UNVEILING THE POTENTIAL OF ADDITIVE MANUFACTURING IN DENTISTRY

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Abstract

Technological developments in dentistry have increased diagnosis precision, facilitated treatment administration, and shortened chair times, enabling dentists to handle patients more successfully. This article presents in a unified way the evolution and current scenario of various resin 3D printing techniques, and their application in various sectors from education to health care sectors. The article briefly describes the most preferred resin 3D printing techniques used for printing novel and conventional resin materials including ecofriendly and biomaterials, mainly (i) stereolithography, (ii) digital light processing, (iii) continuous digital light processing, and (iv) liquid crystal display. A dentist may now see, precisely measure, gather data, and fabricate prototypes of both soft and hard tissue by using different types of rapid prototyping techniques including filament, resin, and metal based 3D printing. Every technology has unique benefits when it comes to produce a certain kind of product. The most often utilized technologies in dentistry are vat polymerization based techniques. The applications in the dental sector comprise crowns, bridges, occlusal splints, retainers, implants, drill guides, and other oral restorations. In pursuant to these goals, the paper will deliver useful information and make a prominent contribution to the plight of knowledge in the area of additive manufacturing.

Keywords: 3D Printing, Stereolithography, Computer Aided Designing, Digital light processing, dentistry.

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1. Introduction

With the use of design software, additive manufacturing offers a combination of materials for producing an object from a 3D data model [1]. These consist of MRIs, dental implants, foreign bodies, etc. AM has recently received a lot of attention as a promising technology for creating intricate 3-Dimensional (3D) constructions. The rapid image generation of several images and instantaneously blending all images to create a full 3D-based digital model are important functions of 3-dimensional scanners (3D printers) [2–3]. Layer-by-layer automated deposition of materials or biological substances served as substrates by AM allows for the fabrication of 3D structures [4, 5]. The patient-specific product or critical bodily part is created from scratch using AM technology. During surgery, the medical professionals require a good picture of the components being operated on. The data is subsequently translated into a Standard Tessellation Language (STL) format after the virtual model is finished because this format is used for machine-based rapid prototyping. This method helps to save time and money while producing an optimal match for the implant. Currently, AM is heavily used in medical and health science disciplines, including the photographic printing of medical models and creating custom biomaterials. Rapid technology is one of the best ways to create 3D models using different biomaterials and other materials that are used for different medical applications, such as the creation of new orthopedic-based products and a modified model of the maxillo-facial prosthesis that also retains appropriate relevance in the field of dentistry [6]. In addition to creating models for the medical industry, additive manufacturing is being utilized to create building components [7]. Additive manufacturing significantly altered the manufacturing process and was crucial to the development of new products. During quick product development and ultimate product development, AM aids in lowering capital expenses [8]. The manufacturing sector initially utilized AM only to increase the output of prototype mechanical parts, but it has since expanded into the medical industry. AM is currently used in the medical industry to create prototype models for prosthetics, dentistry, operation practice, and many other things [9]. Different fabricating sectors can quickly adopt AM by defining it through products and changes to the supply chain [10]. Illustrated manufacturing sectors are prepared to employ additive manufacturing (AM) technologies to increase customer satisfaction, but they are not seeking a radical transformation of their products, services, or supply chains. It also appears that the items manufactured by AM define new business events that satisfy the client and profit the company. Examples include the creation of medical equipment and artificial limbs. Demonstrates how several approaches have been altered by using AM-based technology to create the new product. Electronic systems with embedded components serve as examples [11]. Identifies the manufacturing sectors whose business models, in terms of their products and such products, are based on emerging AM technologies illustration of a 3D-printed glass frame for a customer [12].

In the modern era, dental labs are progressively incorporating digital processes, including CAD/CAM, 3D scanning, and additive manufacturing technologies. The 3D scanner captures the unique data and converts it into a functionally editable/printable 3D digital CAD file. The created 3D digital CAD file is directly converted to a 3D solid object using Additive manufacturing technologies. It has been widely used in dentistry for manufacturing dentistry models such as drill guides for dental implants [13, 14]. It can also help the dentist and improve communication with patients by capturing dental anatomy data by projecting light on teeth, dental implants, and arches [15, 16]. For customized treatment, they require clear and concise dental anatomy during surgery. 3D scanners are the most time and cost-efficient automatic 3D acquisition models which can convert 3D digital CAD files into 3D objects with affordable cost, ease of use, and high accuracy. The accuracy of 3D digital scanned files depends upon camera resolution [13, 17]. It has been widely used for inspection and reverse engineering as it requires less time for 3D digital image capturing [18-21]. This technology can be used to reconstruct and visualize complex human body parts like bones, prosthetics, and orthotics [19-23].

*1.1 **Recent study in field of dentistry using additive manufacturing***

The development of 3D technology has resulted in important breakthroughs in various fields, including the automotive, medical, and military industries. Traditional methods are progressively being superseded by digital fabrication and design procedures in the field of medical applications. Hollow, tiny, complicated, and sophisticated sculptures may be made with this method with astounding precision and accuracy while yet being reasonably priced [24, 25]. The no. of publication for last 15 years were searched in the database of PubMed and ScienceDirect by using the keywords (3d printing) AND (Dentistry). The results are plotted in form of bar graph in the Fig. 1. The results indicated that the number of publication in this area are increasing abruptly every year. As the year of 2023 is still going on and the number of publication has reached almost near to the year 2022.

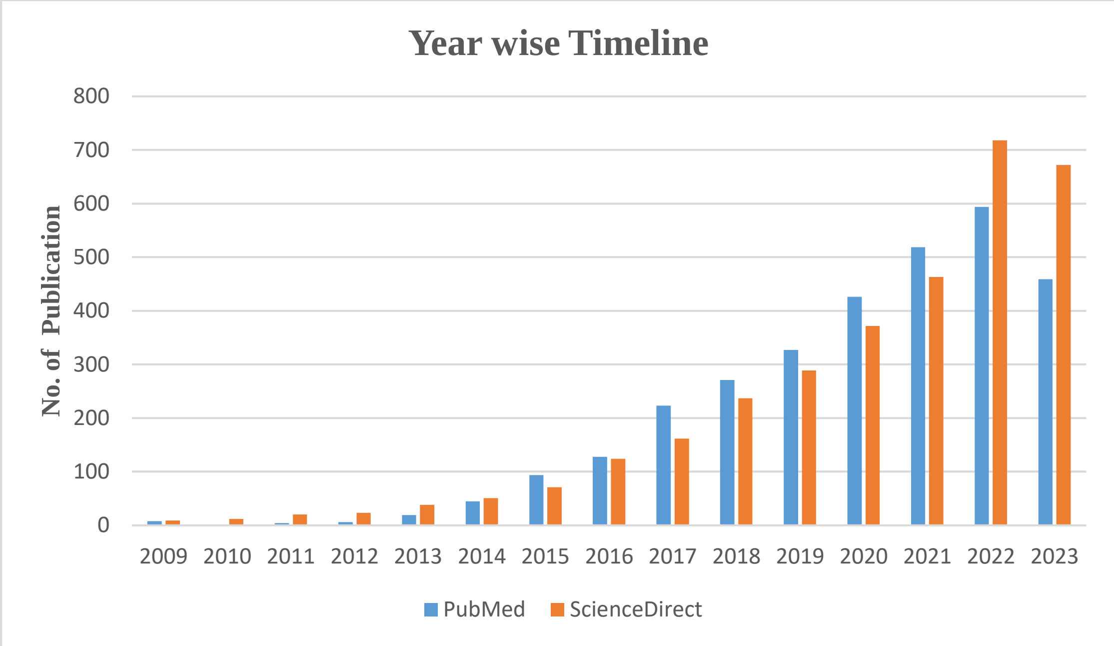

Fig. 1: Year-wise timeline results of ScienceDirect and PubMed with keywords [(3d printing) AND (dentistry)]

1.2 Need of the study

There is a need to understand the various types, pros, and cons of additive manufacturing, as it has revolutionized the manufacturing processes by enabling the fabrication of complex and customized objects. By studying the different types, their workflow, and the benefits of these technologies, researchers can explore their applications in dentistry, leading to advancements in dental fabrication and diagnostics. Understanding the steps involved in creating and applying these technologies, specifically in dentistry, can provide insights into optimizing the workflow and ensuring high-quality outcomes. Researchers need to study the various types of materials used in dental applications for the selection of appropriate materials, taking into account their mechanical properties, biocompatibility, aesthetics, and durability. This research will provide valuable insights into addressing these challenges and exploring potential solutions to enhance dental care delivery. Overall, conducting research on this topic is essential to advance dental technology, improve patient care, optimize processes, and find innovative solutions to the challenges faced in dentistry.

2. Additive Manufacturing

Various technologies are used to build products layer by layer and obtain data from CAD models, with the help of 3D scanners, MRI, CT, and other designing software. Stereolithography (SLA) is a technique in which products are formed with the application of UV laser in vat resin. It provides lesser wastage with a better surface finish and is limited to light-sensitive polymers [26, 27]. Direct metal laser sintering (DMLS) is the technique in which a laser beam is used to fuse powder, and metal is added layer by layer. It provides better mechanical strength with high accuracy [28, 29]. Selective laser sintering (SLS) is the technology in which powder sintering is done with the help of a laser beam, and powder is used as a raw material [30, 31]. Laminated object manufacturing (LOM) is a technique in which a defined sheet of materials is added layer by layer in order to fabricate 3D models. Sheet materials are cut with the help of a laser beam, while adhesives are used to combine layers [32, 33]. Fused deposition modeling (FDM) is similar to the extrusion process, in which models are fabricated with heated thermoplastic material. In this process, multi-nozzle and different types of materials can be extruded simultaneously [34, 35]. Inkjet 3D printing (IJP) is the technique in which different fluids are used to build a product layer by layer with less cost and time [36, 37]. Electron Beam melting (EBM) is the technology in which a metal powder product is built with a powerful electron beam with exact geometry [38, 39].

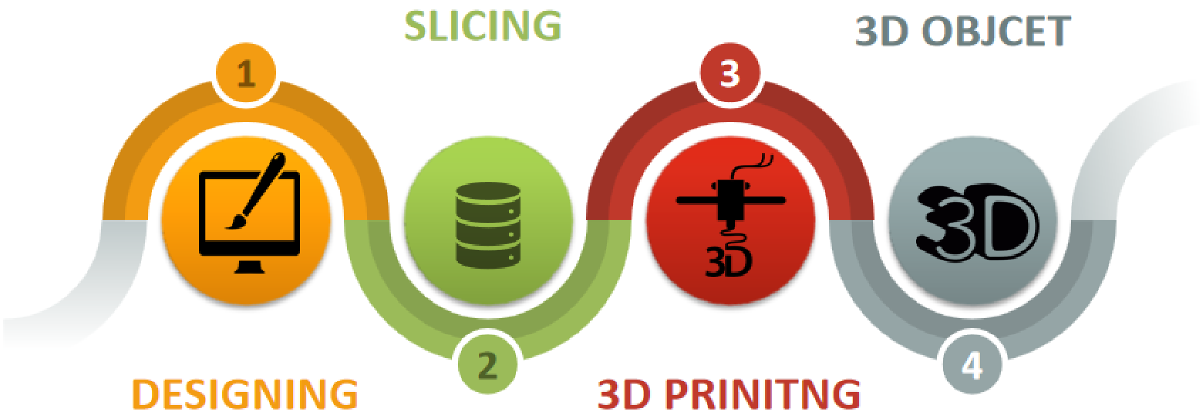

Fig. 2: Fabrication process of a 3D model.

The 3D model provides an accurate perception of patient anatomy to surgeons and dentists using AM. Figure 2 depicts the fabrication process of a 3D object by using additive manufacturing. Specific patient Implants are created with geometric freedom to solve challenges in dentistry. The following are the various benefits of Additive manufacturing in dentistry:

- Cost-effective with lesser fabrication time
- Accurate sizing for implants
- Reduction of inventory with its digital storage
- Determining the geometry of teeth
- High accuracy
- Highly customized implants
- Rapidly produce custom design

3. Resin 3D printing and its classification

3D printing also known as rapid prototyping is classified into seven types as per the standards of ISO/ASTM 52900:2015 AM based on their general principles as shown in figure 3 [40]. All of these methods of AM are different from each other based on their fabrication process, principle, type of material intake, and power used [41]. The method from which the 3D printing processes begins was vat polymerization [42]. This section of this article is all about resin 3D printing or vat polymerization.

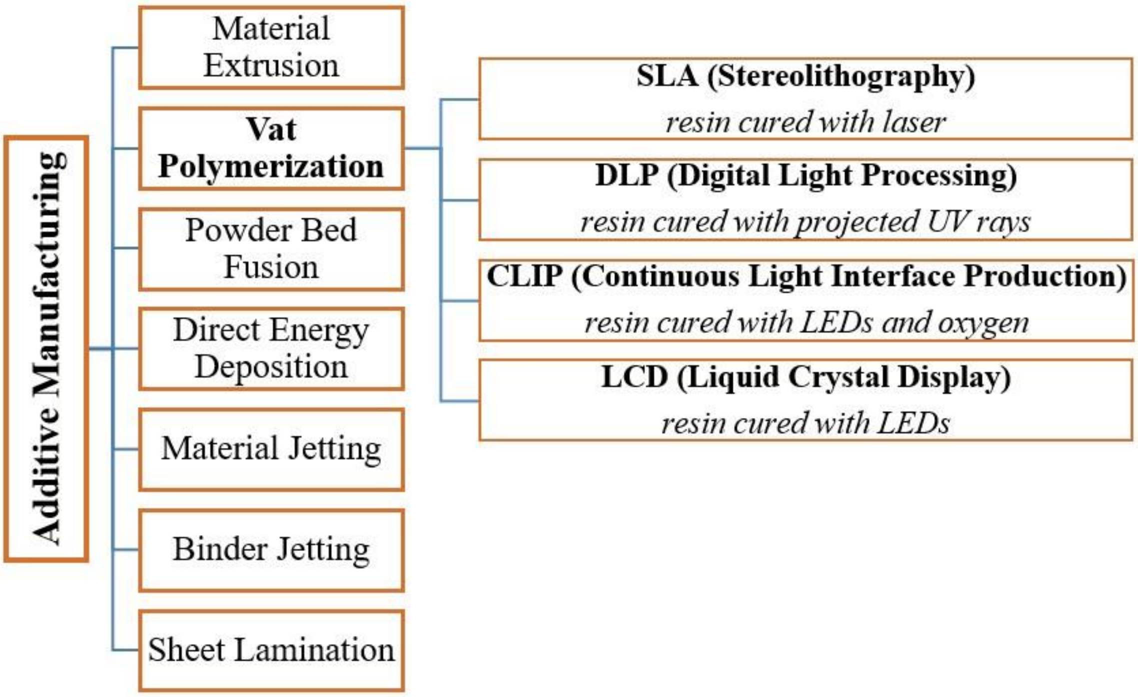

Fig. 3: Classification of AM techniques based on ISO/ASTM 52900: 2015 AM – General Principles and types of vat polymerization.

3.1 Stereolithography

In SLA 3D printing technology, the laser beam is used to make the 3D model which is sliced into layers [43]. The build plate is dipped into photo curable resin and the laser beam travels on the coded path for fabricating a single layer. When single is layer is formed, the build plate moves in upward or downward direction depending on the SLA which is being used, either it classic SLA or reverse SLA. In classic SLA, the laser beam comes from upper direction, so the build plate will move downwards and the inverse in case of reverse SLA. The process continues layer by layer until the formation of complete product [44,45]. The layer thickness may vary from 12 to 150 micron in SLA 3D printing technology. The dimensional accuracy of the printed parts from SLA depends on the spot size of laser beam. Smaller the spot size (diameter of laser beam), higher will be the accuracy [46]. The principle of SLA 3D printing is shown in figure 4(a).

3.2 Digital Light Processing

In DLP 3D printing technology, the projector is used as light source to cure the photo curable resin. The projector projects UV radiation of specific wavelength (365-405 nm) on the photo curable resin through DMDs (Digital micro devices) [47]. The DMDs are the micro devices which are having capabilities to tilt as per ordered guidance from the coded printable file so that the UV rays will fall on the entire layer [48]. Digital Light Processing (DLP) is more rapid than SLA because every single layer is completely exposed to the curing light beamed from the DMDs. The accuracy of the printed item is highly dependent on the projector's resolution because each layer needs to seem pixelated [49,50]. The DLP 3D printing technique is depicted in figure 4(b).

3.3 CLIP/CDLP

The CLIP 3D printing technology is the modification of the DLP technique. It is also known as continuous digital light processing (CDLP) 3D printing technique [51]. In this method, the projector light is assisted with oxygen permeable window to form a dead zone to enhance the accuracy and reduce the peeling effect. In this technique, the resin is permitted to flow in the dead zone (region between the window and the fabricated part). So, the fabricated part does not stick the window resulting in less separation force and high resolution printing [52,53].

3.4 LCD 3D Printing

In the LCD 3D printing technology, a number of LEDs (liquid crystal display) are used to project the UV rays on the photo curable resin directly. Not any mirrors or DMDs are used in this technology [54]. The printing process is similar to the DLP technique. The printing quality of this fabrication method depends on the resolution of the LED screen. The 3D printers working on this technique comes with 2K, 4K, 6K, 8K, and etc. resolution system. Higher is the resolution of the printer, higher will be the accuracy of the printed parts [55,56].

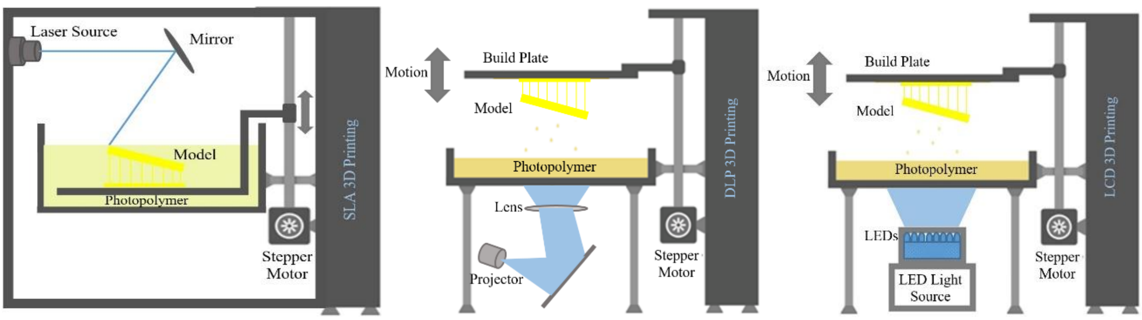

Fig. 4: Vat polymerization classification (a) SLA, (b) DLP, and (c) LCD 3D printing techniques.

4. Major application of resin 3D printing in dentistry

Resin 3D printing, also known as vat polymerization has several major applications in dentistry due to its high precision and ability to produce detailed, custom objects. In the dental sector, 3D printing is a technique that permits the manufacture of components that are tailored to the demands and specific shape dimensions of every person [57,58]. Some significant applications include:

4.1 Dental models

Resin 3D printing transforms dental workplaces into places where the accurate manufacturing of dental models, crowns, bridges, and other prosthetics is possible [59]. Dental practitioners can make patient-specific prostheses (tailored to the individual anatomy of the patient), that will make them more comfortable to wear and functional. Through the implementation of digital making and designing of dental structures, resin 3D printing avoids errors compared to the traditional methods where the manual approach is the norm [60,61]. Dentists will also be able to develop digital models from these object scans for treatment planning purposes and patient communication that will translate to an improved dental experience. Moreover, resin 3D printing simplifies the workflow in dental laboratories, since it enables technicians to produce replicas of high precision and quickly with consistent results [62].

4.2 Surgical Guides

Resin 3D printing performs one of the most important tasks of the making of surgical guides used in the dental implant treatments. implants are implanted with the help of radigation guidance, which can be customized based on digital imaging data of the patient’s anatomical features. So planning and implemention are more precise [63,64]. 3D resin printer is designed to transform virtual treatment plans into real-life aids that help in the precise placement of dental implants, which is inherently needed for obtaining the correct functional and aesthetical results. Custom surgical guides improve safety during implantation, prevents damage to nearby tissues, and guarantees a flawless procedure, saving both time and resources. The technology of resin 3d printing allows creating surgical guides, which are individualized in his regard for patients' unique anatomy, with which the results of the treatment improve for patients and their satisfaction [65,66].

4.3 Temporary Crowns and Bridges

Resin 3D printing has become, not only fast but also cost-effective when it comes to the manufacturing of inexpensive, but also durable provisional crowns and bridges for dentistry practice [67]. These resins not only safeguards the teeth from cracking; but they also ensure proper occlusion, which in turn creates the exact replacement for subsequent restoration from the dental laboratory. With the 3D resin printing technology, dental professionals have now the opportunity to develop custom-made temporary caps and bridges that are specially made to fit each patient accurately [68,69]. The establishment of in-house temporary restorations is a huge time and resource saver, putting patients on the track to the therapy shortly after a dental emergency and preserving teeth while waiting for a permanent solution. Also resin-based material presents very aesthetic and durable solution. In such case, the temporary crown as well as temporary bridge will serve as good dentures and aesthetics until permanent restorations can be made [70].

4.4 Orthodontic Aligners

Resin 3D printing has given orthodontists the ability to make day long whooper aligners for teeth straightening, which results in a mass production. Recent trend in using clear aligners has been to provide patients with an inconspicuous and pleasant experience that significantly boosts their confidence and comfort in comparison to the classic braces [71]. The resin 3D printing technology enables orthodontists to develop aligners that can be minutely adjusted for each fresh patient's general dental misadjustment. With the help of the scans of the teeth, the orthodontist traces a path of movement for the teeth, which leads to the final position. This kind of a material provides optimum required flexibility and clarity to fabricate thin and clear aligners which are extremely convenient to put on and even more, they are virtually invisible yet can be worn very comfortably. By using resin 3D printing dentists can be able to create whim aligners at their dental offices hence they reduce the lead times and the patients get their teeth treated elegantly [72-74].

4.5 Prosthodontics

The introduction of resin 3D printing has brought about considerable changes in the prosthodontic field; this method offers a variety of different possibilities for cost-effective manufacturing of dental prostheses. It may be crowns, bridges, veneers, or dentures, but 3D interpretation of resins enables the manufacturing of individual restoration furnished with the highest accuracy and esthetics [75]. 3D resin-based printers can be used in dental laboratories and clinics to make perfectly matching prosthetic restorations which keep within the contour or morphology of the patient’s original dentition, thus, enabling the fit and function consistency is ensured. The digital workflow allowed by the resin 3D printer enables fast and cheap prosthetic fabrication that leads to quick turnaround times and less labor workmen to spend. In addition, resin-based materials provide high biocompatibility and durability properties, and, given that, prosthetic restorations are resistant to wear and can give the patients long term performance satisfaction [76].

4.6 Educational Models

Anatomic Resin 3D Printing is an irreplaceable professional tool for dental teaching since it can fabricate high-quality models for demonstrating the anatomy [77]. Dental schools and institutions conduct trainings by applying the resin-based 3D printers which allow for the reproduction of realistic oral cavity models with exceptional accuracy and complexity. The models give the learners real physical objects to build the knowledge of dental structures and procedures as though they were three-dimensional, therefore, their understanding of anatomy, pathology as well as treatment techniques are improved. 3D printing with resin enables the making of unique educational models that are adapted to the needs of the user [78]. The models help the students better grasp and memorize anatomical features by providing them with a practical experience in a setting that mimics a clinic. Educational institutions can integrate 3D printing into their dental learning and increase the quality of instruction, in response to this, students can be easily trained efficiently for the dental practice [79]. Besides that, resin 3D printing allows for the sophistication of the development of a patient-oriented model that features case studies and interprofessional collaborations thereby advancing the approach to patient cases by incorporating the entire dentistry chain [80].

5. Conclusion

The 3D printing industry has taken the lead position and is having a significant influence in all areas. It makes it possible to generate a complicated geometric shape using a range of materials based on digital data collected from individual patients. It is already being used effectively in patient care by fabricating models of dental restoration as the 3D data is can be collected easily, thanks to the growing usage of intra-oral scanning systems. The use of a 3D printed anatomical model is becoming more important in craniofacial and implant surgery since it assists in the treatment planning of difficult operations. With the use of surgical guides created from resins, it is a commonly held belief that the operation will be less intrusive, as well as more predictable and accurate in its results. Even if three-dimensional printing is growing more in the present, there are still areas of worry about the cost of operating the machines, the cost of the materials utilized, and the cost of maintaining the equipment. It is important to take into consideration the high demand for operators who have received enough training, as well as post-processing and adherence to stringent health and safety procedures. It is essential for the dentist to stay abreast of any developments in dental technology since the field is always advancing, and these developments might one day be of use to both the patient and the doctor. The advent of additive manufacturing as a potentially useful technology, along with the natural inquisitiveness and inventiveness of dental professionals, makes this an exceptionally exciting moment to work in the sector.

Declaration of interests

The author(s) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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