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Prosthetic treatment protocol with fixed dental constructions made on 3D printed cast patterns

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ABSTRACT

Purpose: of the present paper is to develop prosthetic treatment protocol for fixed partial dentures made of 3D printed cast patterns.

Design/methodology/approach: The clinical and laboratory protocols for manufacturing of fixed prosthetic constructions upon 3D cast patterns are developed on the basis of the literature review and our previous experimental investigations. Comparison between the conventional technique and innovative approach is made.

Findings: The terms "semi-digital treatment plan" and "fully digital treatment plan" are defined according to the way of obtaining data for the virtual 3D model and the production method of the fixed prostheses. A classification of treatment protocols with non-removable partial dentures produced by additive technology is developed. Protocols for "semi" and "fully" digitized treatment plans with fixed partial dentures made by casting with 3D printed models are created.

Research limitations/implications: Implementation of the fully digitized protocol for manufacturing of fixed prosthetic constructions via 3D printed prototypes requires specific equipment in the dental office and dental technician laboratory – intraoral scanner and CAD/CAM system with 3D printing machine.

Practical implications: Establishing of systematic clinical and laboratory protocols helps dental specialists to implement the innovative working approach in their practice with no risk of neglecting or omitting of some important procedures which increases the quality and long lasting effect of the dental constructions.

Originality/value: Following the developed protocols reduces the role of the subjective factor in production technology of fixed prosthetic constructions while saving labour and time.

Keywords: Materials, Biomaterials, 3D printing, Cast patterns, Treatment protocol

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BIOMEDICAL AND DENTAL MATERIALS AND ENGINEERING

1. Introduction

A sophisticated treatment plan in prosthodontics is always built upon individualities of the exact patient and the present features of the prosthetic field. However, establishing of clinical protocols helps to reduce the risk of neglecting or omitting of some important procedures which increases the quality and long lasting effect of the dental constructions. Prosthetic dentistry differs from other branches of the dental medicine and general medicine as well for the alternation of the clinical manipulations in the protocol with laboratory stages for fabrication of the prostheses during the whole treatment process [1-4]. Development of the material science and technologies shortens some of the procedures in treatment with fixed prosthetic constructions [5]. Digitalization and computerization in dentistry has made this trend increasingly clear in the recent years. This leads to a reduction or even to exclusion of the subjective factor, which increases the accuracy of the constructions and reduces the production time for their construction [6-8].

In 2007, J.-P. Kruth, I. Naert and B. Vandenbroucke [9,10] patented a method for construction and fabrication of over-implant infrastructure for complex dental prosthesis using Selective Laser Melting (SLM). According to the way the data for the 3D virtual model is collected, manufacturing of prosthetic constructions via SLM can be done by three ways: 1) conventional partially digitized (standard); 2) conventional fully digitized (accelerated); 3) completely digital approach (fast) [11]. The first mode includes conventional impression technique and pouring gypsum cast which is then scanned. In the second one direct scanning of conventional impression is done which skips the gypsum model fabrication. The third mode characterizes with direct scanning of prosthetic field in the oral cavity, i.e. digital impression.

The information available for the protocols about prosthetic treatment using additive technologies for production of fixed dentures is targeted mainly to the SLM process. While there is not sufficient information about the stages of clinical treatment and manufacturing of metal infrastructures of dental constructions, using 3D printed cast patterns. The aim of the present paper is to develop prosthetic treatment protocol with fixed partial dentures made of 3D printed cast patterns. The clinical and laboratory protocols are developed on the basis of the literature review and our previous experimental investigations [6,12,13]. Comparison between the conventional technique and innovative approach is made.

2. Classification of protocols for treatment with fixed prosthetic constructions made by additive technologies

In general, there are two main technological approaches for fixed constructions' fabrication. The first one is the well known conventional way of dental alloy casting by lost-wax technique. The second possibility includes the new

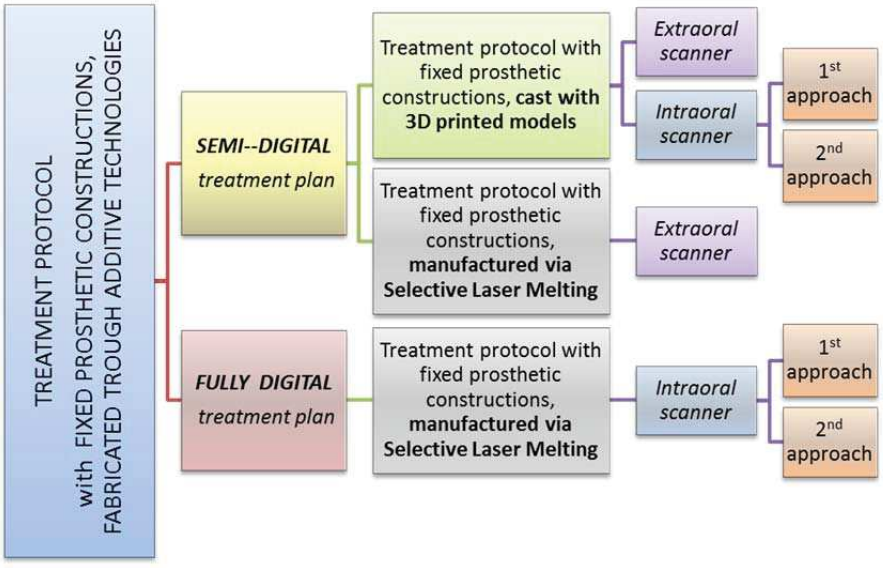

Fig. 1. Classification of the protocols for treatment with fixed prosthetic constructions made by additive technologies

technologies (subtractive or additive) where the CAD-CAM systems are integrated. The "CAM unit" is a cumulative term because it may include different machines using various technologies such as: ultrasonic milling machine; 3D printer based on the principle of stereolithography for manufacturing of provisional constructions and cast patterns from polymers; printing machines for selective laser melting of metal alloys or selective laser sintering of porcelain for fabrication of final prosthetic constructions.

As an attempt to systemize the variety of possibilities for manufacturing of dental restorations better, a more generalized classification with two divisions only can be used for the clinical and the laboratory protocols - semi and fully digital (Fig. 1). It can be referenced to the treatment plan also.

- In *semi-digital treatment plan* the fabrication of the fixed constructions begins as usual with conventional impression taking, followed by the first laboratory step of pouring a working model from gypsum. Next, the gypsum cast is scanned and a virtual 3D model of the future construction is created into the special software (CAD unit). The digital image is further transferred to the CAM unit, where the real object is going to be fabricated – cast pattern, temporary or final construction. Some procedures at the end are done by hand.
- *Fully digital treatment plan* starts with digital impression made with intraoral scanner. Then CAD/CAM machine directly produces the prosthetic restorations from polymers, porcelain or metal alloys by cutting, melting or sintering. For the exclusion of the initial handmade manipulations regarding impressions and gypsum casts this approach is considered to be entirely digitized.

3. Conventional technology – short overview

Treatment plan with fixed prosthetic constructions, produced through conventional technology is presented within Table 1. It consists of 6 clinical and 3 laboratory stages and each of them includes several clinical or technological manipulations. In the classical mode of operation, the metal frameworks of the prosthetic constructions are produced by centrifugal casting on dust free burning out wax patterns, all operations in the laboratory stages being performed manually. This technology is labor-intensive and time-consuming on the one hand, and on the other - it helps to generate errors and to get low quality constructions.

4. Treatment protocol for fixed prosthetic constructions made upon 3D printed cast patterns

With the development of communications, the use of the potential of digitization and the implementation of modern production technologies in the dental offices and dental laboratories, it becomes possible a part of the clinical manipulations (impression taking) and a large part of the technological operations (generating virtual models of prosthetic constructions, working with CAD/CAM systems) to automate. This allows: 1) to eliminate multiple manual operations and to increase the accuracy and quality of the fixed prosthetic constructions; 2) to shorten part of the technological operations and reduce the production time.

Table 2 presents the protocol of treatment plan with bridge constructions, manufactured through casting with 3D printed patterns**.** It differs from the conventional approach in the third clinical and second laboratory stage. Depending on the available equipment in the third clinical stage, there are two possibilities for work: with extraoral or intraoral scanner.

a) *Working mode with extraoral scanner* upon standard procedure requires conventional final impressions of prosthetic field after retraction of the free gingival margin around abutments; determining of the colour and material of aesthetic veneering; establishing of jaw relation.
b) *Working mode with intraoral scanner* starts with optical (digital) impression and the data is formatted into a specific file (STL).

The second laboratory stage is illustrated by Fig. 2. It includes 3 main technological steps (Table 2):

1) fabrication of cast patterns via 3D printing; 2) casting the bridge construction and 3) divesting and cleaning the casted bridge. The approach for production of 3D printed cast patterns depends on the way impression is taken – with extraoral or intraoral scanner. When using the *working mode with extraoral scanner* a gypsum model is needed for scanning in laboratory scanner and obtaining the data for the virtual model (Fig.2-1). The *working mode with intraoral scanner* requires digital impression and gives two possibilities for the further operations. The first one is direct structuring of virtual construction in the software of CAD unit upon the data from the digital impression.

Table 1.
Treatment protocol with fixed prosthetic constructions, manufactured through conventional technology [2]

Clinical protocol	Laboratory protocol
First clinical stage Registration of the patient, anamnesis, examination, paraclinical study, determination of abutment teeth, discussion of the type of prosthetic construction, preliminary impressions of upper and lower jaws.	
	First laboratory stage Pouring of two pairs of working models from the preliminary impressions: one for documentation, and the second for fabrication of provisional construction.
Second clinical stage 1. Preparation of abutment teeth according to the indications – shoulder, bevel, chamfer, featheredge, etc.; 2. Fabrication of provisional construction for protection of the abutments against chemical and physical irritants as well as restoring the occlusal and articulation balance; 3. Insertion of the provisional construction with temporary cement for the time of healing process of the soft tissues around the abutments.	
Third clinical stage 1. Final impression of the prosthetic field after retraction of the free gingival margin around abutment teeth; 2. Determination of the material and the colour for the aesthetic veneering; 3. Determination of jaw relation.	
	Second laboratory stage 1. Pouring of gypsum cast with removable dies; 2. Handmade fabrication of wax prototype of the final construction's framework; 3. Investing the wax pattern and preparation of mould; 4. Casting the construction of dental alloy; 5. Divesting and cleaning of the cast prosthesis – preparation for metal framework clinical try-in before aesthetic veneering.
Fourth clinical stage 1. Fitting and adjustment of the metal structure according to the preparation margin of abutments; 2. In cases of vestibular veneering only- adjustment according to the adjacent teeth and antagonists is also necessary.	
	Third laboratory stage 1. Aesthetic veneering of the metal framework.
Fifth clinical stage 1. Adjustment of the ready final constructions; 2. Cleaning and disinfection; 3. Final cementation to the abutments. For metal-ceramic constructions there is an additional ceramic try-in for establishing the proper occlusal and approximal contacts before the final fixation.	
Sixth clinical stage Not mandatory- analysis and observation of the prosthetic construction and surrounding soft tissues condition.	

Table 2.
Treatment protocol with fixed prosthetic constructions, manufactured through casting with 3D printed patterns

Clinical protocol	Laboratory protocol
First clinical stage Registration of the patient, anamnesis, examination, paraclinical study, determination of abutment teeth, discussion of the type of prosthetic construction, preliminary impressions of upper and lower jaws.	
	First laboratory stage Pouring of two pairs of working models from the preliminary impressions: one for documentation, and the second for fabrication of provisional construction.
Second clinical stage 1. Preparation of abutment teeth according to the indications – shoulder, bevel, chamfer, featheredge, etc.; 2. Fabrication of provisional construction for protection of the abutments against chemical and physical irritants as well as restoring the occlusal and articulation balance; 3. Insertion of the provisional construction with temporary cement for the time of healing process of the soft tissues around the abutments.	
Third clinical stage	
With extraoral scanner 1. Conventional final impressions of prosthetic field after retraction of the free gingival margin around abutments; 2. Determining of the colour and material of aesthetic veneering; 3. Establishing of jaw relation.	*With intraoral scanner* 1. Digital impression;. 2. Formatting the data into a specific file type (STL).
	Second laboratory stage (Fig. 2)
	1. Fabrication of 3D printed cast patterns
	Working mode with extraoral scanner 1. Pouring a gypsum model with removable dies. 2. Scanning the model into laboratory scanner and transferring the data to a computer with CAD software. 3. Generating virtual model of the prosthetic construction (Fig. 2). 4. Constructing the bridge according to the preparation margin, adjacent teeth and antagonists. 5. Formatting the data into STL file and transferring it to 3D printer, working with wax or polymers. 6. Choice of optimal technologic regime. 7. Printing cast pattern of the bridge construction. It is possible at this stage to produce resin provisional bridges via 3D printing of cutting.
	Working mode with intraoral scanner Two possibilities: *First possibility:* Direct production of cast pattern for the bridge construction upon virtual model by following steps 3-7 from *" working mode with extraoral scanner"* . *Second possibility:* 1. Printing working model of the prosthetic field from polymers. 2. Scanning the model into laboratory scanner. Technological operations continue following steps 3-7 from *" working mode with extraoral scanner"* .

Clinical protocol	Laboratory protocol
	2. Casting the construction 1. Investing the 3D cast pattern and fabrication of the mould; 2. Casting from dental alloy.
	3. Divesting and cleaning of the cast construction. Preparation for metal try-in before aesthetic veneering.
Fourth clinical stage 1. Fitting and adjustment of the metal structure according to the preparation margin of abutments; 2. In cases of vestibular veneering only- adjustment according to the adjacent teeth and antagonists is also necessary.	
	Third laboratory stage Aesthetic veneering of the metal framework.
Fifth clinical stage 1. Adjustment of the ready final constructions; 2. Cleaning and disinfection; 3. Final cementation to the abutments. For metal-ceramic constructions there is an additional ceramic try-in for establishing the proper occlusal and approximal contacts before the final fixation.	
Sixth clinical stage Not mandatory- analysis and observation of the prosthetic construction and surrounding soft tissues condition.	

The second one is 3D printing of resin working model which afterwards to be scanned. Both working modes have the purpose to collect and transfer data from the physical prosthetic field to the special software where a virtual bridge will be generated and formatted in a compatible for the printing machine STL file. The special software makes possible adjustment of optimal thickness of the building layer as well as the number and position of the supports (Fig. 2-2). The choice of the printing parameters is done according to the material and printing machine. The final result is obtaining a highly precise cast pattern (Figs. 2-3, 2-4) which guarantees the quality of the final constructions (Fig. 2-5). The casting process of the 3D printed polymeric prototypes (second laboratory stage, Table 2) does not differ itself from the conventional one (Fig. 2-4) no matter of the working mode chosen. It is important at this stage the compliance requirement of the investment material and the thermal regime of the mould heating to be met with the material of the 3D printed model.

The analysis of the protocol for treatment with bridge constructions made by casting with 3D printed paterns shows that it belongs to the group of partially digitized treatment plan (Fig. 1). Whether extraoral or intraoral scanners are being used, many manual casting operations remain in a second laboratory stage.

5. Conclusions

The present article defines the terms "semi-digital treatment plan" and "fully digital treatment plan" based on the way of obtaining the data on the virtual 3D model and the method of production of the fixed prosthetic constructions. A classification of treatment protocols with fixed prostheses produced by additive technologies has been developed. Based on the preliminary experimental and research work, "semi" and "fully" digitized treatment plans with fixed partial dentures, made by casting on 3D printed models, were developed.

They will be of great practical benefit to the specialists, working in dental clinics and dental laboratories, in the successful implementation of the 3D printing technologies for casting of high-quality frameworks for fixed prosthetic constructions.

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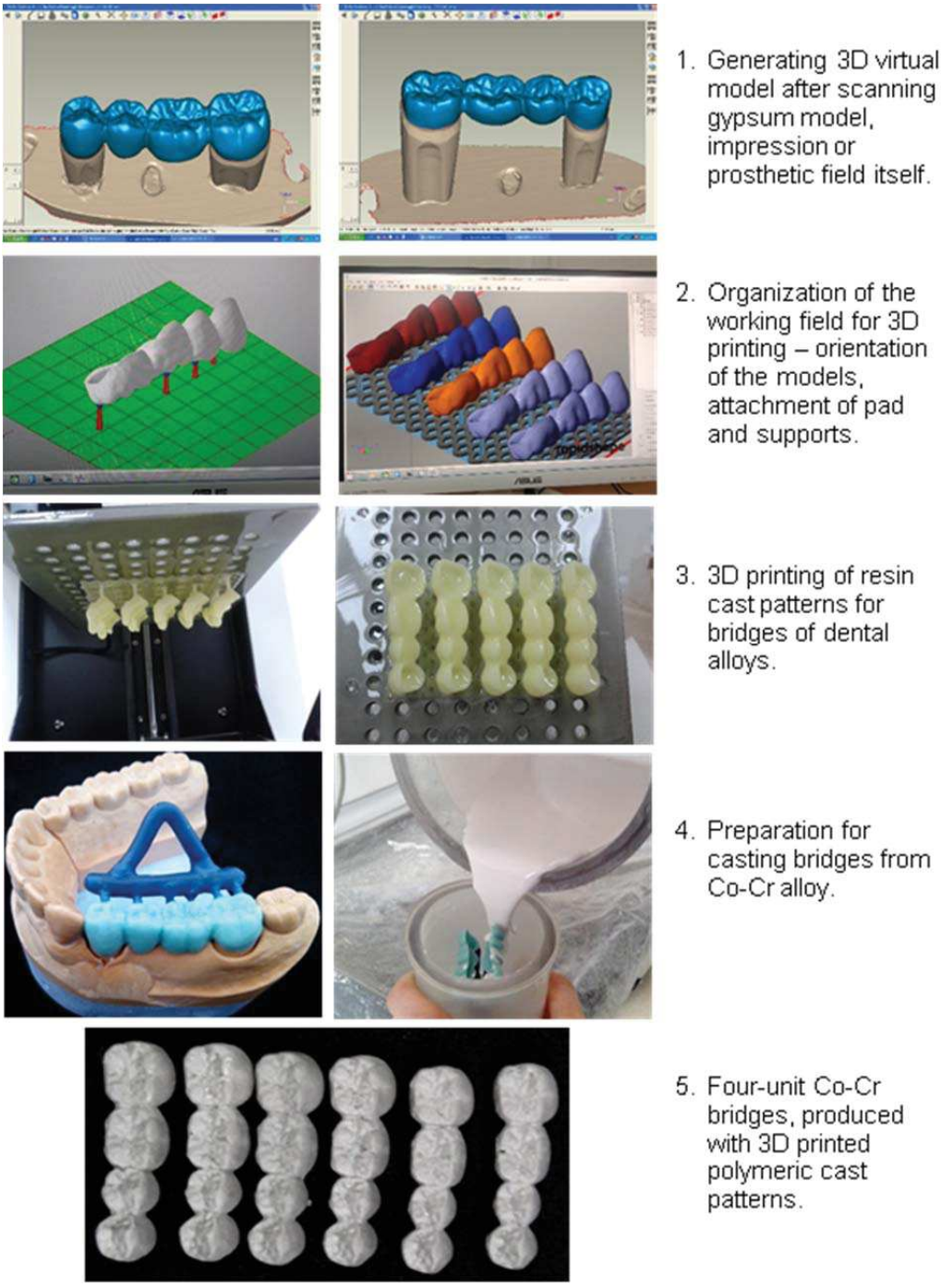

Fig. 2. Manufacturing of Co-Cr fixed prosthetic constructions via casting of 3D printed polymeric models

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