ADDITIVE DIGITAL TECHNOLOGIES IN CONTEMPORARY DENTAL MEDICINE. A REVIEW

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ABSTRACT

With the vast development of digital technologies in dental medicine more opportunities for their application emerge. As processing of dental appliances through computer-aided design (CAD) is still dominated by subtractive computer-aided manufacturing (CAM) technologies, additive manufacturing offers a wide range of options in the different areas of contemporary dentistry.

Keywords: *additive manufacturing, additive digital dentistry, 3D printing*

INTRODUCTION

Prosthetic dentistry deals with a wide range of methods and technologies in both removable (1) and non-removable prosthetics (2, 3). Digital technologies are increasingly entering everyday clinical practice. In Bulgaria a significant scientific contribution to the creation and testing of a methodology for digital occlusal analysis in patients with bruxism and bruxomania is made by the scientific developments of Dimova-Gabrovska (4,5,6), which expand the possibilities of modern occlusodontics.

Additive manufacturing, also known as 3D printing, is the process of building up an object layer by layer (drop by drop, particle by particle, etc.) (7). When compared to subtractive processing (8) (carving an object into a desired shape), it allows far more complex shapes and structures being processed (with almost any geometry). Also printing saves raw material and the quality of the processed object is not limited by the condition of the rotary carving instrument (9). Printing allowed some game-changing products in dentistry as clear aligners (10), implant and surgical guides (11).

Digital technologies are applicable in all areas of prosthetic dentistry—from prosthetics in childhood (12) to maxillofacial prosthetics (13).

All this argues the need to present a review on all methods for digital additive manufacturing.

AIM

The aim of this brief review is to summarize and analyze the different technologies and applications of additive manufacturing in contemporary dentistry.

MATERIALS AND METHODS

The article is based on various researches including retrospective, randomized trials and case report articles in PubMed, ResearchGate, ScienceDirect, and Google Scholar databases. The survey concerns a variety of techniques and analyzes previous systematic reviews on the topic.

All the articles included are in English only.

ADDITIVE TECHNOLOGIES

1. Polymerization-based printing:
   - 1.1. Stereolithography (SLA)—polymerization of a photosensitive monomer resins with a laser UV-light source.
     - 1.1.1. Digital light processing (DLP)—polymerization with a digital micromirror device—faster production but with rougher surface structure (consisting of tiny rectangular cubes—voxels).
   - 1.2. Solid ground curing (SGS)—polymerization with a UV source through a mask. Too complex processing.
   - 1.3. Liquid thermal polymerization (LTP)—polymerization with a heat source. Not very accurate.
   - 1.4. Beam interference solidification (BIS)—polymerization with two UV sources. Not very precise.
   - 1.5. Holographic interference solidification (HIS)—polymerization with a holographic image in a resin tank.
2. Laser melting:

2.1. Selective laser sintering (SLS)—heated fine powder is preheated and fused by a laser beam. Can be used with wax, nylon, composites, metals.
2.2. Selective laser melting (SLM)—similar to SLS, but with higher laser power for melting the powder.
2.3. Direct metal laser sintering (DMLS)—a.k.a direct metal printing (DMP)—used only for metal powders. According to Barazanchi et al. (14) the use of this additive method can make the fabrication of CoCr elements easier.
2.4. Laser engineered net shaping (LENS)—a.k.a. SLC, DMD, LPD (15), uses laser beam and a powder distribution nozzle. Enables production of larger objects, but lacks surface smoothness and precision.
2.4.1. Selective laser cladding (SLC)
2.4.2. Direct metal deposition (DMD)—similar to LENS, but with more than one powder nozzle.
2.4.3. Laser powder deposition (LPD)

3. Electron beam:
3.1. Electron beam manufacturing (EBM)—similar to SLS, but with electric beam, instead of laser. Works only with metal powder. Less precise than SLS

4. Extrusion processes:
4.1. Fused deposition melting (FDM)—a moving extruding head deposits a heated material onto a substrate. The most popular "desktop" printing system, usually with two moving heads—one for the object material and one for supporting material. Due to shrinkage not very precise.
4.2. Robocasting—layer-wise deposition technique for highly loaded colloidal slurries for dense ceramics (16) and composites.

5. Material jetting—objects are printed out of powder with sprayed adhesive (binder) or molten material:
5.1. Three-dimensional printing (3DP)—binder is placed by a moving nozzle into a descending powder bed layer by layer.
5.2. Multijet modelling (MJM)—thermo/photo polymer is placed by a moving nozzle into a descending powder bed layer by layer and polymerized with heat/UV light.
5.3. Ballistic particle manufacturing (BPM)—builds up molten droplets of thermoplastic material.
5.4. Thermojet—builds up molten droplets of thermoplastic material, similar to MJM.

6. Adhesive-based processes:
6.1. Laminated object manufacturing (LOM)—layers of special paper with thermo activated adhesive on one side are shaped with a laser beam and adhered together.
6.2. Solid foil polymerization (SFP)—layers of semi-polymerized plastic foils are layered and polymerized in shape.

7. Bioprinting—although still in an early stage, these technologies promise great improvement of guided tissue regeneration in dentistry (17):
7.1. Photolithography—used for tissue engineering scaffolds and microdevices (18).
7.2. Magnetic 3D bioprinting—manipulating cells in particular order with the help of magnetic nanoparticles ("nano-shuttles") and magnetic fields (19)
7.3. Stereolithography (SLA)—layer-wise bioink (20) scaffold printing (21).
7.4. Direct cell extrusion—similar to inkjet printing. Pressure during extrusion reduces cell viability (22).

APPLICATIONS IN CONTEMPORARY DENTISTRY

01. Orthodontics—additive manufacturing has been used for producing appliances as:
- study models
- clear aligners—both models for thermoforming and aligners (23)
- clear retainers—both models for thermoforming and retainers (24)
- models for indirect bonding technique and printed indirect bonding jigs (25)
- printed individual brackets (26)
- custom-casted removable appliances

02. Prosthodontics
- study models
- dentures
- crowns and bridges
- inlays, onlays, endocrowns
- digital smile design mock-ups and visualizations
- splints
- night guards
- maxillofacial ecto- and endo prostheses
- working models
- mouth guards
- preparation guides
- individual implant abutments
- ecto prostheses in the maxillofacial region

03. Conservative dentistry
- study models
- endodontic guides

- printed tooth models for endodontic student bench exercises
- tooth prototypes for tooth autotransplantation procedures
- templates for direct tooth restorations

04. Oral surgery
- study models for surgery preparation
- soft tissue retractors
- implantation guides
- individual implants
- individual guided bone regeneration (GBR) scaffolds
- individual soft tissue scaffolds

05. Maxillofacial surgery
- study models
- soft tissue retractors
- individual osteosynthesis implants
- individual GBR scaffolds
- individual soft tissue scaffolds
- ecto prostheses in the maxillofacial region

06. Periodontology
- surgical guides
- study models
- individual GBR scaffolds
- individual soft tissue scaffolds
- soft tissue retractors

CONCLUSION

The first commercial SLA printer—3D Systems SLA-1 was introduced in 1987 by Charles Hull. With the advancement of digital technology in the last decade many new applications of additive manufacturing have found a place in contemporary dentistry. Having the hardware for digital imaging, scanning and software for processing allows many of the procedures in the different fields of dental medicine to be planned and executed with precision and predictability of the results. With the combination of digital subtractive and additive manufacturing methods dental clinicians can achieve full customization of the appliances for their patients. Bioprinting is referred to as the "next big thing" (27) in medicine as the development of this technology will provide the opportunity to produce custom fabricated teeth and surrounding tissues (28).

The manufactured constructions optimally restore the masticatory function regardless of the food preferences (29, 30) of the patients and satisfy the medico-biological indicators for prophylaxis and aesthetics.

In conclusion—the presented review allows a clear approach when discussing the different methods for digital additive manufacturing. The presented information can be used for future research in the field, as it can also be used by dental medics in their everyday practice.

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