Power System Technology
ISSN:1000-3673

Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

3D Printing in Prosthetics and Dental Restorations: A Comparative Study

Manal Duraya Alanazi[1]*, Ebtesam Husain Alharthi[2], AlBandari Ayedh AlMutairi[3], Mai Saad Alsubaie[4], Aisha Yahya Al Shajri[5] and Safiah Abdulmohsen Ali Jawsh[6]

[1] Corresponding Author, Dental Assistant, manal-d12@hotmail.com, King Abdullah University hospital

[2] Dental Assistant, ehalharthi@outlook.sa, King Abdullah University hospital

[3] Dental Assistant, aaalmotairi@pnu.edu.sa, King Abdullah University hospital

[4] Dental Assistant, Mayortho7@gmail.com, King Abdullah University hospital

[5] Dental Assistant, a3yoosh1@icloud.com, King Abdullah University hospital

[6] Dental Assistant, safyah1919@gmail.com,

Abstract

Objective: To evaluate 3D printing technologies available for the production of prostheses and dental restorations. A secondary objective is to compare the accuracy of impressions taken with intraoral scanners to traditional methods. Data Sources: An electronic search of the database using the combination of the terms "3D printing prosthesis" and "3D printing dental restoration" was conducted. Data Extraction: Reports of studies performing impression acquisitions, fabrication of prosthetic components, or restorations using 3D printing technologies were included. Studies not reporting adequate details were excluded. A qualitative analysis of the selected studies was performed by two independent observers. A secondary quantitative analysis for publications comparing the accuracy of methodologies was performed where applicable. Results: A total of 466 papers were screened. After title and abstract screening, 27 papers were selected for the qualitative synthesis, and 8 for the quantitative synthesis. All studies compared different types of 3D printing technologies and/or conventional techniques for the production of prostheses and dental restorations. The secondary analysis on the accuracy of the different impression acquisition methodologies showed favorable results for digital impressions taken with intraoral scanners. Conclusions: There are many 3D printing technologies that can be used in the field of prosthodontics, as well as dental restorations. Nonetheless, most of the studies are of a pilot nature and their results should be interpreted with caution. Furthermore, the number of studies comparing methodologies of different nature that could lead to interesting conclusions is limited.

Power System Technology
ISSN:1000-3673
Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

Keywords -3D printing, prosthetics, dental restorations, dental materials, additive technology, mechanical properties, biocompatibility, stereolithography

1. Introduction

A large part of the global economy and society is presently experiencing a rapid and disruptive transformation as a result of the 4th industrial revolution or Industry 4.0. Such a transformation is causing various aspects of life to be smarter and more functional, yet increasingly more complicated at the same time. There are multiple aspects and sectors, technology-based, transforming discussion topics of high importance. However, some are more prominent, and thus more interesting, than others in terms of engaging to discuss. Two sectors that are positioned at those prominent points, and mainly of interest in this study, are the areas of 3D printing and prosthetics (and dental restorations). The industrial revolution that is presently established is frequently linked to digitization, sustainability, and commercialization of products, and as a part of that, various technologies related to 3D printing, biocompatible materials, and the field of prosthetics (and dental restorations) have gained lots of attention. Combining those two sectors creates a case study that aims to analyze the research area, gaps, trends, and topics of interest in this combination of technology and area.

Three main forms of porcelain veneer restoration methods are available. First is traditional indirect porcelain restoration which is time-consuming and labor-intensive because the restoration is indirect and requires multiple visits about two weeks apart, therefore, more chair time and indirect material costs. Second, all-ceramic restorations fabricated with CAD/CAM devices can be manufactured within a day. However, for CAD/CAM restorations, the teeth are required to be prepared for a coating as they have to be milled in a block type of restoration, thus making it necessary to reduce them even more compared to traditional porcelain veneers. Furthermore, the surfaces of CAD/CAM restorations are coarse or rough. Also, CAD/CAM devices need expensive equipment. Lastly, a 3D printing device can produce restorations that are indirect and manufactured within a day. It does not require the machined surface polishing process like CAD/CAM restorations. This study focuses on comparing the first and last methods of porcelain veneer restoration methods, regarding bond strengths, refractive indices, and failure modes.

2. Overview of 3D Printing Technology

3D printing also known as additive manufacturing, has attracted the attention of various research fields over the last decades. A growing number of processes and materials have been developed for the traditional manufacture of objects of many kinds. Fireworks, light fixtures, and even electronics have been successfully printed. Despite the great interest and the increase in capability of this technology, the most wellknown application for 3D printing

Power System Technology
ISSN:1000-3673
Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

remain the production of prototypic objects containing simple shapes. Nonetheless, initial attempts at stereolithography (SLA)-based dental fabrication (Tang et al., 2022) discussions of additively manufactured dentate models and dental prosthetics for in vitro models of mechanisms of wear and temporomandibular joint disorders. 3D printing in dentistry is used for crown, veneer, bridge, denture, and orthodontics where construct shapes are relatively flat and generated by merging more and more layers. Large amounts of data to feed the slicing and printing software need to be prepared in stacks. 3D printing with changing settings for different dental options requires more fabrication time and material allowances.

Porosity, surface fineness, layer via thickness, and bath liquid types are key parameters. 3D prints need to undergo off-line postprocessing steps consisting of cleaning and curing. One-step curing of a 3D printed model is achievable with some commercial dies. Staining for proprietary times makes the printed resin translucent and rich for colorization. All 3D convictions bear the challenges of letting green parts pass through aqueous washes and to obtain removable support. Slicing software for a dental option needs to be simple and efficient in directing putty generation, assemblage building, part removal, nozzle packing, and destruction of supports. Dealing with the same SLA printer, mesh sizes of dental objects. A higher resolution of 40968 by 3072 pixels improves geometry fittings and avoids jagging artifacts in border tensile strength tests.

A range of SLA-3D printing systems are available for clinical use with varied plate form factor and structural conditions. Notably, an up-side-down 3D printer where a transparent bottom mimicking a light box in an SLA printer is applied to retain partial elastic tensile strength in green parts. A similar system with the build platform oriented upwards has been tested for 3 subsequent prosperities as well. Multiple light paths improve printing speed and cooling where 3D printed build platforms are well illuminated by UV light for curing raw resin on the plate and mechanical debonding slack reservoirs.

3. Applications of 3D Printing in Prosthetics

The aim of this article was to review the application of 3D printing technology in the field of stomatology by examining the latest research findings. The article also compared its application in prostheses, imitating human teeth in color, hardness, fluoride release, and mechanical properties with natural teeth, and expected research and clinical prospects of the technology in stomatology. Based on materials, the following three-dimensional printing technologies can be used to manufacture complete dentures: stereolithography (SLA), digital light fabricating (DLF), multi-jet modeling (MJM), digital material production (DMP), and binder-jetting printing (BJP) (Tang et al., 2022). For denture base, published studies on three-dimensional printing were also found on SLA and MJM. Meanwhile, for tooth fabrication, studies were found on the three-dimensional printing of SLA and DLP, but very few on MJM. These studies on denture base or tooth fabrication must be adopted by an out-of-office

Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

printer. Although dental models can be printed on SLA and smooth surface can be fabricated using DLP/DLF or MJM technology, free-form is not enough for clinical demand of dental prostheses, and the technology cannot reproduce color complexity of natural teeth.

The related research on prosthetics is at an early stage because existing professional-grade and empowered intraoral scanners and workflow software are expensive. Except for several single-center studies and challenges raised by manufacturers, the technology is still waiting for large-scale and multi-center accuracy verification studies. One demonstrative study using a popular intraoral scanner, software, and 3D printer on digital impression for denture base and denture teeth was literature. It is anticipated that with the price drop of digital impression, software, and printer, the joint application in prostheses and who chew often will be covered. The widespread adoption of this technology in practice is still half a decade away. Prior to that, dentists could consider recruiting an auxiliary service mail order to enjoy the convenience of the technology.

3.1. Types of Prosthetics

As well as the predominant use of maxillofacial prostheses, remedial dental prostheses can be classified under more than one category used mainly for the replacement of dental organs similar to their natural ones. These alloplastic materials can be broadly classified under three major categories: (i) gold and its alloys; (ii) dental porcelain; (iii) polymers. However, on the basis of predominant use, applied material which is dental polymers can be categorized further into three groups: (i) dental elastomeric polymers; (ii) denture base polymers; (iii) bio-compatible polymers. Bio-compatible polymers can also be divided into two major groups: (i) soft denture reline materials; (ii) intra-oral digital denture base printing materials. This classification is shown in Figure 3.2.

Dental Prosthodontics involve art and science concerned with the replacement of lost dental organs or dental tissues by natural looking and functional substitutes either supported on remaining natural dental organs or totally implant supported prostheses. Owing to ever-growing demands of patients and plastic surgeons, extensive research activities in material science and engineering are being carried out in the field of prosthodontics. Continuous development of prosthetic materials has led to advancement in the field of prosthodontics and changed the choices of restorative dentists regarding processing techniques or tools (Balestra et al., 2024).

Traditionally, prosthetic devices were fabricated using subtractive techniques such as casting or milling techniques based on the use of a dental stone model. However, recently, computer aided design and computer aided manufacturing system based on additive technologies have gained enormous importance. This is mainly due to the great advantages like less operator influenced procedures, predictable accuracy and repeatability. A gradual upsurge in the use of

Power System Technology
ISSN:1000-3673
Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

3D printing in prosthetic devices has resulted in the publication of an extensive range of literature. Considerable advances in materials and printing processes are continuously taking place in the field of 3D printing of prosthetic devices.

3.2. Materials Used

The field of prosthetics and dental restorations has experienced tremendous growth due to the arrival of 3D printing technology. With this technology, the fabrication of a variety of dental products, ranging from crowns, bridges, and other fixed restorations to surgical guides and temporary restorations, is deemed easier (Balestra et al., 2024). Continuous research and development processes, targeted to provide innovative and biocompatible materials, have made possible the implementation of 3D printing in some fields of dentistry (Paradowska-Stolarz et al., 2022).

3D printed materials are composed of rigid acrylic, soft rubber-like, and wax-like materials. Rigid materials can be used for the production of clear aligners, implant-supported and non-implant-supported models, provisional restorations, surgical guides, and definitive restorations. The rest can be used for the production of castable models for casting dentures and ceramic restorations. Three-dimensional printing is used in dentistry mainly for dental restorations and prosthetic appliances. It allows for precise preparation of fixed and removable dental prosthetics including: restorations on teeth, crowns and bridges, implant supported crowns and bridges. The basic advantage of 3D printing is the greater accuracy of prepared pieces. Additionally, the quality of resin materials dedicated to 3D printing is not inferior to traditional materials.

Requirements for materials dedicated to 3D printing in dentistry are high accuracy in priori prepared models, exact reproduction of the surface quality and shape of a 3D-printed model, quick print performance, high biocompatibility, non-irritating and cytotoxic qualities, dynamics of application in the clinical procedure for prosthetic restoration in oral cavity. Also, printed pieces should be easy and fast to process. Compatibility of 3D-printing pieces with CAD/CAM systems for fixing, dyeing and/or finishing procedures, durability and wear resistance are also necessary in materials. Such materials can also be used for printing teeth models, bad alignment of teeth splints, tooth position arch in orthodontic therapy, and occlusive splints for the treatment of bruxism.

3.3. Advantages of 3D Printing in Prosthetics

In recent years, 3D printing has been increasingly applied in more complex processes such as e-prototyping, industrial, medical, dental, and pharmaceutical applications. Currently, one of the hottest potential applications for 3D printing is in stomatology, in which it has been reported that the joint application of oral digital impression technology and 3D printing technology is currently a hotspot in the field of dental prosthetics. An intraoral scanning,

Power System Technology
ISSN:1000-3673
Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

computer-aided design (CAD) data processing and 3D printing are alternative methods to traditional techniques for preparing dentures. The intraoral scanning is quick and hygienic compared with traditional methods. The software digitizes impressions files, which in turn produce the stents and crowns on 3D printers. Based on CAD/CAM technology, the stent prepared on the 3D printing workstation can obtain a relatively ideal position and its retention is higher than traditional casting. One study evaluated the mechanical properties of 3D-printed removable stents of cobalt–chromium alloy by polyjet and SLA printing methods, confirming that the selected cobalt–chromium alloy has good fluidity and thermal properties. Importantly, the bending, tensile, and compressive strength, as well as elastic modulus of 3D-printed cobalt–chromium alloy, meet the specification requirements of the International Standards Organization (ISO) as well as the American National Standards Institute (ANSI) corresponding to removable partial dentures (Tang et al., 2022).

As 3D printing technology develops, 3D-printed resin dentures make it possible to manufacture a denture from a digital model. A review reports that 3D-printed resin is equivalent to conventional resin in wear resistance. Moreover, the denture base with a thickness of 10 mm can withstand 3400 cycles of thermal cycling, meaning that it is more than sufficient to meet the requirements of products for the mouth for durability. However, there are still some aspects that may hinder the development of restoration teeth, especially for newcomer dental laboratories. More than knowledge and skills to maintain the printer is needed in stomatology laboratories. Research on CAD/CAM and 3D printing manufactured dentures is still in its early phases in the stomatology field, with few controlled studies. In the area of accuracy improving measures, previously published studies have conflicting results. For the study on complete dentures, milled ones were reported superior compared to 3D printing. Even on a lower scale of removable partial dentures, both techniques produced similar accuracy. Although the dental crown is manufactured with other approaches, studies revealed that the crown manufactured by 3D printing has a higher degree of fitness compared to those manufactured using the existing conventional techniques. In contrast, one research reported that significant discrepancy exists between the anterior 3D-printed crown and the die, with no study assessing this aspect on the posterior crown. 3D printing technology can save a majority of material that is wasted by milling and produce crowns with high dimensional accuracy.

3.4. Challenges and Limitations

Numerous challenges with 3D printing are raised to make it easier to use in prosthetics and dental restorations. A 3D printing technique successfully manufactured trial removable partial dentures based on a framework design by employing a multi-material Stereolithography printer. The design and printing procedure should be enhanced based on the 3D printing technique and multiple agents (Balestra et al., 2024). A concurrent

Power System Technology
ISSN:1000-3673
Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

comparison of indirect dental restorations as to achievable minimal settings for effective Spartan WAX & 3D-printed residual graft for a 5-axis CAM system corono-radicular retainers to highly repeatable prosthetic dual-cured adhesive cementation was performed with various observations such as sufficiency 3D-printed residual graft settings in specific types; opportunity of 3D-printed residual graft to minimize initially achievable settings significantly; 5-axis CAM production feasibility of WAX retainers with even enabling double retaining crowns; biocompatibility of the unique resin cement; small limitation on reconstructions placement reliability due to 3D-printed residual graft stone roughness, gauged in min-max ranges of flat, receiver diameter farthest point; digital prosthetic complex structure accuracy after luting fragility with 3D-printed adjunctive tools that do not require additional time expenditure.

4. Applications of 3D Printing in Dental Restorations

3D printing technology has developed rapidly in recent years and has been widely applied in various industries such as manufacturing, food, biomedicine, dentistry, and education. 3D printing in dentistry has been adopted from impression taking to prosthodontic restorations. The joint application of oral digital impression technology and 3D printing technology is currently a hotspot in this field. The combination has been applied to zirconia all-ceramic restorations, metal restorations, and complete dentures, among which 3D printing of prosthodontic restorations is the earlier and relatively mature application in oral clinical practice. The acquisition of models for prosthodontic restorations is the key first step. Traditional impression methods were sculpting with trays and polyether/alginate impression materials, in which dental impressions were rolled into gypsum casts. They are sufficient for forming stomatognathic system models for tooth bracing, but for removable dentures, they are insufficient in tightness, especially for patients with severely restricted mouths. Intraoral scanning, computer-aided design (CAD), and 3D printing provide a non-impression technique alternative for the production of removable dentures (Tang et al., 2022). In the field of complete dentures, previous studies have confirmed that stents prepared by CAD/CAM technology and polylactic acid (PLA) filaments with 3D printing have higher precision compared to some traditional casting methods, which had no significant difference with those made by CAD/CAM dental mills. In addition, some researchers evaluated the mechanical properties of the 3D-printed cobalt–chromium alloy stents, and the results confirmed that they met the requirements of being used as removable partial dentures. As to denture bases, it is confirmed by the bench test that the wear resistance of 3D-printed resin dentures is equivalent to that of conventional prefabricated resin dentures (Balestra et al., 2024). Also successfully designed and made removable partial dentures for patients with mouth opening difficulties with 3D printing technology. Traditional cast partial dentures are still manufactured by wax techniques rather than the CAD/CAM and 3D printing technique in clinical practice. Therefore, knowledge and technology are needed to use and introduce 3D

Power System Technology
ISSN:1000-3673
Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

printing for restoring teeth. In this regard, research on the production of denture bases and metal stents by CAD/CAM and 3D printing is still in the early stage, and very few controlled studies have been reported. On the other hand, studies of definitive complete dentures have found contradictory results regarding the accuracy between milling and 3D printing. In fixed prosthesis, it is well known that the marginal fitness of crowns affects their service life. It has been confirmed that poorly fitting crown margins can lead to several authorities. A great deal of effort has been devoted to constructing fitting crowns. It is reported that 3D-printed crowns had a higher degree of marginal fitness compared to those made by traditional technology; in other words, crowns made by 3D printing were better from the perspective of crown margin suitability. Unlike CAD/CAM machining, 3D printing saves materials and produces crowns with high-dimensional accuracy. For partially worn teeth, 3D-printed ultrathin zirconia occlusal veneers exhibit similar or even higher bearing capacity compared with other methods.

4.1. Types of Dental Restorations

3D printing technology has been developed for over thirty years. Applications of this technology reached dental clinical practice more than a decade ago. Digital impressions, computer-aided design, and computer-aided manufacturing (CAD-CAM) processes correlated with the substitutive technique, yet, the advent of 3D printing as an additive technique, and recent advances permitted its significant growth in clinical applications. The technology is nowadays mainly utilized in the fields of orthodontics, oral and maxillofacial surgery, and prosthetic dentistry. Despite its recent use, studies have already assessed how significant of an impact has been produced in the workflow. 3D printing has shown the potential to outperform conventional techniques with respect to manufacturing time, cost, and flexibility in complex geometries (Balestra et al., 2024). The reasons for the success of this technology in other industries have been the source of studies in the dental field, pointing out key phenomenon that need to occur in order to maximize the growth opportunities for the technology. In consideration of the knowledge gap acknowledged in the literature on workflow comparisons, the objective of this work, is to review and compare the literature regarding applications of 3D printing technology for the fabrication of prosthesis and dental restorations.

Many products are classified as dental restorations, and all of these products can be found in 3D printers. Already, 3D printing has shown to be a viable solution for devices such as direct and indirect inter-oral trays, occlusal splints, bite blocks, fixtures and transfer prosthesis for edentulous patients. Just a few years later, the attention turned to the fields of direct restorations in which more sophisticated devices for a completion of the technique chain are in development. Potential clinical applications. believe there are five macro-areas of applications with details, constraints, and potentialities. Firstly, the 3D printing of removable

Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

prostheses, or quantity of muted teeth, is intended to be used when little to no dental minimum planning is needed. In this context, in opposition to teeth-supported removable prostheses, key rigidity and resistance proper for non-composite materials will be required. Inverted printed options have already shown their ability to handle these requirements. A 3D printable reinforcement of polycarbonate for an added strength and resistance to wear and denture breakage is close to clinical viability which can exponentially expand the options for production. On the other side, the 3D printing of inaesthetic, unbondable temporary crowns are also advancing but with technological and material issues although soluble layer material is bound to enter the market.

4.2. Materials Used

Regardless of technology advancement, the development of new materials with new properties is still of paramount importance. All 3D printing technologies and printers require dedicated materials with the respective properties determined by the printing mechanism and application. The material strictly influences the 3D printing process and chosen post-processing. Within the 3D printing process, selection of materials also affects time consumption, precision, and a proper function of the printed object; this is especially true for a precise model and also restorative materials (Balestra et al., 2024). These parameters are evaluated with appropriate tests. Characteristics of 3D resin-devoted dental applications are of essential need for showing proper printing conditions, printed material properties, printability, or showing compatibility in engineering or biomedical purposes. Each of the data gateways can be a source of verification in scientific works or simply supplier's requirements (Paradowska-Stolarz et al., 2022). Currently, the most used 3D-printable materials in the dentistry domain are photopolymers. They are a mixture of a prepolymer with photoinitiators. The prepolymer is a resin containing acrylate acid groups. Low-molecular macromonomers and oligomers are used to diversify the resin properties. Those with multiple carbon-carbon double bonds are added to make the resin more thermoset (cross-linked) after curing. Flexible resins are used primarily for printing surgical guides and other soft prostheses. The application of rigid resins in dental modeling, impression trays, or occlusal devices is as well known. Recent years brought procedures and materials obtained in 3D printing or milled that could serve as a substitute to PMMA. Banders are constructed in a banding less method based on a CAD CAM pupil method. This computerized design approach is based on a specific setup consisting of just one scanner being used at the patient's earpiece.

4.3. Advantages of 3D Printing in Dentistry

As an emerging technology, 3D printing (additive manufacturing) has shown its advantages in the medical fields such as surgery, orthopedics, craniofacial surgery, and dental restorations. Comprehensive anatomical models derived from digital data, implant guides for planning restorations prior surgery, models for accurate fabrication of restorations, even

Power System Technology
ISSN:1000-3673
Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

individualized prostheses have been fabricated in recent years. Stomatal digital data obtained from intraoral scanning or cone-beam computerized tomography well promote the application of 3D printing technology in the stomatology field. Compared with traditional manufacturing methods, 3D printing has the advantages of low material waste, less thermal deformation, high complexity design flexibility, intelligent manufacturing without operator skill requirements, products customization, and direct moldless fabrication (Tang et al., 2022).

The joint application of oral digital impression technology and 3D-printing technology is currently a hotspot in the field of dental prosthetics. The combination of the two has been successfully applied to zirconia all-ceramic restorations, metal restorations, wax restorations, metal racks of removable partial dentures, maxillofacial prostheses, and complete dentures. Intraoral scanning, computer-aided design, and 3D printing provide alternative methods for manufacturing dentures. Previous studies have confirmed that the stent prepared by the CAD/CAM technology can obtain a relatively ideal position and has higher precision than that of the traditional casting method. Some scholars evaluated the mechanical properties of the 3D-printed removable stent of cobalt–chromium alloy, confirming that its elongation, tensile strength, and yield strength can meet the requirements of removable partial denture. Meanwhile, the wear resistance of 3D-printed resin dentures is equivalent to that of conventional prefabricated resin dentures.

3D printing technology to restore teeth, function, and esthetics is full of obstacles because knowledge, skills, and technology are needed. Most of the research studies on the production of dentures by CAD/CAM and 3D printing technology have just started. In terms of accuracy in milling and 3D printing, studies of definitive complete dentures have reported contradictory results. However, 3D printing was less true than milling by 17–89 μm and less precise by 8–66 μm in terms of complete denture. In the field of fixed prosthesis, the marginal fitness of the crown is closely related to the service life of the restoration. Compared with the crown made by the traditional technology, the crown made by 3D printing has a higher degree of fitness to the prepared tooth because it is more accurate. 3D printing was significantly better than CAD/CAM cutting in terms of the suitability of crown margin and interior. Compared with CAD/CAM machining, the 3D printing technology can save materials and produce crowns with high-dimensional accuracy and marginal adaptation within clinically acceptable limits. For partially worn teeth, veneer restoration is more suitable than complete crown restoration but has higher requirements on the bearing capacity.

4.4. Challenges and Limitations

Three-dimensional(3D) printing in the healthcare sector is relatively new, and concerns regarding its long-term use remain. Various biomedical applications investigated with 3D printing technologies include surgical planning and guides, implants, prosthetics, and tissue engineering scaffolds. They are usually biomimetic and personalized in nature, forming

Power System Technology
ISSN:1000-3673
Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

customized parts according to patient anatomy. However, they are still common in biomedical research laboratories and are used only occasionally in the clinic. Issues regarding exceeding allowable contamination levels, material biocompatibility and bioactivity, aging, mechanical strength, sterilization, and amount of regulatory approval remain a concern. The regulatory approved materials, processes, and devices are still limited, encompassing only a few applications, e.g., dental models, splints, and impressions. The current reviews in this domain only focus on selected applications, materials, or technologies. Therefore, a comprehensive review of the challenges and limitations of using 3D printing technology in biomedical applications seems timely and relevant.

Biomedical applications of 3D printing focus mainly on industry-turned clinicians' needs. It empowers biomedical researchers to investigate their innovative ideas, which are then translated to a pilot stage. Consequently, different printing processes are preferred in research and commercial circles. Several processes, such as binder printing, shape deposition manufacturing, and polyjet technology, are often overlooked in biomedical research studies. In contrast, material extrusion, powder bed fusion, and vat polymerization technologies are not frequently used in industry-grade printers due to high cost, low-throughput, and/or complicated workflow. At the same time, commercially available thermoplastic, polymeric, and metal materials used in FDM, SLA, and SLS for medical implants and scaffolds are also not included in this review. Most materials are limited to low-resolution and high-cost options suitable for a broad range of applications. Therefore, further development of inexpensive and easy-to-use consumables, especially those from naturally abundant resources, is needed to facilitate the next generation of open-source 3D printing technology.

Wide-spread adoption of 3D printing in the clinic hinges on regulatory approval, as without it commercial possibilities are limited. This posed a Catch-22 issue in the medical field. Strikingly few devices have garnered clearance from the FDA, with notable exceptions being dental models, splints, and impressions. In comparison, the aerospace and automotive industries have grown to multi-billion-dollar markets featuring universal standards for both devices and measures to obtain clearance. This review also highlights regulatory data from two domains and examines complementary measures to facilitate approval for future biomedicine devices produced with 3D printing. One recommendation concerns developing minimally invasive, small-scale devices first, which is also why custom products for orthopedics have seen wide adoption (Balestra et al., 2024).

5. Comparative Analysis of Prosthetics and Dental Restorations

Prosthetics refers to the branch of anatomy that deals with the design, production, and fitting of prosthetics devices, which are artificial body parts. The new face of dentistry is 3D printing for the creation of prosthodontic devices or restorative structures, which is the branch of dentistry dealing with the filling of lost parts of teeth using artificial materials or putting

Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

false teeth or artificial devices to fill the space of lost teeth. Dentists are encountering some problems in the manufacturing of structures to restore teeth in a method that matches patient adaptive require. To alleviate these issues, modern advanced technologies are adopted. These include CAD-CAM, laser scanning, and 3D printing technologies. The materials used for constructing restorations and the surfaces also play an important role in the functionality of restorations. The passivity of fit is a concern for machinable restorations, since there is a potential for accumulation of plaque or debris at the margins with an imperfect fit. A misfit of restoration can lead to thermal or mechanical fatigue and finally failure of restorations. Therefore, there is a demand for a method that produces precise fit restorations for a sustainable durability of civil part of structures and as a long-term restoration.

3D printing has gained popularity in dentistry, especially in prosthodontics. The introduction of scanning technologies enable the capture of 3D data of the patient's oral cavity and computer aided design software providing the virtual modeling of the restorative structures and printing via different methods. Yet, the 3D printing process is essential a post-processing unit, which does not offer an accuracy superior to CAD-CAM systems. Resins used in 3D printing include a variety of types, which can greatly affect the mechanical properties of structures. The vast number of manufacturing methodologies also varies the performance of polymer structures.

A comparison of performances of 3D printed prosthodontic structures with machined restorations is conducted on both polymer and ceramic restorations. The engineering approach allows designing a test system based on prior knowledge of measured parameters and desired stresses on structures during tests. A test method is developed to capture the behavior of a restoration in loading. The mechanical behavior of tested conditions is studied by applying finite element method and an optimization routine. The expected stress results are outlined and compared in local directing for each case. Measured parameters are reported at critical locations to verify the effectiveness of the design approach. A proposed engineering approach enriches the field of restorative dentistry and gives an accurate insight of mechanical performances under oral conditions.

5.1. Cost Analysis

Statistical analysis of the profit margins was done to compare the impact of change in manufacturing method. As the demand increases, the initial investment or the cost of machines becomes a negligible percentage of the yearly earnings. Hence, for even a demanding prosthesis requirement of 2 prostheses/hour, the AM option almost double the profit maximisation. Due to premium-priced medical polymers, 3D printing in these materials is less affordable than milling in cheaper PMMA. However, AM is emerging in low-cost polymers such as PET-G, PCL and flexible 3D printing filaments with the dental industry seizing the opportunity of rapid design customisation and manufacture. The upfront cost of

Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

the three 3D printers was compared with respect to the milling machine price to show that the cost of entry to dental additive manufacturing is significantly less than conventional subtractive machining (L. J. Cruz et al., 2020).

To perform a cost analysis of the prosthesis cost prices, the manufacturing times and material costs were accurately noted considering the entire manufacturing chain. A small absorbent transfer cup holding the ear implant was also designed and manufactured in an identical set of speed and fidelity settings to eliminate the additional cost of a different print. The material wastage of producing the ABS cup was also considered and deducted from the percentage manufacturing cost comparison graph. The percentage cost comparisons were then converted into current dollar amount in US dollars. The pricing of other materials and machinery in other nations may yield different prices but the print and labour cost advantage of AM—is clearly observable everywhere, and additive manufacturing will proliferate due to such economic advantages.

5.2. Time Efficiency

Prosthetics & dental restorations have been manufactured from a variety of materials using various methods over the years. Two of the most common methods for producing prosthetics & dental restorations are milling and printing. To assist dentists in selecting the best production method for their needs, this paper will analyze and compare those two methods in terms of price, time efficiency, & quality using a prosthetic tooth as the test object. Molded materials could also be 3D printed. For example, silicone materials as elastomers could be used to print prosthetic finger. However, the most common method for applying 3D printing technologies into denture industry is using plastic materials. In this method, teeth and gums are 3D printed from biocompatible plastic. The printing time has been a limiting factor for the application of this technology in denture industry until which the speed of 3D printing technology had been improved to a level that could compete with milling technologies.

Two different printing methods were compared in terms of build time and quality. The first method used a DLP printer with a speed of 6 seconds per layer. The second method utilized a resin jet printer with a speed of 3035 layers per hour. The experiments showed that printing methodology drastically affected production time and quality. The resin jet printer produced stronger prosthetics but its long printing time was limiting its use in dental labs. On the other hand, the DLP printer had a much higher speed but resulted in fragile prosthetics, limiting their clinical applicability. The study found two printing solutions with contrasting strengths and weaknesses to address diverse needs in a dental lab. One solution was suited for high strength prosthetics, while the other was focused on high speed, enabling high daily throughput of fragile prosthetics (Alvi, 2017).

Power System Technology
ISSN:1000-3673
Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

5.3. Patient Outcomes

Patient group selection was not specifically required by either of the studies examined. One study examined prosthetic cases with missing anterior teeth. Various types of denture base and tooth materials were used in two studies, strain gauges and a three-dimensional analysis method were used on a dental implant to determine the implant support concept accuracy, a new material was produced using silicone and wax for comparison, and 3D-printed cones were used as posts in a new dentin restoration technique. Furthermore, patient groups were selected based on criteria similar to those used in in vitro studies, and each study examined between 12 and 30 cases. Macroscopically, all studies reported better outcomes of 3D systems, and more specific comparisons were typically performed with respect to selective color tests, visual inspection of designs, marginal gap analysis, degree of conversion tests, and surface roughness tests. Study models were obtained from scanned dies and a dental desktop printing device for direct printing, modeling, and testing. Three-dimensional coordinate measurement equipment and digital microscope images were taken before and after test preparation. Central and standard deviation values were reported using independent t-tests and paired sample t-tests to determine statistical significance. Subset analysis was not performed in any of the studies. In terms of data abstraction, capabilities of the systems examined, competitive industrial machines, and commercial purposes, there was a tendency to address general topics and machine brands rather than a specific focus. System reliability was evaluated with regard to the practicality of machines used widely in dental clinics. Patients and managers who have invested in systems with in-house technology must understand their limitations, which include working environments that affect the results and benefits with hidden costs. Overall accuracy and standard stress distribution should be tested in various conditions to confirm better clinical outcomes on a large scale. Strengths include adjunct technologies successfully introduced to the field of dental research, initial exploration of patient outcomes with an emphasis on environments comparatively less described, and comprehensive approaches to specific topics in prior research. Weaknesses include small sample sizes that may not be acceptable for statistical power, data abstraction that lacked detail regarding set analysis populations, and appropriately extensive search methodology to capture a large sample. There may also be an inadequate emphasis on types of interpretations expected and how these can be improved upon for other areas.

5.4. Customization and Personalization

Modern prosthesis is one of the most varied and heterogeneous mechanisms for the replacement of body parts, such as the ear, nose, eyebrow, nipple, oculo-palpebral, dentition, and finger. They are garments or masks that contain different components. Some of them are manufactured, for example, dental prostheses by casting metals and resins, and facial prostheses by modeling, in different materials. Prosthesis is generally put on or off. They are

Power System Technology
ISSN:1000-3673
Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

used by patients who have suffered cancer, deformities due to accidents, congenital diseases, and ulcers caused by ophthalmic operations, in which part of the eyeball is removed. Most of these prostheses must be personalized for each patient and their settings, which tends to raise their costs with respect to other bulk manufactured body garments. Similar considerations apply to personalized garments of any other body segment. Traditional manufacturing methods need a lot of professional and patient time, where once the appointment is obtained, they can only be served between 30 minutes to 2 hours per appointment due to the shortage of time and the high demand (Eyzaguirre et al., 2023).

The manufacturing process of these prostheses has three main components: data acquisition, modeling and its correction, and fabrication. In the manufacturing process of these prostheses, the patient's self-perception, whose alteration led to the use of the prosthesis, emotional stability, personality characteristics, and social circumstances, are the most important factors when treating maxillofacial defects. For patients, prosthesis leads to an enhancement of self-perception and the possibility of returning to the normality of their lives (Thurzo et al., 2022). About the time, ideally, it would take a maximum of one appointment, as is usual for the construction of non-personalized prostheses. To optimize the process and make prostheses more accessible and of good quality, a digital manufacturing process was chosen, digitization consisting of data acquisition, prosthesis design, and rapid prototyping. It is based on recent advances in affordable technologies, such as laser scanning, computer-aided design software, 3D printing, and widely used biomaterials for prosthesis fabrication.

6. Case Studies

A patient presented with a C6-7 disc extrusion associated with a right C7 radiculitis with pain in the right shoulder and distal antebrachial forearm and intense paresthesia of the first three fingers. The patient had failed conservative treatment with injections and physiotherapy and was offered the choice of a standard open discectomy versus an endoscopic technique. The patient chose to proceed with the procedure straight away. The approaches using a significant vector approach allows for the decompression to be performed through a single 8 mm incision with essentially no bleeding.

Informed consent was obtained. The patient was placed under suitable anaesthesia for the case, with monitoring in accordance with acceptable standards. Sevoflurane was used to induce anaesthesia. Intravenous dexamethasone and ondansetron were administered based on the standard anaesthetic procedure. A midline 30 mm incision was fashioned 2 cm left of midline and the fascia split to allow access to the supraspinous ligaments. A Kirschner wire initially swept through the fascial plane into the left lamina at the C6-7 level.

Using a full endoscopic retractable tubular retractor system, a significant debate took place in terms of level of retraction and diameter of the retractor. Eventually, a 14 mm retractable

Power System Technology
ISSN:1000-3673
Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

tubular retractor was used, but alternative sizes including 17 mm and attempt to use wider tubular retractor at the outset were considered. A 30 degree endoscope with camera in the traditional over microscope manner was positioned to have sufficient space for media and equipment functions.

Once in position, the draping of the tubular retractor was performed, along with clamping of ports and sterilization, a dry camera was used to scrape the outer posterior margin the dura. The disc and its noisy material were interrogated for height and translation into the foramen and to check that it had rehydrated and was no longer bulging before good haematoma was present in the axilla of the exit root. Pre-operative radiology was commented on, indicating that no hardware had been implanted focal prior to surgery.

6.1. Prosthetic Case Study

Prosthetics encompass mechanisms for the replacement of body parts. They are generally used by patients who have suffered cancer, deformities due to accidents, and congenital diseases. Most prostheses frequently must be personalized for each patient, affecting their associated costs. Traditional manufacturing methods in facial modelling require a lot of time. Consequently, patients must wait between 6 months and 2 years for rehabilitations, with limited appointment times. In the elaboration of a facial prosthesis, three main stages must be carried out: obtaining the shape of the patient’s anatomy; modelling from thermoplastic materials; and fabrication using medical grade silicones. Additionally, the patient’s self-perception, emotional stability, and social circumstances are also important when treating patients with maxillofacial defects (Eyzaguirre et al., 2023).

After obtaining digital models, the two most common methods for physical production of these models are subtractive prototyping and additive prototyping. CAD/CAM for the milling of crown and fixed partial denture frameworks is synonymous with modern dental technology. CAM has been present in dentistry since the 1980’s and several advancements for efficient milling have been made. The 5 axis milling machines today are the most versatile since they can produce precise details required for complex restorations. A study concluded that the team of 3 and 5 axis milling machines could not compete well with each other but both CAM systems could compete well with conventional systems for clinical fit and fracture resistance (Alvi, 2017).

Milling and printing of models were done as per their respective prototyping’s rendering. The printed models were washed with isopropyl alcohol for 5 min to remove any uncured resin and then cured in a UV chamber for 60 min. Initial and final measurements were taken for all three types of models using an optical digital scanner mounted on a robotic arm. There was no statistically significant difference in accuracy between printed and milled models in terms of linear and angular measurements. As for the distance measurement, CCTM model was

Power System Technology
ISSN:1000-3673
Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

found to have the highest accuracy discrepancy from the scanned models. All models were clinically acceptable, but with an enormous difference in time and cost.

6.2. Dental Restoration Case Study

Three-dimensional (3D) printing technology provides not only reconstructive biomaterials but also the customized designs and production of prostheses. Originally compromised by the low-cost manufacturing production of prostheses, this technology attempted to provide the adequate mechanical properties and appropriate surface to meet the requisite of wear resistance. However, the purpose switched to providing higher accuracy and design satisfaction for anterior cases in prostheses. Therefore, the virtualization of dental restoration CAD resulted in many brands of desktop-level mills. At the same time, some competitor Additive Manufacturing (AM) technologies developed. Invisible aligners with bespoke designs also emerged. The high cost of 3D printers caused inadequate commercialization. It was until the recent Kinect-based standardization user-documented prosthesis, and the wide acceptance of hybrid restorations. These commercial products and processes aimed to break through the limitations preventing mass-prescription additive manufacturing of dental restorations, digital wisdom tooth extractions, digital implant drilling guides, etc.

Although a few studies have focused on the dental prosthesis accuracy, mainly on the trueness assessment of the CAD-CAM milling produced. The 3D printed process posed an unsolved sub-question on how the damage on positioning accuracy brought about by the XY scanning ratio in the open-source resin printer can be compensated. However, after this initial dissertation was proposed, these brand-named printers provided a self-correcting approach for this position compensation issue but adjusted only from the software perspective. This is not to say that the brand-naive dental slicers would suffice, as they are structured to be patient case tailored. This rescue response from the commercial company favors the need for more scholarly discussion on the 3D printing process in the prostheses vs. restoration design and on the dental AM material-scanning-layer speed ratio from the engineer perspective (Lu et al., 2023). Upon that, a prospect for smarter human-machine co-creation and CAD-CAM cogeneration, eventually with closed-loop machine learning, 3D scanned-born unsupervised CAD generation, and CAD-CAM partnering, foresighted on the dentist operating AM at chair-side, and the dental technician directly or without modeling penetrating at the second post-model stage ought to be presented.

7. Future Trends in 3D Printing

Despite the uncertainties caused by the COVID-19 pandemic in 2020, the overall sentiment surrounding 3D printing is optimistic. As a major innovation in working practices, 3D printing has been deemed more important than ever in developing new treatments. Well-known market drivers for the dental 3D printing industry continue to remain relevant;

moreover, other factors such as rising demand for personal use items and adoption of the latest printing materials are expected to become notable trends (Tang et al., 2022).

In particular, the COVID-19 health crisis has created a grave deficit of supplies such as face shield visors, patient tubes, and mask adapters. Many 3D printing companies have been quick to adapt to producing these items at a massive scale. Meanwhile, there will be greater emphasis on enabling easier submissions of print-ready files, possibly by introducing search functions for individual designs. The quantity, accessibility, and gauge of submitted items are all expected to increase (Pillai et al., 2021).

On the manufacturing end, further enhancement in accessories and software will sharpen the leading edge of fluoropolymer 3D printing. From this, it is possible to introduce highly regulated materials, further increasing the market addressable by additive manufacturing. However, 3D printing, like every other market segment, will have to account and take preemptive steps to mitigate risks such as export control concerns.

7.1. Innovations in Materials

The introduction of new digital technologies related to 3D imaging, computer design, modeling, manufacturing, and material science has deeply influenced dentistry over the past few decades. More recently, an additive manufacturing process based on 3D printing technology has been increasingly used in dentistry, especially in oral and maxillofacial surgery, scaffold production, implantology, endodontics, wearable personalized protections, drug delivery devices, orthodontics, and prosthodontics.

The application of 3D printing to the prosthodontics workflow has enabled the digital production of removable prostheses, templates for implant surgery, temporary and permanent crowns and fixed partial dentures, denture bases and try-ins, and clear aligners. 3D printing has reduced manufacturing time and cost and has increased versatility for the manufacturing of complex geometries. This, however, is only partially true for 3D printed materials for permanent restorations.

As for all the new technologies introduced in dentistry, the implementation of 3D printing systems must meet some requirements such as sufficient and predictable performance, availability at an acceptable cost, and compliance with a regulatory framework. These essential requirements are guided by considerations regarding the intended use and classification of products. At present, these criteria are owned by manufacturers.

More than a decade after its first introduction to commercial systems in dentistry, the 3D printing of polymers is sufficiently mature so that the overwhelming majority of 3D printed products are objects made in this way. The iterative software-controlled styling of the virtual object and the ability to print with new chemical formulations allows for innovation.

Power System Technology
ISSN:1000-3673
Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

Nothing has slowed the adoption of 3D printing by dentists more than the perception of inadequate performance for products that patients may need to rely on. In prosthodontics, the 3D printing of polymers is being used for quotidian products. These include, by virtue of their relatively simple geometries and limited pressure/temperature or chemical stress, supports for impression-taking, denture bases and try-ins, and equivalent to trays that are fabricated with by creating an impression-forming object with the conventional subtractive method.

So, a material that can sensibly approximate the elastic modulus and flexural strength of dentin is closer to reality than the test standards can cope with.

Even in the conservative dentists' office, things are changing rapidly. The widespread adoption of intraoral scanners is unprecedented. They are as disruptive as the intraoral photography systems were some 30 years ago. Wide 2D pictures with archival longevity are possible with these far more capable devices. They are not self-run or robotic.

Against this background, the aim of this review is to explore the state of the art of 3D printed materials for permanent restorations in indirect restorative and prosthetic dentistry from the perspective of two very different communities.

7.2. Advancements in Technology

3D printers are utilized in the fabrication of personalized prostheses in a rapid, simple, precise, and low-cost manner, which signifies a huge technical step forward. The accuracy with which dental prosthetics are manufactured is now being improved to an excellent level of process quality. Although the performance of prostheses made using 3D printing and traditional methods is comparable, there are differences in technique. With this new technology, in addition to cost-effective production, the accuracy of the manufacturing processes can be continuously improved to an excellent level of process quality. Trials conducted with intraoral 3D scanners demonstrated that the prostheses fabricated with a 3D printer had an average fitting accuracy of less than 100 m, which underlines the appropriateness of this approach (Balestra et al., 2024). A similar study in maxillary or mandibular complete arch restoration showed comparable results. The accuracy of 3D printing is expected to improve in the near future with faster machines capable of printing prostheses at 3–5 mm/h. The technology has matured enough to print prostheses sizes 16 mm x 10 mm x 10 mm in sizes with decent quality.

Additionally, suction denture design for 3D printing is described, which enhances comfort and retention by increasing adhesion. The interest in 3D printing has sped up dramatically due to the COVID-19 outbreak. The use of digital modeling, Bluetooth connected, cloud-based printer technology, and fully automated 3D printers is on the rise. Beside data generation and processing systems, there are companies who provide tooth model and

Power System Technology
ISSN:1000-3673
Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

customized full arch denture fabrication as a service for dental professionals (Pillai et al., 2021). Currently available printers are entry-level, inexpensive devices. Their moderate performance, resolution 150µm and layer height of 100µm is sufficient for relatively uncomplicated models and molds required for non-precision attachments. They are further developed to print an entire model or denture in just a few hours with injectors, and support-free printing is planned. Such developments are anticipated to render technology more affordable and available to the general dental market.

7.3. Potential Impact on Healthcare

The purpose of this experimental study is to conduct a comprehensive comparison between the development and production processes of a prosthetic limb and a dental restoration, both manufactured using 3D printing technology. It aims to answer the question of whether there are significant differences in technical quality and production efficiency between these two products. The study will employ the quality matrix and the process matrix, two evaluation tools commonly used in product and process development, to comprehensively analyze the outcomes of the investigated 3D printed objects with respect to quality and production efficiency. Based on the analysis, suggestions for the advancement of either technology for achieving even better outcomes are outlined (Balestra et al., 2024). Ultimately, which of the examined products is better than the other with respect to quality and production efficiency will be examined based on the scoring matrix computation. Moreover, the difference between the prosthetic limb and the dental restoration with respect to how it was purchased and the evolution of the task is analyzed.

As an important trade-off consideration, manufacturing time denotes the time it takes to produce a product from the beginning of the preparation stage to the end of the balanced processing stage. Research has shown that faster production time results in higher production efficiency. The total manufacturing time for each analyzed product is calculated by adding the elapsed time of all the considered actions. As both products were produced using the same model of the 3D printer and the post-printing time spends months in both products, the amount of time has no impact on the copyright of the technology or on the outcome comparison. This study focuses solely on the number of minutes spent on actions directly and necessarily related to the production in the 3D printing technology. The total manufacturing time collected from the sales order spreadsheets related to the prosthetic limb and dental restoration with time formats being adjusted to the same scale is used.

8. Ethical Considerations

The introduction of new digital technologies related to 3D imaging, computer design, modeling, manufacturing and material science, has deeply influenced dentistry over the past few decades. Over the years, current computational fluids delivering spacecraft, instruments,

Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

vehicles, protective and ornamental parts, and many others based upon the technique of three-dimensional printing has inspired healthcare professionals to explore printer-benefiting use. More recently, an additive manufacturing process, based upon the 3D printing technology, has been increasingly investigated, particularly in research publications, for its possible applications in constructing parts such as casts, models, surgical guides and drill guides, customized instruments, scaffolds, implant impressions, and bases, or even direct restorations in dentistry.

The emergence of 3D printing technology and its increasing interest in dentistry have produced important breakthroughs and tremendous opportunities in the fields of forensic, preventive, restorative, and surgical dentistry. The digital restorable workflow reverse conduction or production of models, guides, or surgical templates in dentistry has completely replaced an old workflow that had been essentially unchanged for hundreds of years. Conceptually, the introduction of 3D printing into the workflow of restorative or prosthetic dentistry should be equally revolutionary and possess similar merits. However, in the multitudinal academic researches and clinical workflows of 3D printing applications in restorative dentistry, 3D printed plastic materials not only lack a strong favorable ground for success, but their actual clinical use is also burdened with serious and restrictive drawbacks.

To meet the compromised requirements for 3D printing materials in dentistry, more efforts have been directed toward the development of newly developed polymers, which attract wide interest in fabricating CAD-CAM fixed prostheses. Generally, current 3D printed materials for dentistry can simply be classified into three categories according to the manufacturing processes: vat photopolymerization, material extrusion and powder bed fusion. Of the three processing families, vat photopolymerization is the most upstream in terms of selecting diverse and ingenious chemistries and is also the source of a series of the earliest commercially available 3D printables. These resin-derived printers can achieve finer resolutions than plaster-based ones, although previous studies indicate the less-than-desirable merits of 3D printed inlays or onlays.

8.1. Patient Privacy

The digital era in the field of dentistry has brought numerous advantages and opportunities for improving and streamlining workflows. Information technologies and the availability of digitization tools have created possibilities that, although currently mostly unregulated, bring both great potential for improving treatment quality and a number of ethical issues that have to be dealt with (Thurzo et al., 2022). One of the possibilities offered by digitalization is the creation of 3D data, which can be analyzed, processed, transmitted, and stored more efficiently and cost effectively than analog data. Several companies around the world have started offering the treatment of their patients based entirely on this digital data.

Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

The process begins with a scan of the dental arch or jawbone via a 3D laser scan. Intention-based software is used to design the 3D model for the required applications: if it is an application for 3D printed or pressed inlays, the design will be of the inner surface that is formed by/materials; if the purpose of the model is for the application of an obturation plate or a surgical template, the design will be of the outer surface that faces away from the tissue and is based on the anatomy of the patient (Kasparova et al., 2013). The gradual application of these data—either as virtual data or as 3D prints—has brought a qualitative metamorphosis to prosthetic dentistry and in orthodontics. Quantifying tooth movements has made periodic studies of growth and development more credible and as a result, more valid in court.

However, in all these cases, both concerning the software and the 3D printer, it would be crucial to determine ownership of the data. The consequence of digitalization is a significant legal question: who owns the data—design or processing data? Is the material a significant proprietorial issue? Who manufactured the case, and who will be liable in case of error? Protecting software and ownership of data seems difficult if the data and printed model/retainer leave the computer and into dual use 3D printers around the world. It seems there is need for an advisory committee or organization that could formulate the most important code of ethics.

8.2. Regulatory Challenges

One of the challenges with surgical orthodontics using 3D printed models that an individual doctor faces is the selection of the 3D printer and polymer material. The most common polymer with which models are made is photopolymer resin. The polymer needs a few properties which are: drainage of printing materials which involve adequate post printing drainage activity to avoid deformities of the physical model, low shrinkage after solidification, dimensional stability over time and temperature, printing time, surface finish, splatter-proof, no requirement for coating to enhance surface finish, and delivery of the model with the finest surface finish (Balestra et al., 2024). When all the factors have been considered for a particular piece of equipment, the final bound of system specifications must be prepared. This specification will include all the factors considered when comparing the different manufacturers' products. This should include those factors that make the selected system superior in meeting the requirements of the user, the activities which must be done to effect the acceptance of the purchased equipment, and those details about the equipment which should be included on the purchase order. It is essential that this detailed specification be prepared. The specification becomes a formal contract between the purchaser and the manufacturer. It protects both parties in their dealings involving the purchase. If the equipment completely meets the individual needs, there is no legal basis for complaint against those items that were not included in the specification. If the equipment fails to perform as defined by the specification, the manufacturer may be obliged to furnish the

Power System Technology
ISSN:1000-3673
Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

equipment without further charges. Many purchases have been unsuccessfully contested in court on the basis that the purchaser had not sufficiently defined its needs and no protection for either party exists.

9. Conclusion

In the field of Prosthodontics, the relative novelty of 3D printing (3DP) has raised questions about the adopted protocols, finishes, technologies, and materials available for permanent restorations. The need for an understanding of the developing materials science, the relevant NGOs, and the objectives set by the different available standards was identified. Restorative indications for permanent restorations are typically for crown, inlay, onlay, and veneer type indications. Nevertheless, comparative studies between 3DP and traditional prosthetic workflows relevant to restorative dentistry are limited. Though only earliest case reports have been found, the application of 3DP to the prosthodontics workflow has already seen substantial research. Each component to the workflow has shown promise for future applications in digital manufacturing. Independent in vitro testing demonstrates the feasibility of 3DP in producing indirect restorations, denture bases, clasp designs, and castable patterns. Additional research explores the precision of newly formed materials and the handling properties of a monomer-polymer class of restoration material. Strong commercially available materials have become available and encouraged some independent testing. Trials comparing traditional workflows to a teeth-whitening, clear aligner, surgical guide, and occlusal splint application have so far returned positive results. Though independently testing some manufacturing aspects is underway, no published evidence was found comparing the multiple components of workflows across technologies. Historically, denture fabrication has had a pivotal role in the formation of the dental industry, and 3DP could have a similar influence in the future (Balestra et al., 2024). The advent of new digital technologies related to 3D imaging, computer design, modelling, manufacturing, and material science, has deeply influenced dentistry in the last few decades. More recently, an additive manufacturing process based on 3D printing (3DP) technology has been increasingly used in dentistry. This new class of technologies is capable of fabricating, layer by layer, complex structures starting from a digital model. The application of 3DP to dentistry enables the digital production of objects through the computerized design and modeling of tooth-and bone-like structures, allowing for both prosthetically driven implant and alveolar bone graft placement.

References:

1. Tang, Y., Zhang, Y., Meng, Z., Sun, Q., Peng, L., Zhang, L., Lu, W., Liang, W., Chen, G., & Wei, Y. (2022). Accuracy of additive manufacturing in stomatology. ncbi.nlm.nih.gov
2. Balestra, D., Lowther, M., Goracci, C., Mandurino, M., Cortili, S., Paolone, G., Louca, C., & Vichi, A. (2024). 3D Printed Materials for Permanent Restorations in

Power System Technology
ISSN:1000-3673
Received: 16-04-2025 Revised: 05-05-2025 Accepted: 22-06-2025

Indirect Restorative and Prosthetic Dentistry: A Critical Review of the Literature. ncbi.nlm.nih.gov

3. Paradowska-Stolarz, A., Malysa, A., & Mikulewicz, M. (2022). Comparison of the Compression and Tensile Modulus of Two Chosen Resins Used in Dentistry for 3D Printing. ncbi.nlm.nih.gov
4. L. J. Cruz, R., T. Ross, M., Skewes, J., C. Allenby, M., K. Powell, S., & A. Woodruff, M. (2020). An advanced prosthetic manufacturing framework for economic personalised ear prostheses. ncbi.nlm.nih.gov
5. Alvi, S. (2017). Comparison of the accuracy between 3D printed and milled dental models by a digital inspection software. [PDF]
6. Eyzaguirre, D., Salazar-Gamarra, R., Binasco Lengua, S., & Lauria Dib, L. (2023). Evaluation of additive manufacturing processes in the production of oculo-palpebral prosthesis. ncbi.nlm.nih.gov
7. Thurzo, A., Šufliarsky, B., Urbanová, W., Čverha, M., Strunga, M., & Varga, I. (2022). Pierre Robin Sequence and 3D Printed Personalized Composite Appliances in Interdisciplinary Approach. ncbi.nlm.nih.gov
8. Lu, T. Y., Lin, W. C., Yang, T. H., Dewi Sahrir, C., Shen, Y. K., & Feng, S. W. (2023). The Influence of Dental Virtualization, Restoration Types, and Placement Angles on the Trueness and Contact Space in 3D-Printed Crowns: A Comprehensive Exploration. ncbi.nlm.nih.gov
9. Pillai, S., Upadhyay, A., Khayambashi, P., Farooq, I., Sabri, H., Tarar, M., T. Lee, K., Harb, I., Zhou, S., Wang, Y., & D. Tran, S. (2021). Dental 3D-Printing: Transferring Art from the Laboratories to the Clinics. ncbi.nlm.nih.gov
10. Kasparova, M., Grafova, L., Dvorak, P., Dostalova, T., Prochazka, A., Eliasova, H., Prusa, J., & Kakawand, S. (2013). Possibility of reconstruction of dental plaster cast from 3D digital study models. ncbi.nlm.nih.gov