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Experimental research on some modern technologies and materials applied in prosthetic dentistry

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Abstract. The paper presents some modern techniques for dental prostheses and prosthetic dental prototypes - technologies by adding material. Several dental prostheses have been obtained using different additive technologies, high-quality metal and polymeric materials, including biocompatible materials. There were presented the technologies, such as: selective laser melting for metallic dental prostheses, thermoplastic extrusion and vat photopolymerisation for polymeric prosthetic dental models. These manufactured prosthetic elements have considerable advantages over those manufactured by conventional fabrication processes.

Keywords: Additive technologies, biomaterials, dental prostheses.

1. Introduction

Modern prosthetic dentistry has taken the best ideas since antiquity and has multiplied them into current technologies and materials. As a result of this symbiosis, the dentures of today, which are worthy of admiration, have appeared. Dental prostheses are dental structures designed to restore the anatomy and physiology of the dental system. Most often, dental prostheses should be installed if one or more teeth have been lost from different causes. Almost all modern prosthetic restorations are very close to the properties and appearance of the natural teeth. However, there are many disadvantages in their realization, such as manufacturing time and human factor errors. The manufacturing technologies with

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the best denture performance are undoubtedly the CAD / CAM (milling and additive technologies) computerized technologies that eliminate these deficiencies.
However, in additive technologies unused material can be used in the following processes, making this technology more economical than milling (Fig.1). These technologies provide an efficient and rapid method for designing and manufacturing biocompatible metal carcasses for complex dental prostheses and polymeric dental prototypes [1, 2, 3].

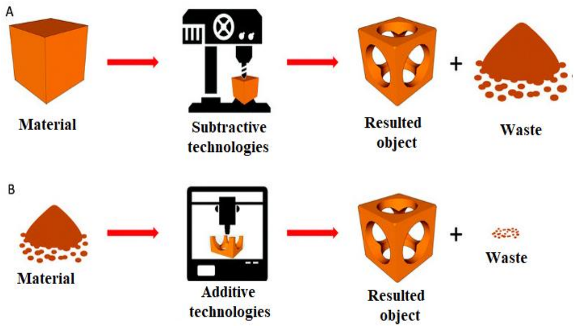

Fig. 1 Comparison between subtractive and additive technologies [4]

2. Material and methods

In this study three different additive technologies were used: selective laser melting for biocompatible metallic prostheses, thermoplastic extrusion and vat photopolymerisation for dental prosthetic polymeric prototypes.
Selective laser melting (SLM) is a layer manufacturing process that allows the generation of 3D metal complex parts by consolidating successive layers of the sprayed material over one another.

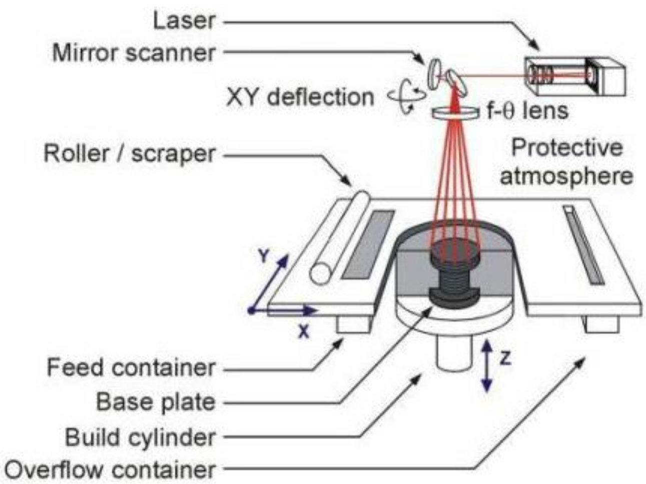

Fig. 2 Selective laser melting operating principle [1], [5], [6]

Consolidation is achieved by processing selected areas using the thermal energy provided by a focused laser beam (Fig.2). The common materials for this technology are titan and Co – Cr alloys. It is the technology with the greatest development in the dental sector due to its incomparable performance regarding the quality of fabricated prostheses or implants and the properties of biomaterials.
Fused deposition modeling (thermoplastic extrusion) is the most used 3D printing technology: it is the world's largest 3D printer base and is the first technology to expose people. Fused deposition modeling (FDM) is an additive manufacturing process that belongs to the material extrusion family. These processes use a filament of different material qualities, which it heats up to a temperature with several degrees below the melting temperature, then reduces its diameter to 0.12-0.15 mm by extruding it into a depositing device, a device that moves in the XOY plane to materialize a section of 3D virtual model (Fig.3). In the FDM, an object is obtained by selectively depositing the molten material in a predetermined layer-by-layer form. The materials used are thermoplastic polymers in the form of filament [6].

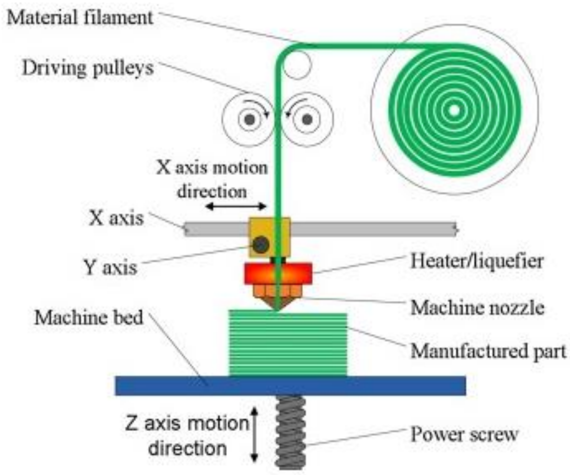

Fig. 3 Fused deposition modeling operating principle [7]

Additive processes based on photopolymerisation use a liquid photopolymeric resin vat, of which the designed model is constructed layer by layer. Ultraviolet light is used to cure the resin where necessary, while a platform moves the object downwards after each new layer is hardened (Fig.4). Digital light processing (DLP) technology follows an almost identical method of producing parts compared to stereolithography (SLA). DLP can obtain faster printing times compared to SLA for certain parts because each whole layer is exposed simultaneously instead of tracing the area with a cross section with a laser. Photopolymeric resins sensitive to ultraviolet light are used as materials.

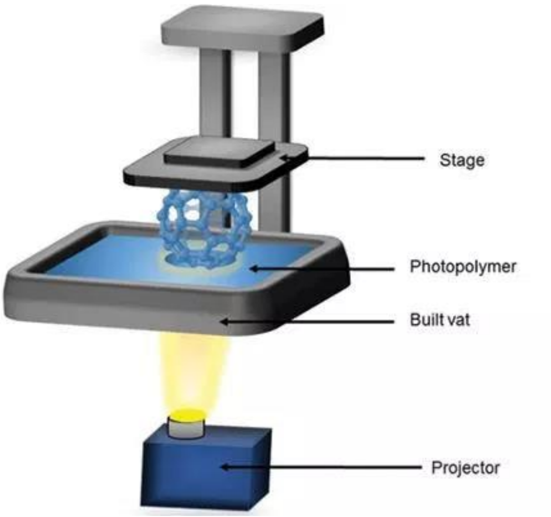

Fig. 4 Digital light processing operating principle [8]

In this study, the three technologies described above and four different materials (including two biocompatible - certified for medical use) were used. The properties of used materials are presented in the Table 1.

Table 1 Properties of used materials [9-12]

Material	**Technology**	**Properties**	**Value**	**U.M.**
Co-Cr alloy	*SLM*	Density	8.8	g/cm^3
		Elastic modulus	200	GPa
		Tensile strength	1250	MPa
		Biocompatibility	Yes	-
ABS Medical SmartFil	*FDM*	Density	1.05	g/cm^3
		Printing temperature	240	°C
		Tensile strength	36.48	MPa
		Biocompatibility	Yes	-
CarbonFil	*FDM*	Density	1.3	g/cm^3
		Printing temperature	220	°C
		Tensile strength	52.5	MPa
		Biocompatibility	No	-
Industrial Blend resin	*DLP*	Density	1.016	g/cm^3
		Elongation	13	%
		Tensile strength	40	MPa
		Biocompatibility	No	-

The raw material for the metallic dental prostheses was the powdered Co-Cr metal alloy with the following composition: Co 59%, 25% Cr, 9.5% Cr, 3.5% Mo, Si 1% Fe, Mn < 1%. In addition to high material biocompatibility, this alloy also has the following advantages: very high corrosion resistance, thermal expansion coefficient that allows great flexibility in the selection of ceramic coating and provides very good mechanical properties.

ABS Medical Smartfil filament is a high quality filament designed specifically for medical applications. This 3D filament has been manufactured with ABS pellets that meet the biocompatibility requirements of USP Class VI or ISO 10993-1 certifications, which ensures its biocompatible up to 30 days in contact with the human body.

CarbonFil is based on the PETG polymer with 20% ultra lightweight and relatively long carbon fiber, which has led to a particularly rigid 3D fiber reinforced filament. CarbonFil is twice as rigid as pure PETG and yet even 10% more impact resistant, which is a remarkable feature of the carbon fiber reinforced filament.

Industrial Blend resin is widely applicable in the field of high-precision three – dimensional printing for 3D printers, printing on stereolithography technology (DLP) due to its compatibility and versatility. Industrial photopolymer has a fairly high polymerization rate (on average 0.5 seconds for a layer of 0.05 mm on standard DLP printers with a lamp power of about 240W).

3. Experimental

Each additive technology is an advanced manufacturing method with a well-established work plan, but almost all have the same implementation steps. The first step of the realization is to create a 3D model of the dental restoration (Fig.5).

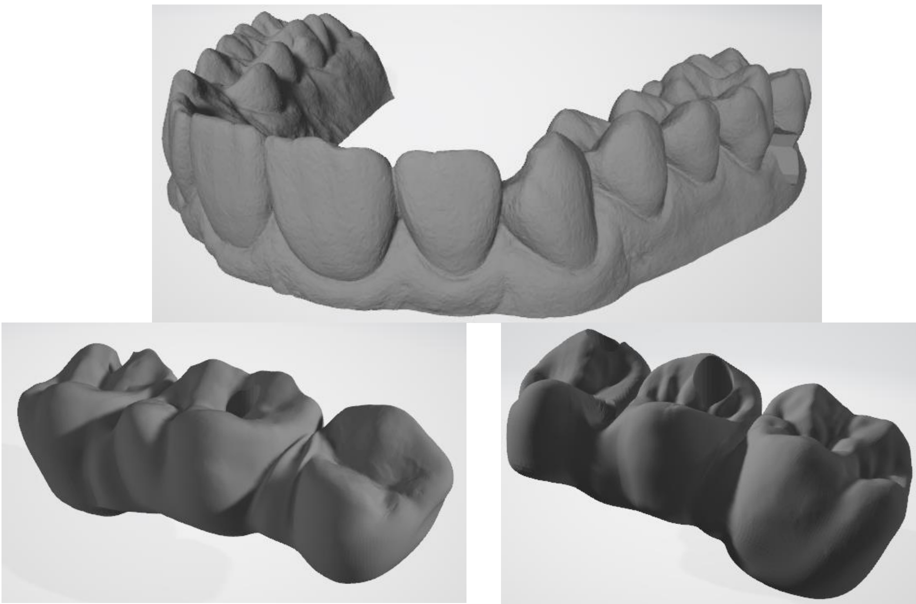

Fig. 5 Some designed three-dimensional models of dental restorations

When 3D modeling is completed, the resulting file is transferred to .stl format, which is recognized by most modern 3D printers. The STL file with future dental element pieces is processed by a special slicing program, which translates it into a control code G for the SLM, FDM or DLP printer. Fig.6 presents the interface of slicing softwares for each used technology.

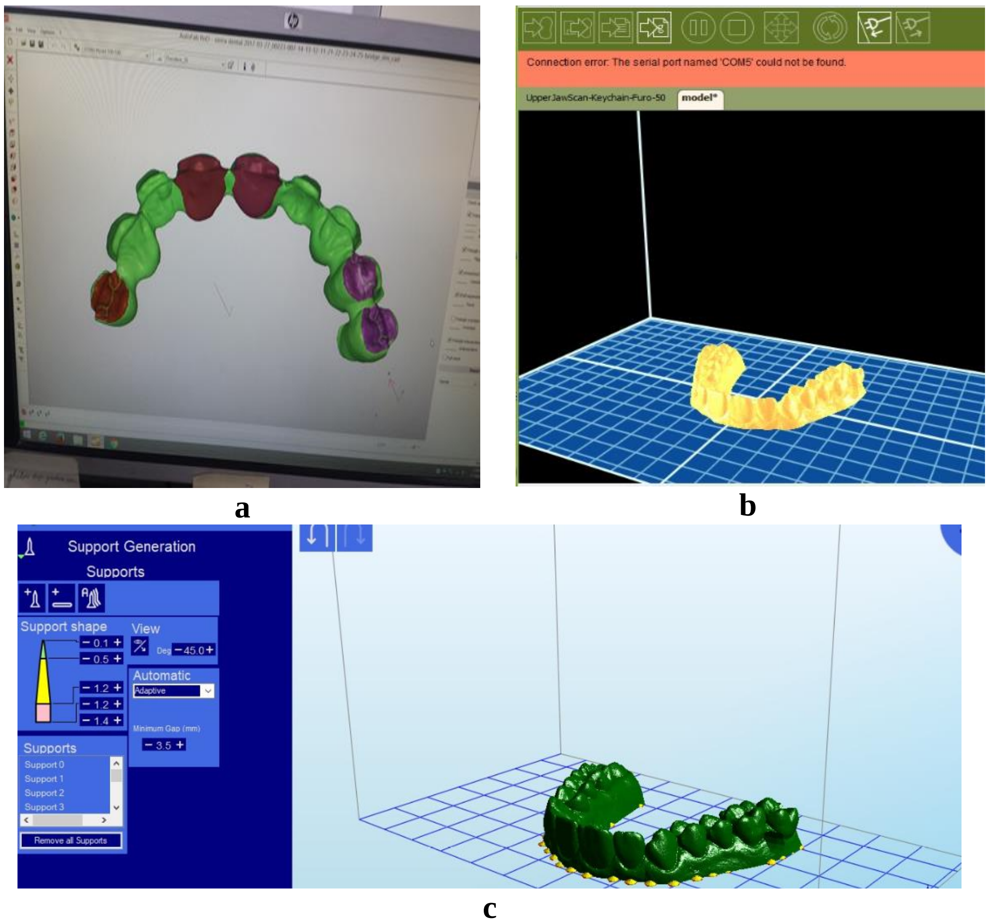

Fig. 6 Slicing software interfaces: a – Autofab for SLM printer; b – Replicator G for FDM printer; c – Creation Workshop for DLP printer

The slicing software for processing the file in case of fused deposition modeling technology (FDM) is Replicator G. The software has a preview panel that informs the users about how the output file will look and also allows the complex effects such as "Move", "Rotate", "Scale" and "Mirror" to be applyed. This function is useful for performing last minute improvements on the future model and for fine-setting some issues that might become evident only in a 3D environment too. This software cuts the model into thin horizontal plates and turns it into digital code G,

which the printer recognizes. As main working procedures, the software sets the trajectory of the print head when the material is applied. After the model has been prepared, the object is sent for printing. The end of the thread is inserted into the feed nozzle. After few seconds, a soft molten plastic thread will appear in the extruder.
The Creation Workshop software for DLP printing allows the view and positioning of the workpiece on the work plane as well as mirroring, scaling, rotating and the posibility to simulate the deposition of the layers during the construction process of the object. It is very important to insert the sacrificial layers to support the piece during processing. Also, the work platform must be submerged in the photopolymeric liquid before the printing begins.

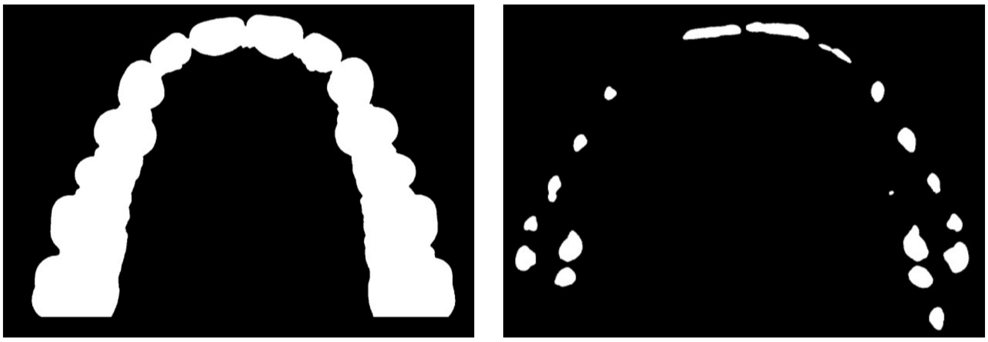

Fig.7 Simulation of deposition layers for DLP printing technology

Fig.8 and Fig.9 shows finalised metallic dental prostheses realized by selective laser melting from Co – Cr alloy and prosthetic dental prototypes obtained by fused deposition modeling technology (ABS medical and PETG with reinforced carbon fiber) and digital light processing technology (industrial photocurable resin).

Fig.8 Co – Cr dental prostheses realized by selective laser melting

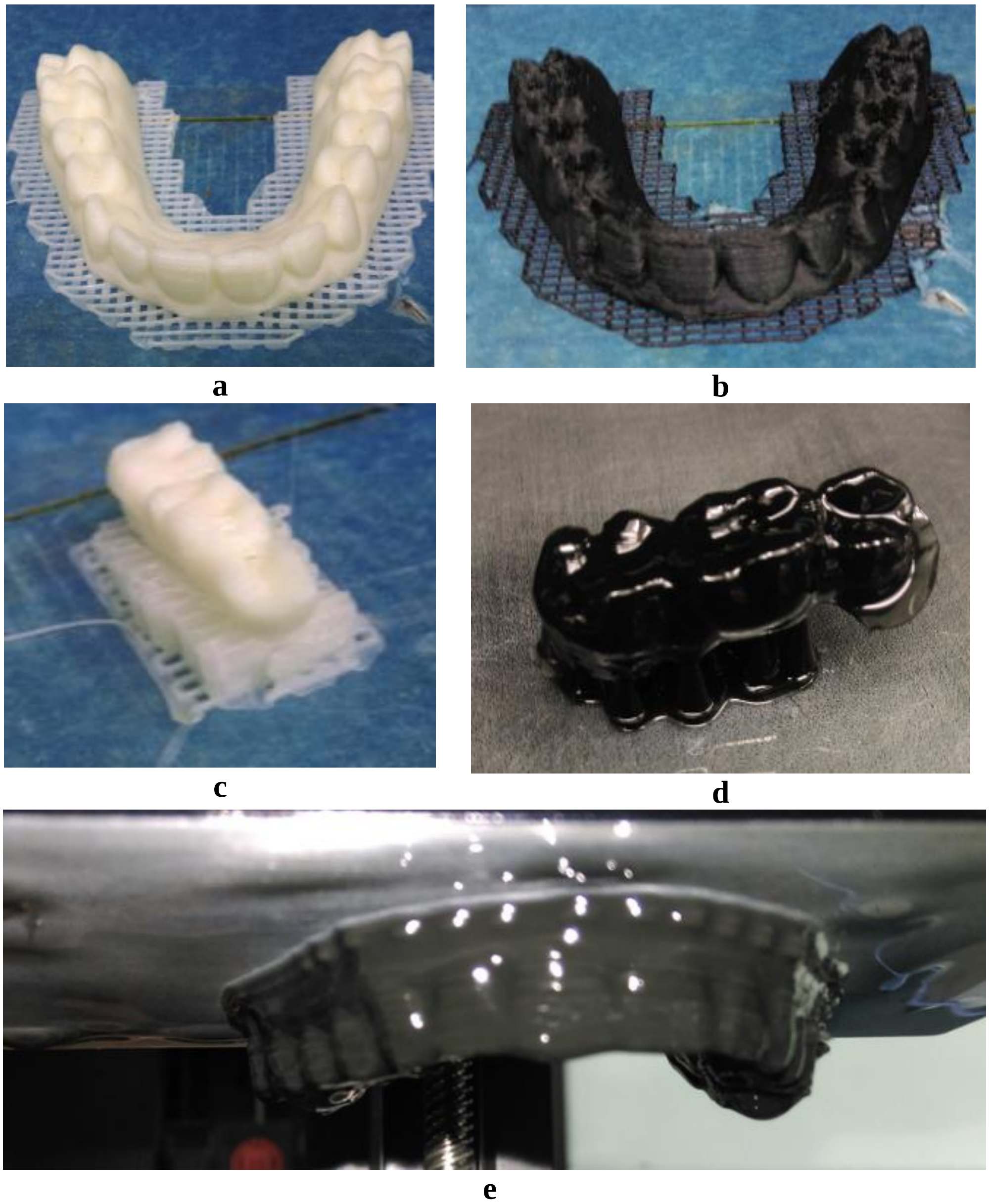

Fig. 9 Polymeric prosthetic dental prototypes: a, c – Dental prototypes realized by FDM technology, ABS medical material; b - Dental prototype realized by FDM technology, CarbonFil; d, e – Dental prototypes realized by DLP technology, industrial photocurable resin material

The final step of realization is the post - processing, so each technology has different finishing methods. In the case of metallic parts, post-processing becomes the most important, because it is a finished bioprosthesis that must not create adverse reactions to human tissues. At the polymer prototypes the final working stage is the removal of the sacrificial layers. Fig.10 illustrates obtained dental prosthetic elements.

Fig.10 Realized dental prostheses and prosthetic dental models by three different technologies

4. Conclusions

Nowadays, additive technologies have gained a great interest among specialists due to the elimination of deficiencies that may arise in conventional processes: human factor dependence and long manufacturing time. In this study, some dental prosthetic prototypes were successfully performed by two additive technologies: FDM (Thermoplastic Extrusion) technology and DLP technology (photopolymerization), obtaining nontoxic and even biocompatible dental prototypes in a very short time. These dental prototypes bring advantages and benefits in medicine, especially in surgery and orthopedics by improving communication between physicians and patients, because of the better understanding of the diagnosis and therapeutic treatment, especially by the latter. Also, the three-dimensional physical model can be used in the planning of very complex surgical interventions that could be practiced on these models. In addition to prototypes realized by FDM and DLP technologies, metallic dental prostheses have been obtained through selective laser melting, which can be used as prosthetic restorations of patients. It is a technology of the future, which will certainly gain even greater interest among specialists and patients, offering remarkable quality prostheses.

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