shape by standard technologies and methods.

The cartridge can additionally be coated on the inner sides (of the reservoir/reservoir region), which are in contact with the composite material. Such a coating can, for example, contain plastic or ceramic or consist thereof.

Thus specific properties, such as the sliding behavior can be advantageously influenced and adjusted.

Preferred plastics are thermoplastics like (PP), (PBT), (PA), (PPA), (PSUP), (PPS), and (PEEK)[15].

A plastic cartridge is inexpensively producible in the necessary piece numbers. The oxygen permeability of the plastic cartridge has a positive effect on the storage life of the composite material[16]. The mechanical stability of the plastic cartridge is sufficient and can still be further optimized with fillers. The light impermeability of the plastic cartridge can be obtained by adding color pigments to the plastic during cartridge production.

A cartridge of a combination of metal and plastic is advantageous since a fine and robust nozzle can be formed[17]. For this, a cylindrical or conical metal channel is preferably attached as a nozzle on a plastic cartridge.

This can, for example, be affected by over-molding the metal channel or by inserting, in particular pressing, cementing, or welding the metal channel in.

The cartridge can further have a piston for displacing the composite material through the nozzle. In this manner, the composite material can be pushed out of the cartridge as required and deposited on a target site[18].

The geometries of the cartridge and the nozzle are preferably designed such that a flow technology optimized material flow of the composite material during the printing process is achieved. In this manner, a high material flow is achieved with low ejection pressure. The factor of 30-50 could increase the flow rate with a conical nozzle. A typical value for the flow rate with a conical nozzle with an end diameter of 0.160 mm is 0.05g/min, at 5 bar ejection pressure and 23 C.

Especially preferably, the nozzle is conically shaped over a broad region, particularly over essentially its whole length; only an end region before the outlet is cylindrically shaped. The cylindrical design in the end region serves in particular to set a defined strand diameter[19]. The cylindrical end region of the nozzle preferably has a length from 1 to 30 times, preferably from 3 to 10 times, the internal nozzle diameter at the outlet. Because of the fine shape of the nozzle, this can preferably be provided with a removable cap[20]. The removable cap protects the nozzle from deformation.

The cartridge can have a positioning device that ensures defined and reproducible mounting of the cartridge in a 3D printer. Defined reinforcement is of use, particularly with the help of several cartridges of different content during the production of a dental prosthetic part, to avoid an undesired misalignment between the materials. The positioning device can, for example, be formed by a conical or truncated cone-shaped centering element that is located around the nozzle. The positioning device can further have a stop to ensure the nozzle outlet's position along the longitudinal nozzle axis. A printing head of a 3D printer, designed to accommodate the cartridge, can have an opposite positioning device corresponding to the positioning element.

The cartridge can also have a sieve which is positioned before the outlet of the nozzle. If the composite material is displaced from the cartridge, then this is passed through the sieve. Here the sieve is positioned in the interior of the cartridge to filter the composite material before it reaches the nozzle. In this manner, agglomerates of filler particles that may have formed in the cartridge are kept away from the nozzle, and blockage of the nozzle is prevented. The sieve can have a pore size ranging from 5 to 1000 um, preferably 10 to 500 um, especially preferably 20 to 100 um. Thus, the system of nozzle opening diameter, maximum filler particle size, and sieve pore size can be adjusted to enable efficient 3D printing of dental prosthesis parts.

Furthermore, the cartridge can have a cover that generally protects the cartridge's contents from the surroundings. In particular, using such a cover, an unintentional actuation of the piston for displacing the composite material can be excluded.

The cartridge can be designed such that a nozzle can be formed by cutting or puncturing, particularly employing a laser. In this manner, a nozzle or a nozzle opening with a size defined according to requirement can be provided.

The cartridge can have a thermal conductivity from 0.1 to 400 W/mK, preferably 0.2 to 250 W/mK, especially preferably 70 to 250 W/mK. In this manner, efficient heat input to the cartridge can take place from a heating unit positioned in or on the unit of the 3D printer corresponding to the cartridge. Utilizing the heat input, the flow properties of the composite material in the cartridge can be adjusted optimally or according to requirements.

The composite material processing and optionally of further materials, such as support material and a parting material as described below at a defined temperature, Set by means of a heating unit, further ensures defined and reproducible properties of the respective materials.

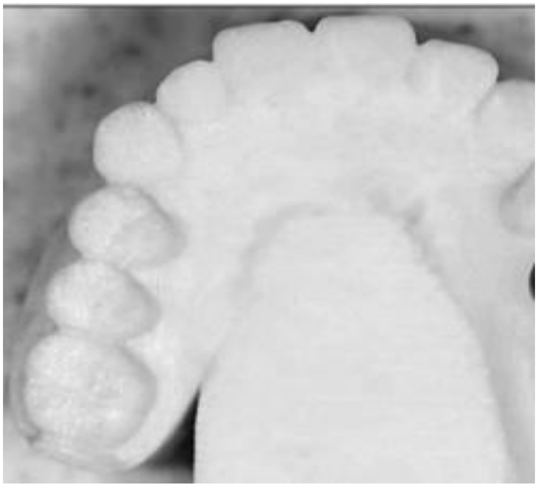
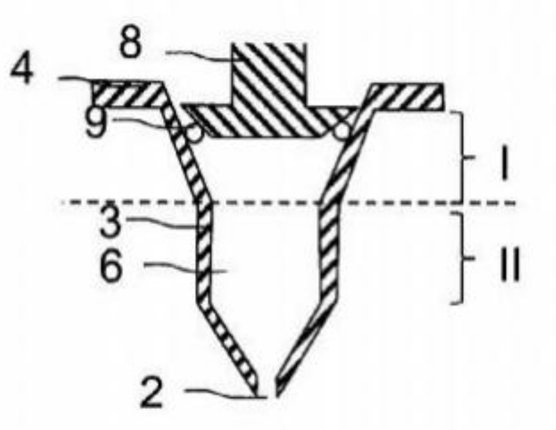


Fig 1 - 3D CAD model of denture



2.2 Digital Light Processing System

In digital light processing system, high power light projection polymerizes the photopolymer and make the CAD model of the dental object layer by layer [5]. When high accuracy is required, layer thickness is minimized. In DLP, digital micromirror device is used for projecting single light-mask image for each layer [6]. This polymerises the entire layer which reduces printing time.

Intra-oral scanning is performed using an intra-oral digital scanner, and the model in STL format is exported. The CAD model of denture is printed in DLP based 3d printer, using photocurable material, which is biocompatible. Then the manufactured object is removed and left over resin is cleaned using isopropyl alcohol. Complete polymerization is performed in light curing system [7].

Fig 2 - 3D printed dental model

3. PHOTOCURABLE MATERIAL

The most important characteristic in the material used should be biocompatibility for it to not have any adverse effect on the user. In addition to that, material should have high tensile strength to perform regular human activities like chewing for the longest period of time.

Other than the glaringly obvious properties, material should also have low specific gravity (light weight), thermal conductivity, ease of cleaning and low cost for patient's comfort.

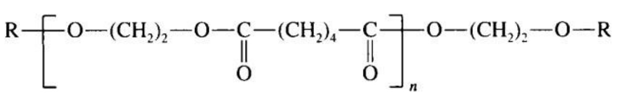
Typesof Properties	Characteristics
Biological	Biocompatible, Non Irritant, Nontoxic, Non-carcinogenic
Esthetics	Ability to tint and pigment to match the color of teeth and gums.
Physical	Low specific gravity, Dimensional stability, Good thermal conductor, Coefficient of thermal expansion similar to teeth, Thermal Stability and Radio-Opaque.
Chemical	Insoluble, Non reactive, Compatible.
Mechanical	High elastic modulus, Proportional limit, Resilience, Adequate abrasion resistance, Fatigue and impact strength.
Others	Inexpensive, Easy to manipulate and repair, Easy to clean, Longer shelf life.

Table 1 – Properties of Material

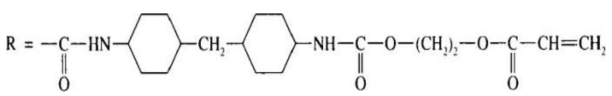
Name of Material	Concentration
Poly(methyl methacrylate)	0-25% by weight
Urethane (meth)acrylate oligomer	5-35% by weight
Bisphenol-A dimethacrylate	30-50% by weight
photoinitiator	0.1-3.5% by weight
Surface modified silica particles	2.5-12% by weight
colorant and stabilizing agent	0.5-5% by weight

Table 2 – Composition of Material

3.1 Chemicals Used



Polymethyl Methacrylate (PMMA)



PMMA (IUPAC name: poly [1-(methoxy carbonyl)-1-methyl ethylene) is a synthetic polymer made by adding a free radical to methyl methacrylate (C5O2H8) and polymerizing it to poly methyl methacrylate (C5O2H8)n.

PMMA is commonly offered as a powder–liquid combination. A transparent polymer (PMMA) is present in the powder, but additives such as colors and nylon or acrylic synthetic fibers are used to alter the physical qualities and aesthetics to simulate oral tissues (such as gums, mucosa). A methyl methacrylate monomer, as well as cross-linking agents and inhibitors, are included in the liquid component.

Properties like low density, aesthetics, cost-effectiveness, ease of manipulation, and tailorable physical and mechanical properties make it a suitable and popular biomaterial for these dental applications [21].Several chemical changes and mechanical reinforcement techniques using various types of fibers, nanoparticles, and nanotubes have recently been reported to increase the attributes (thermal properties, water sorption, solubility, impact strength, and flexural strength) of PMMA.

Although there are some drawbacks to using PMMA, such as denture fracture due to water sorption and poor impact and flexural strength, ongoing research has introduced a number of modifications to overcome and improve its properties (such as conductivity, water sorption, solubility, impact, and flexural strength). Several research, for example, found that PMMA materials improved when reinforced with a range of fibers. As a result of the differences in its physical and mechanical properties, we can conclude that PMMA is not an ideal material. PMMA, for example, absorbs water, compromising its physical and mechanical qualities and making it susceptible to failure under cyclic loading [22]. This is why we used several other chemicals to eliminate its disadvantages as much as possible while keeping it biosafe.

Urethane (Meth)acrylate Oligomer

In the past, urethane (meth)acrylate (UA) oligomers have been studied extensively as biomaterials for contact lenses and surgical implants.In the last two decades, a significant variety of such resin formulations have been commercially available. Urethane oligomers with acrylic functionality and vinyl monomers are the main components of these resins, which are used to manufacture tougher products and/or reduce the viscosity of the precursor liquid to improve processability[23].

The repeating structural unit of a commercially used UA (Uvithane 788) is

where

Diluents are added to UA mainly to regulate viscosity and increase processability, strength, elongation, chemical and scratch resistance, surface quality, and crosslink density control [24]. The amount of reactive diluent used must be kept to a minimum in order to achieve the best characteristics. Low viscosity, good solvent power, high cure rate, low toxicity, low odor, and required physical qualities after curing are all requirements for the optimum reactive diluents for UA.

The structure, molecular weight (MW) of the prepolymer, and the nature and amount of reactive diluents all influence the viscosity of UA [25]. The clean UA oligomers have a viscosity of -100,000 cP, which is higher than their monomeric diluents (21 cP). As a result, the addition of diluents is predicted to reduce the viscosity of UA.

Bisphenol-A Dimethacrylate

Bisphenol A (2,2'-bis[4-hydroxyphenyl]propane) (BPA) is a commonly used ingredient in dental restorative resin-based composites and sealants. A chemically or photo-initiated polymerization reaction "cures" or converts the resin matrix from a fluid containing monomer to a stiff polymer. BPA is extensively used to make polycarbonate plastics, which are employed as protective coatings on food containers and in plastic infant bottles, accounting for approximately 63 percent of its utilization [26].

BAPO (Photoinitiator)

Phenylbis (2,4,6-trimethylbenzoyl)-phosphine oxide also known as BAPO is a radical photoinitiator which serves its purpose as an alternative to the standard CQ-based systems in a model dental resin through the polymerization kinetics and mechanical properties of the polymer. It has a higher extinction coefficient compared to acyl phosphine oxides like TPO or TPO-L, resulting in excellent photo speed in most cases [27].

Surface modified Silica Nanoparticles

Silica nanoparticles were made in a water-in-oil microemulsion and then surface modified using tetraethyl orthosilicate (TEOS) and other organosilane chemicals by cohydrolysis. Back bonding to surface silanol groups is possible with amine-modified silica nanoparticles. As a result, the overall charge on the surface is extremely low , and the particles tend to aggregate due to the lack of a driving force on the nanoparticles' surfaces to keep them apart.

4. CLINICAL PERFORMANCE

The clinical performance is important for adoption by the doctors and patients to improve the treatments. The retention with denture bases from prepolymerized poly(methyl methacrylate) resin is significantly higher than that with conventional heat-polymerized denture bases [8]. Esthetic seems to be pretty low of 3d printed dentures. Lower number of appointments needed for the dental procedure is a favorable point for the patient, while also saving valuable time of doctors. On taking feedback from doctor and patients in form of questions, they gave satisfactory response for less appointments, fast work, custom dentures, and potential of technology to improve the quality of life. However, there was little color change observed of acrylic resin due to slow water absorption over few months.

From clinical perspective, the doctors feel that there is little learning curve for adoption of this new technology in dental clinic. Experienced and old doctors showed little skepticism whereas doctoral students at early age preference for this emerging tech, because they have been using new technologies since very young age. The experienced clinicians prefer higher quality of treatment, and are not ready to compromise with proven processes and patient expectations.

The dental community prefer that quality of treatment and patient satisfaction should improve or at least stay same as the traditional methods. Just reducing time and improving is not enough for adoption. The clinical try-in and patient evaluation will reveal, how the 3d printed denture is performing clinically.

5. FUTURE

As the number of edentulous patients are growing with time, so there will be higher need of 3d printed dentures in future. With increased demand, and limited doctors, they need tools that will help them in saving time, and do more dental procedures for increased patients. The time saved due to less human involvement, virtual teeth arrangement, and more dental procedures is much more useful. Even though the cost of adding new advanced equipments like intra-oral scanner, custom tray etc will be there, the benefits are higher than the incurred cost [9]. So with time, as the cost of hardware and material will decrease with volume and innovation, the technology will get slowly adopted by the dental community.

The amount of waste in traditional subtractive processes are high, and the 3d printed denture resolves this well.

There are many areas across world, like developing countries and low income nations, where there is scarcity of dental technicians. Here, this 3d printing dental prosthesis will solve problem of shortage of dental technicians, and improve public health [10].

In predoctoral community, students are preferring new, fast and less complicated technical tools like 3d printing dental equipments [11]. This improves adoption of the 3d printing digital denture by young dental professionals.

6. CONCLUSION

3D printing dental prosthesis has the potential to reduce time taken in denture procedures, automate it, improve experience of dental technician and patient. 3D printing denture for dental treatments reduces cost, time taken for the treatment, and patient visits. Two 3d printing methods are especially focussed upon. First method is Fused deposition modeling and second method is digital light processing to print using photocurable material. This method has the potential to modernize dental workflow. We showed the 3d printing system, photocurable material composition, clinical performance and the future of this emerging technology for the dental industry.

REFERENCES

[1] Lee DJ, Saponaro PC. Management of edentulous patients. Dent Clin North Am. 2019;63(2):249–61.

[2] Schweiger J, Stumbaum J, Edelhoff D, Guth JF. Systematics and concepts for the digital production of complete dentures: risks and opportunities. Int J Comput Dent. 2018;21(1):41–56.

[3] Schweiger J, Stumbaum J, Edelhoff D, Guth JF. Systematics and concepts for the digital production of complete dentures: risks and opportunities. Int J Comput Dent. 2018;21(1):41–56.

[4] Barazanchi A, Li KC, Al-Amleh B, Lyons K, Waddell JN. Additive technology: update on current materials and applications in dentistry. J Prosthodont. 2017;26(2):156–63.

[5] Gao W, Zhang Y, Ramanujan D, Ramani K, Chen Y, Williams CB, et al. The status, challenges, and future of additive manufacturing in engineering.Comput Aided Des 2015;69:65-89.

[6] Groth C, Kravitz ND, Jones PE, Graham JW, Redmond WR. Three dimensional printing technology. J Clin Orthod 2014;48:475-85

[7] Osman RB, Alharbi N, Wismeijer D. Build angle: does it influence the accuracy of 3D-printed dental restorations using digital light-processing technology? Int J Prosthodont 2017;30:182-8.

[8] 40. AlHelal A, AlRumaih HS, Kattadiyil MT, Baba NZ, Goodacre CJ. Comparison of retention between maxillary milled and conventional denture bases: a clinical study. J Prosthet Dent. 2017;117(2):233–8.

[9] Srinivasan M, Schimmel M, Naharro M, O'Neill C, McKenna G, Muller F. CAD/CAM milled removable complete dentures: time and cost estimation study. J Dent. 2019;80:75–9.

[10] Bidra AS, Taylor TD, Agar JR. Computer-aided technology for fabricating complete dentures: systematic review of historical background, current status, and future perspectives. J Prosthet Dent. 2013;109(6):361–6.

[11] Kattadiyil MT, Jekki R, Goodacre CJ, Baba NZ. Comparison of treatment outcomes in digital and conventional complete removable dental prosthesis fabrications in a predoctoral setting. J Prosthet Dent. 2015;114(6):818–25.

[12] Mohseni M, Bastani S, Jannesari A (2014) Influence of silane structure on curing behavior and surface properties of sol–gel based UV-curable organic–inorganic hybrid coatings. Prog Org Coat 77:1191–1199

[13] Shohet IM, Lavy S (2004) Healthcare facilities management: state of the art review. Facilities 22:210–220

[14] Haritz Sardon, Timothy Long, Hortense Le Ferrand Sustainable Additive Manufacturing of Plastics. ACS Sustainable Chemistry & Engineering 2022, 10 (6) , 1983-1985

[15] A. Folch and M. Toner, Annu. Rev. Biomed. Eng., 2000, **2**, 227–256

[16] K. E. Sung, N. Yang, C. Pehlke, P. J. Keely, K. W. Eliceiri, A. Friedl and D. J. Beebe, Integr. Biol., 2011, **3**, 439–450

[17] T. Thorsen, S. J. Maerkl and S. R. Quake, Science, 2002, **298**, 580–584

[18] Vijayavenkataraman S, Yan W C, Lu W F, Wang C H and Fuh J Y H 2018 3D bioprinting of tissues and organs for regenerative medicine Adv. Drug Deliv. Rev. 132 296–332

[19] Wilson W C and Boland T 2003 Cell and organ printing 1: protein and cell printers Anat. Rec. A 272a 491–6

[20] Murphy S V and Atala A 2014 3D bioprinting of tissues and organs Nat. Biotechnol. 32 773–85

[21] Zafar, Muhammad Sohail. "Prosthodontic applications of polymethyl methacrylate (PMMA): An update." Polymers 12.10 (2020): 2299.

[22] Huang, Su. Improving polymethyl methacrylate resin using a novel nano-ceramic coating. Diss. University of Illinois at Chicago, 2017.

[23] Koshiba, Mitsunobu, et al. "Properties of ultra-violet curable polyurethane acrylates." Journal of Materials Science 17.5 (1982): 1447-1458.

[24]Krishnan, P. Santhana Gopala, Veen A. Choudhary, and I. K. Varma. "Current status of urethane (Meth) acrylate oligomers and polymers." Journal of Macromolecular Science, Part C: Polymer Reviews 33.2 (1993): 147-180.

[25]Nabeth, B., J. F. Gerard, and J. P. Pascault. "Dynamic mechanical properties of UV-curable polyurethane acrylate with various reactive diluents." Journal of applied polymer science 60.12 (1996): 2113-2123.

[26]Joskow, Renée, et al. "Exposure to bisphenol A from bis-glycidyl dimethacrylate–based dental sealants." The Journal of the American Dental Association 137.3 (2006): 353-362.

[27]Meereis, Carine TW, et al. "BAPO as an alternative photoinitiator for the radical polymerization of dental resins." Dental materials 30.9 (2014): 945-953.