# 3D Printing in the Dental Domain

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Edited by

Aditya Mohan Alwala,
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and Deepika Bandarupalli

Cambridge Scholars Publishing

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# FOREWORD

Dentistry has been facing many changes, including the digital revolution. Digitilsationin dentistry has influenced clinical procedures, work flows, and patients's comfort. 3D Printing is a miracle manufacturing technique. 3D Printing in dentistry is a novel topic and has is only recently embraced by undergraduates and postgraduates. A thorough understanding of theory and practical knowledge is essential to working on 3D printers. This book fills a gap in the high-level literature related to 3D Printing in dentistry. It can enhance the knowledge of 3D Printing techniques and their applications in the dental sciences. The reader will be able to gain clarity on 3D Printing concepts. I wish the authors good luck in their endeavor to instigate this book.

Dr. Shanthi Priya Reddy, MDS, Periodontist, Former HOD, Department of Periodontics, Syamala Reddy Dental College, Bangalore, **Author of a Textbook on Periodontics**, Consultant Periodontist with 25 years of experience at Manipal Hospitals, Bangalore.

I am delighted to present Dr. Vidya Hiranmayi's exceptional publication, titled "3D Printing in Dental Sciences." This comprehensive book serves as evidence of her steadfast commitment, vast knowledge, and relentless endeavors.

The field of dentistry is undergoing continuous evolution, and the emergence of 3D Printing technology has positioned us on the verge of a substantial paradigm shift. With a profound comprehension of dental science and the latest technological advancements, Dr. Hiranmayi has adeptly maneuvered through the swiftly evolving terrain, resulting in the creation of this handbook.

The profound dedication of Dr. Hiranmayi to the field of dentistry, coupled with her unwavering devotion to remaining abreast of cutting-edge technological breakthroughs, has resulted in the remarkable transformation of this exceptional work. This resource provides extensive knowledge and pragmatic guidance, making it an indispensable tool for dental professionals across several disciplines and general dental practitioners seeking to integrate 3D Printing.

What distinguishes this work is not only its technical proficiency but also its ease of comprehension. Dr. Hiranmayi's writing style adeptly integrates lucidity and profundity, hence facilitating comprehension of intricate ideas among readers hailing from dental disciplines. The author's capacity to deconstruct complex procedures into more manageable stages guarantees that anyone seeking to include 3D Printing in their dentistry practice will discover valuable insights within this literature.

I am confident that the publication titled "3D Printing in Dental Sciences" will serve as a reliable resource for anybody seeking to delve into the captivating realm of this particular discipline. This book offers valuable information and direction for both experienced specialists looking to improve their skills and general dentistry practitioners interested in integrating 3D Printing into their practice. It equips readers with the necessary knowledge and guidance.

This book, authored by Dr. Vidya Hiranmayi and other authors, exhibits a remarkable display of diligent efforts, unwavering commitment, and profound knowledge. Consequently, it emerges as an essential literary piece for individuals with a vested interest in the convergence of dentistry and 3D Printing

The author's remarkable contribution to our field is deserving of commendation, and I highly endorse this book for all dental professionals aspiring to embrace the future of dental practice.

-Lt Col. (Dr.) Saravanan SP., MDS, MPH, (PhD)

**GOLD MEDALIST, AFMC**

Assistant Professor

Department of Periodontology

Army Dental Centre (Research and Referral)

New Delhi, India, 110010

3D Printing has emerged from being a novel, occasionally used technology to one that has everyday practical applications. Dentistry has embraced this new technology with open arms, and in this book titled “3D Printing in Dental Sciences," Dr. Aditya introduces this very vast and diverse topic in an easy-to-use and practical manner. Dr. Aditya has conducted thorough studies and practical experimentation to investigate diverse implementations of 3D Printing within the field of dentistry. His work encompasses comprehensive elucidations and methodological guidelines that are readily understood by professionals at any point in their professional trajectory.

Dr. Aditya covers this topic comprehensively, from the history to techniques, materials, practical applications, and relevant software, in great detail. This comprehensive book encompasses various subjects essential for achieving proficiency in the field of new digital technologies, including digital impressions and prosthetic manufacturing. I am sure this book will allow many more dentists to consider this evolving field as a practical method to be used in everyday practice. I am certain that this book fills an important void in our understanding of 3D Printing in dentistry. I wish him and the other authors all the very best.

Dr. N. Viveka Vardhan Reddy

MDS, FDSRCS (Eng), FFDRCS (Ire), and DNB

Dean, Professor of Oral and Maxillofacial Surgery, The SVS Institute of Dental Sciences, Mahabubnagar, Telangana State, India

3D Printing is a miracle manufacturing technique and represents a huge opportunity. I hope this book on 3D Printing in dental sciences stands as a remarkable work that will be used as a handbook for both general dentists and specialists.

Dr. Chithra Chakravarthy, MDS, Professor, Dept. of Oral Surgery, Navodaya Dental College, Raichur, Karnataka, Director, Spark Centre for Advanced Dentistry, Hyderabad.

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गुरूब्रह्मागुरूविष्णु, गुरुदेवोमहेश्वरा

**Guru Bramha Guru Vishnu Guru Devo Maheswaraha.**

It would be incomplete without expressing our deepest gratitude to our mentors. Historically, Indian culture worships one's teacher as equal to God, if not more. From Adi Sankaracharya to Swami Vivekananda, the path of knowledge was paved and weaved by their respective teachers. The transfer of knowledge from guru to disciple has been the backbone of our cultural and educational foundation.

It would be incomplete without expressing my profound gratitude towards my beloved teacher, **Dr. Rajasekhar Gaddipati**, the one who held my hand and taught everything from basic extraction to complex surgeries. He is the mentor who initiated the spark of embracing new technologies and mastering them. This led me to explore new horizons, expand my goal posts, and enter the field of additive manufacturing or 3D Printing.

It is a rare quality for a person to be good at many things in distinctive proportions. I think the key to all the above is a blend of **discipline and passion**, for which he is known. It is his passion for the specialty MAX FACE; academics made him commute a long distance for many years to carve out the best future for his students.

A pen might be mightier than a sword in general, but for a surgeon, the sword is the scale. The swiftness and fineness of using scalpels boldly and efficiently for treating patients is an art that he perpetuated for his students. The mighty pen of mine here falls short of his skills in using the sword (scalpel). I take this opportunity to **pen down** my thoughts for teaching me how to wield a "sword "as gracefully as a pen.

It is a great pleasure to express my deepest thanks to **Dr. N. Sleeva Raju**, Principal, St. Josephs Dental College; Dr. Nanda Gopal Vura, my mentor; and **Dr. Chandrakantha Rao,** Senior Oral and Maxillofacial Surgeon, Hyderabad, for their professional and personal support in Dr. Aditya's life.

Dr. Vidya Hiranmayi would like to express her immense gratitude to her mentors, **Dr. Ramoji Rao, M.V.**, Principal and HOD, SIDS, Vijayawada, **Dr. Sirisha Reddy, Dr. Bhagya Lakshmi Gopalan, and Dr. Divya Bhat, for their constant motivation and unwavering support.**

The authors would also like to extend their gratitude to Dr. Haritha Siripuram and Dr. Bharath Uppaluru, oral surgeons, and Mr. Ravi Kumar, computer engineer, for helping them shape this book.

# PREFACE

3D Printing is a rapidly evolving technology that has had a massive impact on different streams ranging from technology, manufacturing, automobiles, medicine, and many more. In fact, it revolutionised how things got manufactured, and the time, effort, and cost it took were considerably less compared to the traditional methods and are still evolving.

In the medical sector, 3D Printing technology is offering a wide variety of scopes in treatment planning and reconstruction of sectioned body parts with precision. It is offering considerable help in both forensics and pathology, too.

The applications of 3D Printing are adopted in numerous treatment strategies in dentistry, starting from oral medicine to endodontics, oral surgery, pedodontics, periodontics, orthodontics, and so on.

Through this book, we tried our best to enhance your knowledge of 3D Printing. This book encompasses details about its history, the process of manufacturing, the materials used by 3D printers, and the applications of 3D Printing in different sectors, with a special emphasis on its applications in the field of dentistry.

# INDIGENOUS SCIENCE

The dawn of Homo sapiens began somewhere in African savannahs 70 thousand years ago. Since then we have been fascinated about inventions, be it taming the fire or sculpting the tools for hunt or invention of wheel, if we are passionate about a single thing that is engineering.

It is a common misconception that early Sapiens were only barbarians and that we have evolved to be intelligent but the average 5 year old in the Eurasian steppes is as intelligent as today's kids. It's just that due to the invention of language especially writing systems such as clay tablets that the human beings have been instrumental in bringing libraries together. When this was coupled with the globalisation of paper knowledge it exploded like compound interest in other words we are sitting on the shoulders of knowledge giants and watching the dawn of a new age.

History has many civilisations which grew gloriously and crumbled down due to the wrath of nature or co sapiens. A few such ancient civilisations were Sumerian, Egyptian, and Indus valley. While Sumerians and Egyptians have been buried under the Middle East deserts with only artefacts surviving, Indus valley and Chinese are the only surviving continuous inhabitants via literature, thanks to Indus valley culture and language Mesopotamian culture being revived and interpreted via IVC and Sanskrit, since the Avesta and Sumerian languages no longer survives.

Be it the bronze cave paintings or the late ice age lion man ivory sculpture 32000 years ago, sapiens always have that itch to leave their mark behind probably the same ability has led us tobuild the pyramids of Egypt and clay tablets of Mesopotamia (artefacts) Vedas of IVC (language), and pottery and silk of China (rise of permanent essentials).

We as Indians have a glory of being one of the only two surviving ancient civilisations and the engineering marvels created by our ancestors in every stage of history (prehistoric, ancient, medieval) while the Eurasians are still adhering to the nomadic cultures.

So, let us embrace and witness the engineered glory of the past and scope of our future within the next chapters of this book.

# CHAPTER 1

# INTRODUCTION

## 1. Introduction

3D Printing or digital fabrication technology creates a physical object by geometric representation of objects through a digital file by successive addition of material.3D Printing is the opposite of subtractive manufacturing which is cutting out / hollowing out a piece of metal or plastic. This method produces complex structures more efficiently using less material than traditional manufacturing. It’s been the biggest advantage of 3D Printing because of its ability to make custom products which opened a wide variety of opportunities in many fields.

It starts with a 3D model, which you can create yourself or download from a 3D repository. When creating it yourself you can choose to use a 3D scanner, app, haptic device, code, or 3D modelling software and there are many different 3D modelling software tools available.

At present 3D Printing is at its tipping point, about to go into the mainstream in a big way.3D Printing is beginning in the manufacturing industry and it may offer many benefits to the people’s companies and government. And now 3D Printing is hailed to change manufacturing (Figure 1).

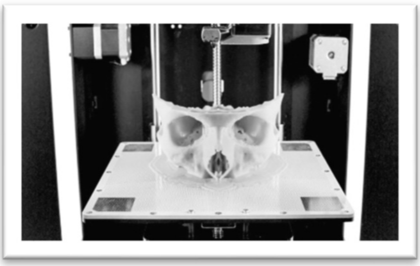

Figure 1: 3D Printing Machine

## 1.1 History

The history of 3D Printing is important to understand the future of manufacturing as this technology becomes more popular and more available to the public.

The earliest record of 3D Printing through the additive process was the Japanese inventor Hideo Kodama in 1981 (Figure 2). He created a product that used ultraviolet lights to harden polymers and create solid objects. This is a stepping stone to stereolithography (SLA).

Figure 2: Hideo Kodama

Charles Hull, an American Engineer, developed the world's first working 3-D printer in 1984[1](Figure 3). He invented stereolithography, a process similar to 3D Printing that uses technology to create smaller versions of objects so they can be tested before spending time and money on creating the actual product. The object is printed layer by layer, rinsed with a solvent, and hardened with an ultraviolet light. The process uses computer-aided designs (CAD) to create the 3D models. The first product he designed was an eye wash.

Figure 3: Charles Hull

Selective Laser Sintering (SLS) is another, more advanced, form of 3D Printing. It uses additive manufacturing and a powder polymer—typically nylon—to create objects. SLS uses a laser to fuse the powder, layer by layer, into more complex shapes than SLA is capable of creating.

Fused Deposition Modelling (FDM), developed by Scott Crump, is the most common form of 3D Printing today. It is known as "desktop 3D Printing" because it is the most commonly used form of the technology. To form an object, the printer heats a cable of thermoplastic into liquid form and extrudes it layer by layer.

In 1999, the first 3D-printed organ was implanted into a human. Scientists at the Wake Forest Institute for Regenerative Medicine printed synthetic scaffolds of a human bladder and then coated them with the cells of human patients. The newly generated tissue was then implanted into the patients, with little to no chance that their immune systems would reject them, as they were made of their own cells.

Designers are no longer limited to printing with plastic. Beyond jewellery and aircraft, 3D Printing is now being used to manufacture affordable housing for the developing world. Visionaries have begun to employ the technology to print everything from smart robotic arms to bone replacements and even particles just a few atoms thick (which could result in even smaller electronics and batteries).

Overall 3D Printing has changed and improved over the past thirty years. SLA, SLS, and FDM show the history of 3D Printing, and thus how it became a vital tool for manufacturing. It allows you to make virtually anything simply by creating a computer file.

**Regularization**

All the 3D-printed products are categorised as custom-made devices under Regulation (EU) 2017/745 of the European Parliament and of the Council of 5 April 2017. They are defined as follows: "*any device specifically made in accordance with a written prescription of any person authorized by national law by virtue of that person's professional qualifications which gives, under that person's responsibility, specific design characteristics, and is intended for the sole use of a particular patient exclusively to meet their individual conditions and needs*". Differently for mass-produced devices "*which need to be adapted to meet the specific requirements of any professional user and devices which are* *mass-produced by means of industrial manufacturing processes in accordance with the written prescriptions of any authorized person shall not be considered to be custom-made devices*" [Regulation (EU) 2017/745 of the European Parliament and of the Council of 5 April 2017 on medical devices, amending Directive 2001/83/EC, Regulation (EC) No 178/2002 and regulation (EC) No 1223/2009 and repealing Council Directive 90/985/EEC and 93/42/EEC.2.Article 2, Comma 3 of the Regulation (EU) 2017/745.[2]

## 1.2 Types of 3D Printing

At present a variety of 3D Printing technologies have been developed based on different applications. According to ASTM standards F2792 [3] it catalogued 3D printing into 7 different types.

They are:

1.2.1) Binding Jetting

1.2.2) Direct Energy Deposition

1.2.3) Material Extrusion

1.2.4) Material Jetting

1.2.5) Powdered Bed Fusion

1.2.6) Sheet Lamination

1.2.7) Vat polymerisation

1.2.8) Inkjet printing and contour crafting

1.2.9) RAFT polymerisation

### 1.2.1) Binding Jet Polymerisation

It is a rapid prototyping and 3D Printing process in which powder particles are joined by selective deposition of liquid binding agent. Through this binder jetting technology, a layer is formed by using a jet chemical binder onto the spread powder. the application of binder jetting produces casting patterns, raw sintered products, or similar large-volume products from sand. This can print a variety of materials including metals, sands, polymers, hybrids, and ceramics. The process of this is simple, fast, and cheap as powder particles are glued together. Lastly, binder jetting also has the ability to print very large products.

## 1.2.2) Directed Energy Deposition

Directed energy deposition is one of the more complex printing processes commonly used to repair or add additional material to existing components[5] as it has a high degree of control of grain structure, directed energy deposition can produce a good quality of the object. The process of directed energy deposition is similar in principle to material extrusion, but the nozzle is not fixed to a specific axis and can move in multiple directions. This process can further be used with ceramics and polymers but is typically used with metals and metal-based hybrids, in the form of either wire or powder. Examples of this technology are laser deposition and laser-engineered net shaping (LENS).[5] Laser deposition is an emerging technology and can be used to produce or repair parts measured in millimeters to meters. Laser deposition technology is gaining attraction in the tooling, transportation, aerospace, and oil and gas sectors because it can provide scalability and diverse capabilities in a single system.[6] LENS can exploit thermal energy for melting during the casting and parts are accomplished subsequently.[7] (Figure 4)

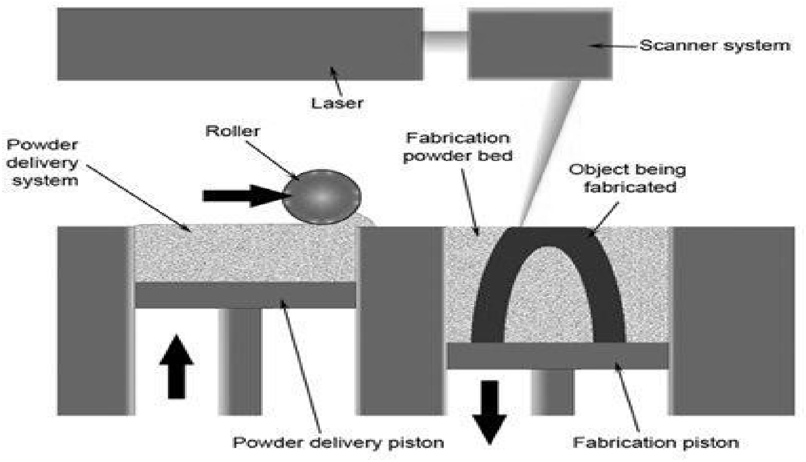


Figure 4: Direct Metal Laser Sintering.

## 1.2.3) Material Extrusion

This 3D Printing technology can be used to print multi-materials and multi-colour printing of plastics, food, or living cells.[8] This is a widely used procedure that can be done at a very low cost and can also build fully functional parts of a product. [5] Fused Deposition Modelling (FDM) is the first example of a material extrusion system. FDM was developed in early 1990 and uses polymer as the main material[9]. FDM builds parts layer-by-layer from the bottom to the top by heating and extruding thermoplastic filament (Figure 5). The operations of FDM are as follows:

I. Thermoplastic heat to a semi-liquid state and deposited in ultra-fine beads along the extrusion path.[10]

II. Where support or buffering is needed, the 3D printer deposits a removable material that acts as scaffolding. For example, FDM uses hard plastic material during the process to produce a 3D bone model.[10]

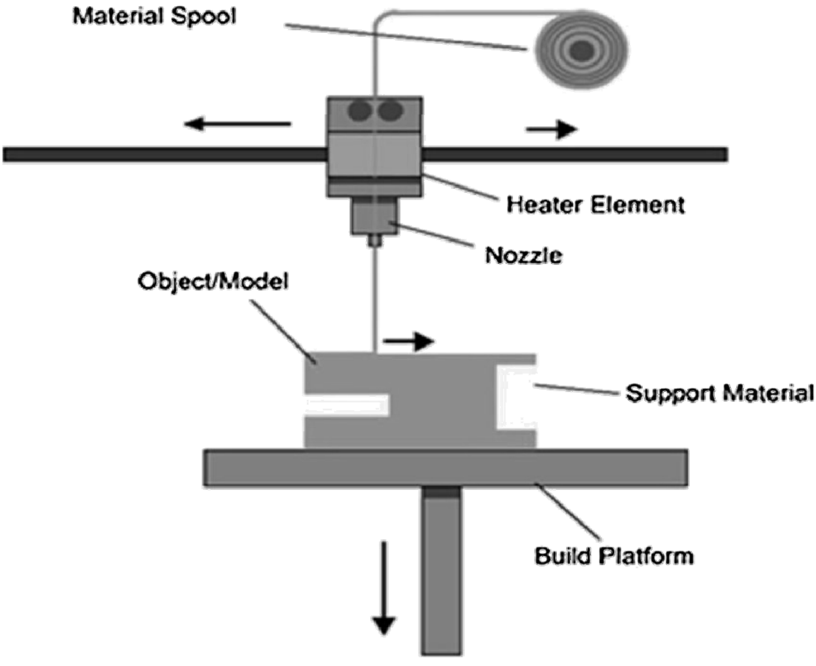


Figure 5: Fused Deposition Modelling.

## 1.2.4) Material Jetting

As per ASTM Standards, this is a 3D Printing process in which drop-by-drop building material is selectively deposited. A photosensitive material that solidifies the print head is dispensed as droplets by this material jetting and building a part layer-by-layer under ultraviolet (UV) light. [11] At the same time, material jetting creates parts with a very smooth surface finish and high dimensional accuracy. Multi-material printing and a wide range of materials such as polymers, ceramics, composites, biological, and hybrid are available in this material jetting.[5]

## 1.2.5) Powder Bed Fusion

The powder bed fusion process includes electron beam melting (EBM), selective heat sintering (SHS), and selective laser sintering (SLS) printing techniques. This method either uses an electron beam or laser to melt or fuse the material powder. and Examples of the materials used in this process are metals, ceramics, polymers, composite, and hybrid. Selective laser sintering (SLS) is the main example of powder-based 3D Printing technology. Carl Deckard developed SLS technology in 1987. SLS is 3D Printing technology that functions at a fast speed, has high accuracy, and varies surface finish [12]. SLS used a high-power laser to sinter polymer powders to generate a 3D product (Figure 6). Meanwhile, SHS technology is another part of 3D Printing technology that uses a head thermal print in the process to melt the thermoplastic powder to create a 3D printed object. Lastly, the material is heated up by the energy source electron beam melting. [13]

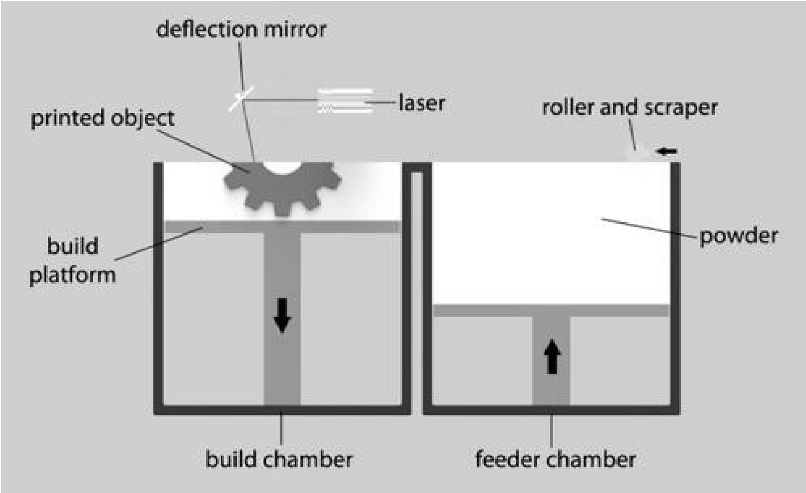


Figure 6: Selective Laser Sintering.

### 1.2.6) Sheet Lamination

Sheet lamination is the 3D Printing process in which sheets of materials are bound together to produce a part of an object. [11] Laminated object manufacturing (LOM) and ultrasound additive manufacturing (UAM) are the few examples that use this technology. They can do full-colour prints, are relatively inexpensive, and offer easy handling and recyclability of the material. Laminated object manufacturing (LOM) is capable of manufacturing complicated geometrical parts with lower cost of fabrication and less operational time.[14] Ultrasound additive manufacturing (UAM) is an innovative process technology that uses sound to merge layers of metal drawn from featureless foil stock.[9]

### 1.2.7) Vat polymerisation

The main 3D Printing technique that is frequently used is photo-polymerisation, which in general refers to the laser, light, or ultraviolet (UV) curing of photo-reactive polymers by the example of 3D Printing technologies by using photo polymerisation methods such as stereolithography (SLA) and digital light processing (DLP). In the SLA, it was influenced by the photoinitiator and the irradiated exposure to conditions as well as any dyes, pigments, or other added UV absorbers.