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UDC: 616.314-76/-77
DOI: https://doi.org/10.2298/VSP220526088S

Dentistry 4.0 concept in designing and manufacturing removable partial denture frameworks

Koncept „Stomatologija 4.0" u planiranju i izradi skeleta parcijalne proteze

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Key words:
computer-aided design; dentistry; denture design; denture, partial, removable.

Ključne reči:
kompjutersko oblikovanje; stomatologija; zubna proteza, oblikovanje; zubna proteza, parcijalna, mobilna.

Introduction

Dentistry and the global concept of digital transformation go together very well. The result is deleting borders between the physical and digital. That deletion of boundaries led to automation and robotization going at the expense of cyber-physical systems (CPS) enabled by the Internet of Things and cloud computing [1–3]. Analogous to the Fourth Industrial Revolution, dentistry conceived in this way is called Dentistry 4.0.

In recent years, Dentistry 4.0 has been the most common topic of many professional meetings. Some authors say that we are in the entrance hall of this global concept, while others, including the authors of this paper, believe that we are well inside it. Thanks to Dentistry 4.0, several diagnostic procedures, as well as laboratory and clinical procedures, have become part of the CPS. There are many areas of dentistry where diagnosis, planning, and therapy are based on highly automated processes and digitalized flows [digital impressions, computer-aided design (CAD) and computer-aided manufacturing (CAM) denture technology, digital radiography and cone-beam computer tomography (CBCT), digital face-bow and virtual articulators, computer-guided implant surgery, and computer-guided diagnostics and treatment in orthodontics, etc.] [1, 2].

In this paper, we described and gave a critical review of the Dentistry 4.0 concept in designing and manufacturing removable partial denture (RPD) frameworks.

RPD frameworks can be made using different techniques. The RPD framework fabricated by casting has a long tradition, and dental appliances obtained using this technique have good clinical results. Cast patterns and frameworks are often used in research to compare results with selective laser melting and sintering frameworks and patterns [4–7]. There are two possibilities for digitalization in manufacturing the RPD framework: the analog-digital and the digital option.

Analog-digital method of RPD frameworks production

The analog-digital method or indirect metal production is a step towards fully implementing the Dentistry 4.0 concept in the design and fabrication of the metal RPD framework. In fact, this method combines analog and digital systems depending on the equipment of dental offices and dental laboratories.

Analog technique (AT) – digital technique (DT) in designing and manufacturing RPD frameworks has the following steps: 1) physical impression with elastic materials – AT; 2) making a master (stone) model – AT and scanning the master model with an extraoral scanner – DT; 3) digital survey and design – DT; 4) print resin framework pattern – DT and investing a printed framework pattern in investment materials – AT; 5) preheating, heating, and casting – AT; 6) sandblasting, surface finishing, and polishing of RPD frameworks – AT.

This technique introduces digitalization elements into the conventional process of creating a metal RPD framework. An RPD framework is designed on a computer using available commercial programs. A virtual RPD design in Standard Tessellation Language format (STL file) is then sent to a 3D printer that prints the RPD framework in a polymer. The print

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ed polymer RPD framework is visually controlled and, after placing sprues, enters the investment material (forming a refractory block) [8]. The following procedure is the same as in the conventional method. The advantages of this combined technique are simplified design (diagnostic survey is performed on a computer) and the facilitated creation of a virtual model of the RPD framework. There is no preparation of the master model for duplication, no duplication of the master model in the investment materials, and no dipping in wax of the refractory model and savings in time and materials.

The disadvantages of this technique include having a computer, a design program, and a 3D printer for polymer materials.

Digital method of RPD frameworks production

The digital method, or direct metal production of RPD frameworks, actually implies the implementation of Dentistry 4.0 at full capacity. The stages of this technique are intraoral digital scanning, digital model creation, digital survey and design, 3D printing and heat treatment, finishing and polishing and printing of the working model.

Intraoral digital scanning

After usual introductory procedures, analysis of the diagnostic cast, and preparation of retention teeth, a digital impression of supporting tissues is taken (Figure 1). Digital impressions, also known as 3D intraoral scanning (IOS) for RPD are indicated for Kennedy Class III and Class IV partially edentulous arches (bounded saddles) with several missing teeth [9–11]. It is necessary to take several scans of both arches. The ultimate result of scanning software processing is a full-mouth image. Caution is required at the free-end saddles (Kennedy Class I and Class II). Free saddle boundaries on the digital impression are equal to the free saddle boundaries taken by the mucostatic impression. The protocol states that the free saddle should be impressed within its functional boundaries, in other words, by the mucodynamic impression. In exceptional cases, a digital impression can be taken with a short free saddle and a saddle with low mucosal resilience [12]. In all other cases of the free saddle, a functional impression is desirable. After taking a full-mouth image, a therapist can send the digital impression to a lab online.

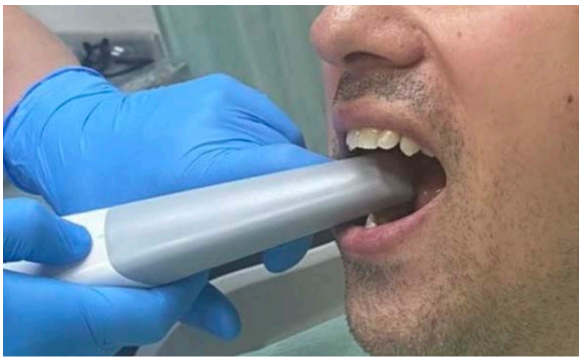

Fig. 1 – Taking a digital impression by using a wand-like tool connected to a computer.

Digital model creation

Using a computer and advanced commercial software, a dental technician created a virtual model (Figure 2).

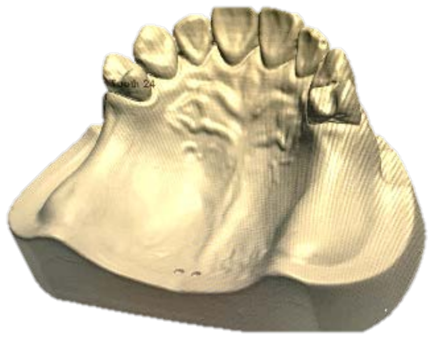

Fig. 2 – Digital model creation – the first step in designing and manufacturing removable partial denture frameworks.

Digital survey and design

RPD frameworks are digitally designed using specialized software through a series of digital steps similar to conventional laboratory procedures. The second step involves determining the path of RPD insertion using commercially available RPD CAD software (Figure 3). The software measures the depth of undercuts and the parallelism of guide surfaces of abutment teeth. The software rotates the virtual model in all three planes and suggests a survey line based on these calculations [13]. The digital model is then oriented for the appropriate path of insertion. The next step includes the blockout of the undercuts and the preparation of the space for the retentive clasp tips (Figure 4). The workflow in the digital design framework of RPD includes laying thin layers of virtual wax and meshwork patterns on the edentulous area, the virtual building of major and minor connectors (Figure 5), and the virtual building of rests and clasp arms (Figures 6 and 7). Before laser melting and sintering a Cobalt-Chromium (Co-Cr) alloy, it is necessary to set up special supports that will be strong enough to hold and stabilize the framework when sintering the alloy (Figure 8). It is often necessary to add cross-arch supporting bars that will connect the left and right sides of the framework and thus further stabilize the object during sintering.

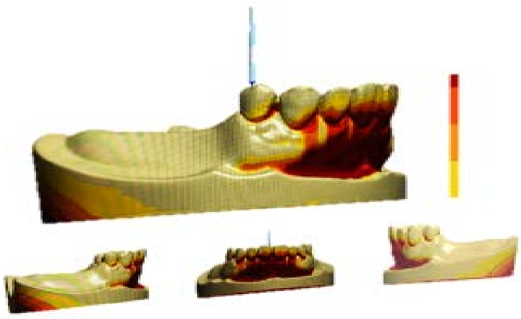

Fig. 3 – The second step in designing and manufacturing removable partial denture frameworks is determining the path of insertion.

Fig. 4 – Virtual blockout of undercuts (pink color) using available removable partial denture computer-aided design software.

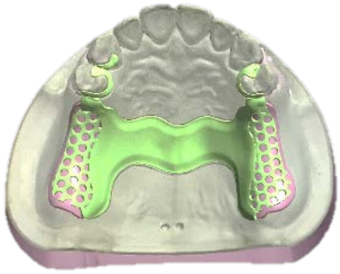

Fig. 5 – Thin layers of virtual wax and meshwork patterns on the edentulous area and the virtual building of major and minor connectors, rests, and bracing parts of the clasp.

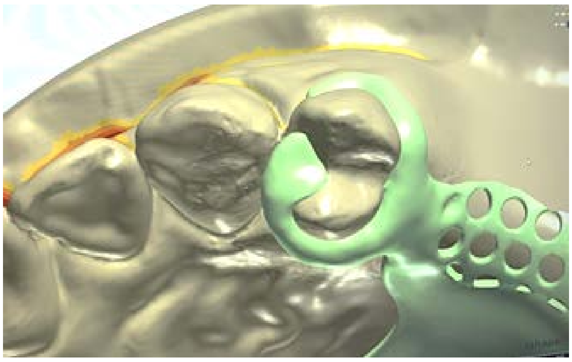

Fig. 6 – Virtual building of the clasp assembly.

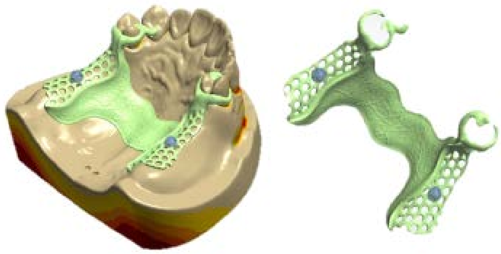

Fig. 7 – Complete adjustment of the framework with connectors, clasps, rests, finish lines, and tissue stops.

Fig. 8 – Illustration of the supports necessary for successfully laser melting and sintering the removable partial denture framework.

Fig. 9 – Moment of laser melting and sintering the cobalt-chromium alloy.

3D printing and heat treatment

From the computer, a digital framework (STL file) is sent to a 3D printer that laser melts and sinters the Co-Cr alloy, building a metal RPD framework. The parameters of the 3D printer are set as default and the dental technician "schedules" the digital frameworks and adjusts their angle to the printer platform. The sintering process takes about 90 min (Figure 9). After the end of sintering, the RPD framework is thermally processed, together with the platform of the 3D machine, in order to release internal stresses.

Finishing and polishing

New DryLyte technology combines at the same time the sandblasting and the mechanical and dry electropolishing of RPD frameworks. Three metal frameworks can be finished/polished simultaneously (about 60 min), which contributes to environmentally friendly technology and time savings (Figure 10).

Printing of the working model and transferring of the RPD framework to the dental office

The digital model (STL file), already used for designing the RPD framework, is sent to a 3D printer (based on the principles of stereolithography) which prints the model in an advanced photopolymer. Now, for the first time, we see the physical working model to which the completed RPD framework is adapted (Figure 11). The RPD framework on the working model is sent to the dental office for further clinical procedures. A finished RPD framework is checked in the

Fig. 10 – Processing of printed metal removable partial denture frameworks by DryLyte technology.

Fig. 11 – A finished removable partial denture framework on the printed model ready to be sent to the dental office.

patient's mouth for fit, retention, and occlusion. The remaining procedure is the same as with conventional methods of making RPDs.

Advantages and disadvantages of the digital concept in designing and manufacturing RPD frameworks

The advantages of the digital concept in designing and manufacturing RPD frameworks are the following: communication between the dentist and the dental technician is simplified; digital impressions, compared to traditional tray-and-putty dental impressions, are much more pleasant for the patient and more comfortable for the therapist; a digital impression, in addition to its accuracy, provides the dentist with the opportunity to have a complete insight into the impression from different angles, allowing them to correct any mistakes immediately while the patient is still in the chair; digital impressions can be sent to the dental laboratory without delay; working time in the laboratory is significantly reduced – there is no preparation of models for duplication and duplication of models in investment materials, no modeling in wax, no placing the sprues, preheating, or casting; *post*-fabrication process of the RPD framework (finishing and mechanical and dry electropolishing) is significantly shortened and facilitated by DryLyte technology; all clinical and laboratory procedures in the manufacturing of RPD frameworks are environmentally friendly; in the long-term estimates, the costs of manufacturing a metal RPD framework have been reduced.

The disadvantages of the digital concept in designing and manufacturing RPD frameworks are negligible compared to the advantages and include the following: the initial costs of an intraoral camera and scanning software; initial costs of 3D printers and the CAD software; increased costs for the education and training of dental technicians; the impossibility of making some special framework shapes of RPD due to limitations of the available software and manufacturing procedures.

Full implementation of the holistic Dentistry 4.0 approach in therapy of the partially edentulous patients with RPD is still not possible. A big step towards achieving this goal has been made with the introduction of the digital concept in designing and building RPD frameworks. The most crucial step in the procedures for fabricating RPD frameworks is to provide as much accuracy as possible in the reproduction of the supporting tissue. Digital impression techniques are recommended for partially edentulous patients with tooth bounded saddles, and the procedure is the same as digital impressions for fixed prosthetics. The accuracy of the digital impression in these cases is excellent, and its indication is unquestionable. Digital impression for free-end saddles is possible with a lot of limitations. Based on the research of many clinicians [14–17], as well as our experience, the traditional silicone impression is recommended in partially edentulous patients with free-end saddles. The silicone impression is poured out in super-hard stone. The stone (master) model is then scanned to obtain a digital model. These are actually the first and second steps of the analog-digital method of RPD framework production. The further procedure is completely digitized. It is possible to do a 3D scan directly from the silicone impression. In that case, it is necessary to print the working model in the polymer on which the framework is adapted and send it to the dental office for further procedure.

The Dentistry 4.0 approach requires the involvement of people of different professions and the knowledge of new-generation dental materials, new technologies, and application possibilities of CPS in dentistry. Materials used today in printing the RPD metal framework are highly sophisticated materials [14, 18–20]. Today, the most precise metal framework RPDs are obtained using special Co-Cr alloys "type 5" according to ISO 22674 (e.g., EOS Cobalt-Chrome RPD, Krailling, Germany; Mediloy S-Co, BEGO, Bremen, Germany).

Thanks to the new technologies (3D printing, DryLyte technology, and other technological innovations) supported by CPS, the degree of automation in the fabrication of metal RPD frameworks today is pretty high.

According to the literature, the accuracy of RPD frameworks fabricated using digital techniques (IOS and Additive Manufacturing techniques) is equal to or better than that of conventional RPD frameworks manufactured in a traditional way [21–25]. Fabricating RPD frameworks using digital design and 3D printing technology is a big step toward creating a smart manufacturing ecosystem in dentistry [15].

The majority of authors believe that, in the future, the expected benefits of this concept in the development of metal RPD frameworks should include high-strength materials with outstanding biocompatibility, excellent precision of fit, and cost-effective dental appliances for dentists and patients [1, 14, 15, 26].

Conclusion

Dentistry 4.0 has changed the face of dentistry over the past decade. The Dentistry 4.0 concept has improved the designing and manufacturing of RPD frameworks in terms of reducing the number of clinical appointments, shorter chair time, and greatly simplifying laboratory procedures. The precise fit of the RPD framework on the supporting tissues, comfort in work for both the dentist and the patient, and the absence of medical waste are a big step forward in the dental profession.

Conflict of interest

The authors declare no conflict of interest.

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Received on May 26, 2022
Revised on September 20, 2022
Accepted on October 4, 2022
Online First October 2022