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Comparative evaluation of conventional treatment induction principles over 3D printing in the effective implementation of treatment plan in dentistry.

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Abstract

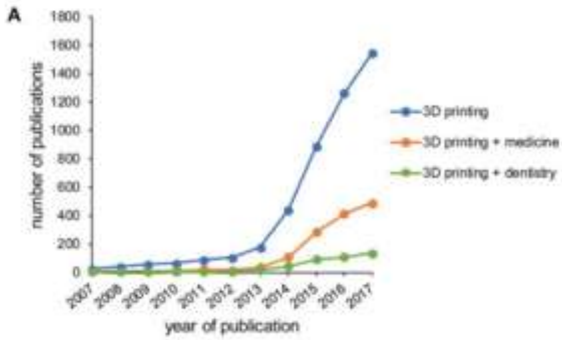
An overview on the currently available 3D printing technologies and their utilization in experimental, clinical and educational facets, from the perspective of different specialties of dentistry, including Oral and Maxillofacial Surgery, Orthodontics, Endodontics, Prosthodontics, and Periodontics; involving research and innovation, treatment modalities, education and training, employing the rapidly developing 3D printing process. Research-oriented advancement in 3D printing in dentistry is witnessed by the rising number of publications on this topic. Visualization of treatment outcomes makes it a promising clinical tool. Educational programs utilizing 3D-printed models stimulate training of dental skills in students and trainees. 3D printing has enormous potential to ameliorate oral health care in research, clinical treatment, and education in dentistry.

Keywords: 3D printing, additive manufacturing, bioprinting, dentistry, education, tissue engineering

Introduction

In the last few years development of 3D printing for medical and dental applications has increased strikingly. The drive behind advancement in 3D printing for medicine and dentistry emerges from the possibility of individualized products, savings on small scale productions, eased sharing and processing of patient image data and educational upgrading. This trend is reflected by the increasing number of publications on this topic (Figures 1A,B). Publication numbers for 3D printing in general, in medicine and in dentistry in particular increased over the past 10 years in which overall number of publications on 3D printing are higher in medicine than in dentistry (Figure 1A). Looking at the dental specialties it becomes evident that the attention in 3D printing is mainly focused on applications in oral surgery and prosthodontics, followed by orthodontics, while there are limited numbers of publications on applications in periodontics and endodontics (Figure 1B).

Figure 1



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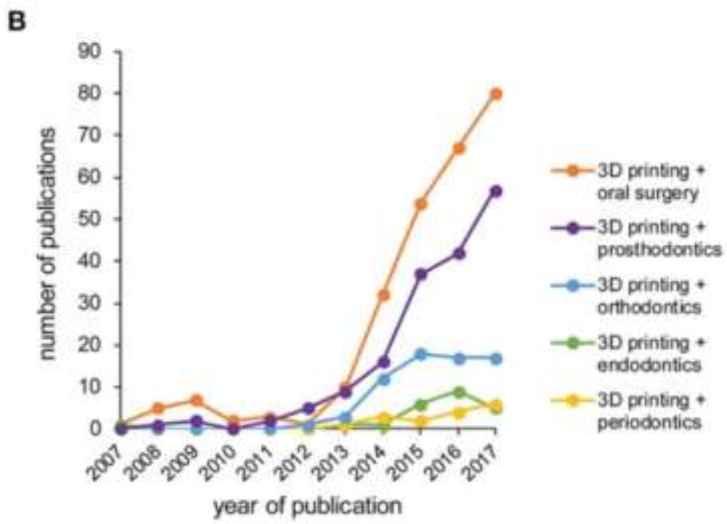

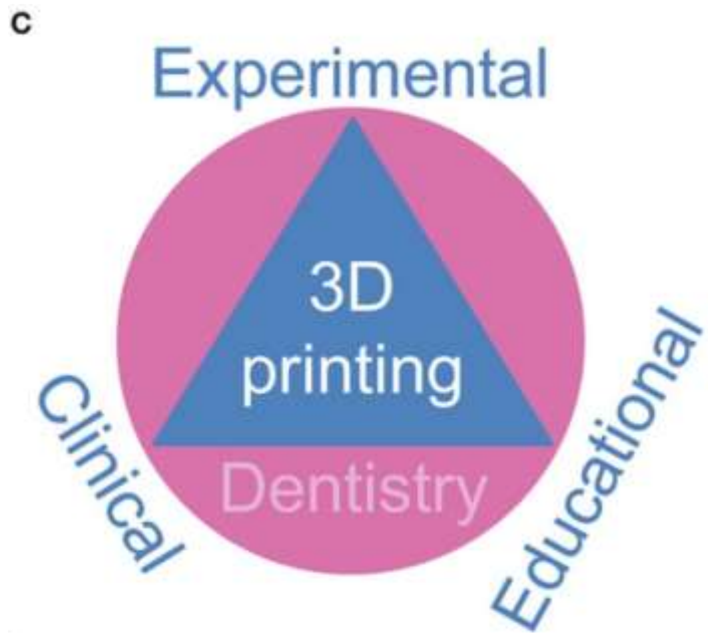

Figure 1

Increasing publication numbers in 3D printing for a variety of dental specialties. **(A)** Number of publications on 3D printing in general and 3D printing in medicine or dentistry in particular (Pubmed.gov; Search date: 01-25-2018; Search algorithm: “3D printing”; “3D printing” AND medicine; “3D printing” AND dentistry) from 2007-2017. **(B)** Number of publications on 3D printing in a variety of dental specialties (Pubmed.gov; Search date: 01-25-2018; Search algorithm: “3D printing” AND “oral surgery”; “3D printing” AND “endodontics”; “3D printing” AND “periodontics”; “3D printing” AND “endodontics”; “3D printing” AND “orthodontics”; “3D printing” AND “prosthodontics”) from 2007-2017. **(C)** Applications for 3D printing in dentistry include experimental, clinical and educational approaches

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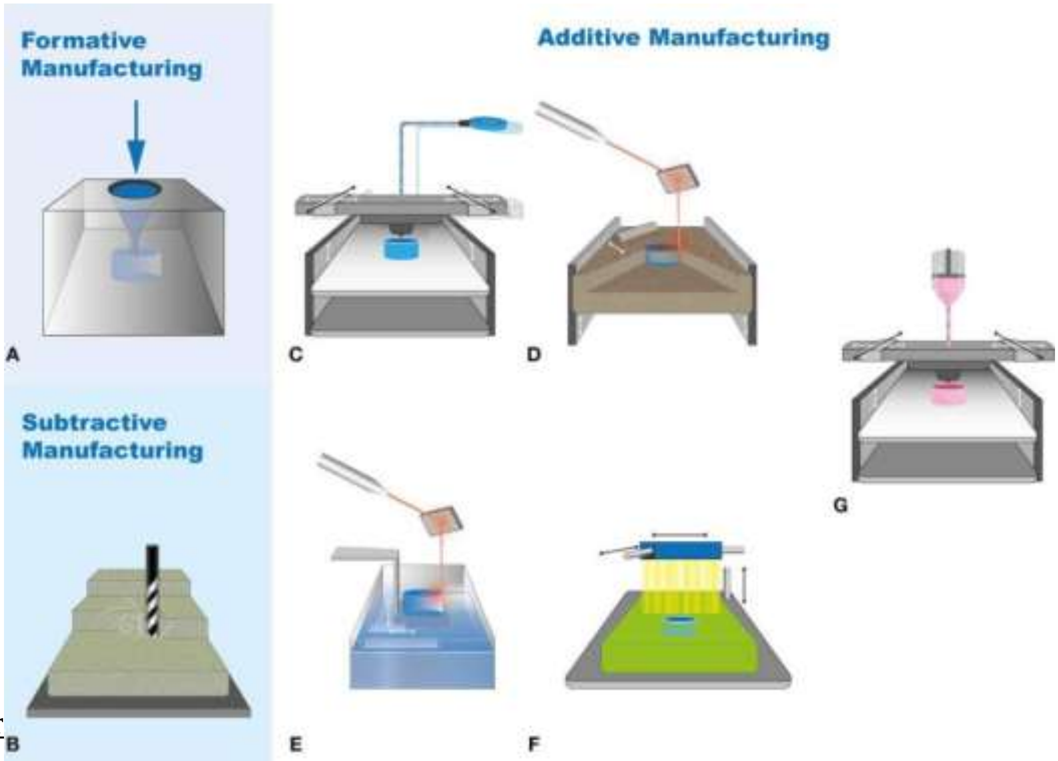
Table 1

Different types of 3D printers and their potential dental application.

3D Printer	Materials	Potential application in dentistry
Fused Deposition Modeling (FDM)	Thermoplastic polymers such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polyether ether ketone (PEEK), etc.	In-house production of basic proof-of-concept models, low-cost prototyping of simple anatomical parts
Stereolithography (SLA)	A variety of resins for photopolymerization, ceramic filled resins, etc.	Dental models, surgical guides and splints, orthodontic devices (aligners and retainers), castable crowns, and bridges.
Selective Laser Sintering (SLS)	Powder such as alumide, polyamide, glass-particle filled polyamide, rubber-like polyurethane, etc.	Hospital set up for metal crowns, copings and bridges, metal or resin partial denture frameworks
Polyjet printing	A variety of photopolymers	Hospital set-up manufacturing of craniomaxillofacial implants, sophisticated anatomical models, drilling and cutting guides, facial prosthesis (ear, nose, eye)
Bioprinter	Cell-loaded gels and inks based on collagen, photopolymer resins, agarose, alginate, hyaluronan, chitosan, etc.	Cell-laden scaffolds for hard and soft tissue printing



Figur

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Overview on the different manufacturing approaches. Conventional approaches comprising **(A)** Formative, **(B)** Subtractive manufacturing; widely applied additive manufacturing methods including **(C)** Fused deposition modeling (FDM), **(D)** Selective laser sintering (SLS), **(E)** Stereolithography (SLA), **(F)** Polyjet and **(G)** Bioprinting. Adopted from (Knowlton et al., 2015; Ji and Guvendiren, 2017; Ligon et al., 2017)

3D Printing in Prosthodontics

Replacing missing teeth has always been a field of progressive advancement in dentistry, dating back to historic times when materials such as wood, stone, gold, silver, and even extracted teeth from cadavers were used to replace the missing dentition and other parts of the jaw (Freedman, 2011). Traditionally, silicone polymers or alginate were used to produce intraoral impressions and compression- or injection-molding techniques (Figure 4) were used to fabricate dentures (Nogueira et al., 1999). This process is time-consuming, cumbersome and requires a highly skilled dental technician (Yuzbasioglu et al., 2014), especially in case of patients with gag reflex (Hacker et al., 2015), tumor resection, scarred lips post-resection of cancer (Kim et al., 2017), temporomandibular joint defects, or oral deformities. Ongoing research based on additively manufactured materials used to fabricate removable and complete dentures in prosthodontics has shown positive results so far with regards to physical and technical properties (Chen et al., 2015). With progressing advancement in digital workflow it is possible to directly print these prosthesis from silicone providing acceptable aesthetics and reducing the number of appointments for the patient at the same time (Unkovskiy et al., 2018). Bioprinting via the production of oral tissue equivalents might help to develop novel models to evaluate the biocompatibility of novel materials and thereby optimize research and development in material science.

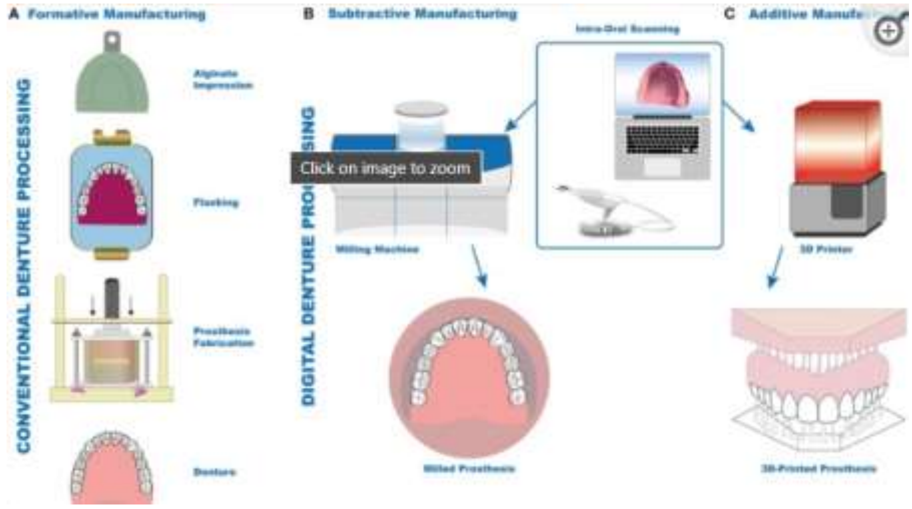

Figure 4

Conventional and digital prosthesis fabrication approaches. Conventional approach for denture fabrication by alginate impression and flasking method (**A**, Formative manufacturing). Digital approach with intra-oral scanning-based impression; manufacturing

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of denture either by CAD/CAM (**B**, subtractive manufacturing) or 3D printer (**C**, additive manufacturing)

Experimental approaches

Metallic and polymer-based materials are common in additive manufacturing of dental prosthesis and crowns while the use of ceramics is yet to be explored (Ebert et al., 2009). Published *in vitro* studies have shown that ceramics manufactured by lithography where the object is printed layer by layer, show comparable mechanical properties to milled ceramics (Uçar et al., 2018). However, manufacturing process, and strength and fracture toughness are areas that require further research. Most of the 3D printing techniques used today as selective laser sintering, selective laser melting or stereolithography usually result in porous structures whereas ink-jet printing enables production of complex dense ceramic-like structures (Ebert et al., 2009). To improve the mechanical properties of ceramics and increase its homogeneity, porosity should be eradicated resulting in a denser and more compact structure (Uçar et al., 2018). More research is required toward accomplishing the state-of-the-art in ceramics manufactured by 3D printing.

Clinical approaches

With the introduction of intraoral scanning and 3D printing, denture fabrication has become a more patient friendly procedure (Hu F. et al., 2017). Published case reports indicate that now it is feasible to successfully fabricate removable partial dentures for patients with reduced mouth opening or lip contractures (Kim et al., 2017). Fixed and removable dentures manufactured by 3D printing are clinically acceptable and have physical properties comparable to conventionally fabricated dentures (Gan et al., 2018). Studies have shown that 3D printing can be successfully employed for metal implant prosthesis using selective laser melting and electron beam melting (Revilla León et al., 2017). This leading-edge technology can be employed to reduce the tedious work of a dental technician and provide a more precise framework compared to the conventional framework. Metal crowns and interim resin restorations have shown comparable accuracy and marginal fit with respect to milled restorations (Alharbi et al., 2017). Thus, we see that additive manufacturing has a promising role to play in prosthodontics, especially in patients with facial disabilities or gag reflexes.

Educational approaches

In the past few years there has been an exemplary shift in the training of dental students and professionals on idealistic plastic typodonts to more real-life 3D-printed models that are based on data obtained by intraoral scans of patients (Hugger et al., 2011). This concept has been utilized in prosthodontics for training dentists on customized real patient-based models for veneer and crown preparation since in the mouth teeth are usually rotated and twisted or contain fillings, which makes the preparation of bridges and crowns more challenging (Kröger et al., 2017). The technique of polyjet printing has successfully been used to create models in different levels of hardness, replicating that of healthy enamel, dentin and caries so that the trainees experience the proprioception of working on a real tooth (Schweiger et al., 2016).

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Conclusion:

3D printing has the capacity to revolutionize dentistry. The different technologies have been applied for a variety of purposes in the field of dentistry (Figures 2,3, Table Table1).1). Currently the main focus is on surgical planning and the indirect production of implants or orthodontic aligners by printing the molds for these objects. In addition, 3D printing is used to create personalized tissue engineering scaffolds for usage in oral surgery. Experimental approaches include the application of 3D printing for the production of scaffolds which serve as carriers for growth factors or other bioactive molecules as well as cells. However, the results of previous studies show that 3D printing has many advantages, be it in the fabrication of fixation splints in oral surgery or in orthodontic orthosis molds. Because the print object is produced according to the image of the patient, the print can be tailored to optimally fit the anatomical conditions and thereby accuracy of aligners or implants can be improved.

When selecting the appropriate printing system, account must be taken of material availability, medical properties of the material, time required, and the desired resolution of the print object. The problem that requires further research is the limitation of the available material assortment in particular when moving beyond the canonical polymers as well as the improvement of printing speed and post processing requires. The used materials must meet the dental and technical requirements and biocompatibility standards. It is therefore of great interest to establish new, printable materials for dentistry that meet these requirements, as the expansion of the material range also opens up new possibilities for clinical applications of 3D printing in dentistry.

3D printing has a high potential for education as witnessed above in all the major disciplines of dentistry. It gives the surgeon a better subjective perception of the bone and teeth as compared to the stereotype typodont or acrylic models. With the advancement in materials and technology, the flexibility to manipulate the physical characteristics of additively manufactured materials, the trainees have the opportunity to develop better operative and proprioceptive skills (Hugger et al., 2011; Torres et al., 2011; Werz et al., 2018). Overall, 3D printing-based technologies have a tremendous potential to transform research, treatment methodology, and educational streams of dentistry ameliorating oral health care.

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