APPLICATIONS OF 3D PRINTING TECHNIQUES FOR OCCLUSAL SPLINTS USED IN BRUXISM

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ABSTRACT

Currently, there are several digital technologies for the manufacture of occlusal appliances used in bruxism, which may involve subtractive technologies or additive technologies. The purpose of the study is the presentation of a digital workflow for occlusal splint through CAD-CAM with 3D printing. Material and method: The technology used for the manufacture of the occlusal splint included as stages: obtaining digital models, creating the digital design of the splint, 3D printing of the splint from a rigid PMMA material, adapting the splint on dental arch and in occlusion. Results: The digital technology for the occlusal appliance was used for a patient with sleep bruxism. The patient wore the occlusal splint for 9 weeks, with positive feedback. Conclusions: The digital technology proposed for occlusal splints in bruxism is reliable, and the rigid PMMA occlusal splints 3D printed are a viable alternative to conventional occlusal appliances in bruxism.

Key words: occlusal splint, 3D printing, rigid PMMA, bruxism

INTRODUCTION

Bruxism is a masticatory muscle contraction disorder that can occur while asleep or awake [1,2,3]. Occlusal splints used in bruxism are removable intraoral devices usually applied to the maxillary arch (e.g. Michigan occlusal splint) and worn intermittently during the night. Occlusal splints have the role of protecting the teeth from dental wear and stabilizing the occlusion [4,5]. The rigid PMMA occlusal splints are frequently used in bruxism, built to patient deconditioning from the position that causes the dysfunction [6,7,8]. The occlusal splints must provide uniform, bilateral occlusal contacts of equal intensity, without altering the mandibular position or dental occlusion [9]. When applied intraorally, the occlusal splints must be processed and adjusted to not generate changes in the dental structures, such as hypersensitivity [9]. The efficiency of the occlusal splints is associated with the frequency of follow-up and the perfect adjustment in occlusion by the dentist [10].

In the oral cavity of patients with bruxism, high occlusal forces are generated (values between 450 N and 650 N) [11,12], and therefore the materials used for the manufacture of occlusal splints must have optimal mechanical properties [13,14,15]. The material of choice for the manufacture of occlusal splints is still poly (methyl methacrylate) (PMMA) [6,16].

Currently, a couple of workflows followed to manufacture occlusal splints, conventional and digital, exist. The conventional workflow
for occlusal splints includes PMMA (a cold polymerized powder-liquid) as a material of choice. The technique includes clinical and technical stages: impressions, casting of plaster models, interocclusal registration, casts mounting in articulator, PMMA application on casts, PMMA polymerization, finishing of the occlusal splint [9]. Poly (methyl methacrylate) has optimal mechanical properties that have made it the gold standard for occlusal splint. Among its benefits are optimal chemical and physical qualities, aesthetics and convenient price, ease of manufacture [6,16]. However, the direct polymerization technique has the disadvantages of long working time, release of a large amount of residual monomer and polymerization shrinkage that can influence the mechanical properties of occlusal splints, affecting their clinical performance and increasing fracture susceptibility [14,17].

In the last decade, the digitization of the dental laboratory has led to the automation of occlusal splints manufacturing processes by computer-aided design / computer-aided manufacturing (CAD/CAM) using additive (3D printed) or subtractive (milled) technologies [6,18]. Subtractive technology is based on the milling of occlusal splints from a prefabricated poly (methyl methacrylate) disc [14]. The resulting milled devices have a good fit due to the lack of polymerization shrinkage, as the PMMA discs are industrial products and have a high double bond conversion rate [6]. The occlusal splints obtained by milling are more expensive and cannot have the desired thickness for every situation, limited by the thickness of the PMMA discs used for milling [19]. Also, this technology is highly waste generating [20].

The additive method (stereolithography) involves the use of a 3D printer that polymerizes the liquid material with LASER according to the digital project. Subsequently, the resulting splint needs further processing and finishing. Stereolithography (SLA) and digital light processing (DLP) are the most used techniques as PMMA 3D printing technologies for occlusal splints [14,15,16,21]. In SLA, photopolymers change from liquid to solid form under the action of ultraviolet light (UV), while in DLP, photopolymers change after exposure to LED light [22]. The exposure to light source of photopolymers is gradual until the appearance of occlusal splint by photopolymerization of PMMA layer by layer [21, 22].

Photopolymer resins used to make occlusal splints are typically 75% oligomers, 25% monomers and photopolymerization initiators, which, when exposed to ultraviolet light, react with the oligomers and monomers to form polymers [23]. Studies have shown that material properties, printing resolution, post-curing processing, light speed and intensity have an impact on the accuracy of 3D printed occlusal splints [6,23,24,25]. Compared to polymer materials used in milling and conventional technologies, photopolymer materials had slightly similar mechanical properties [6].

The study aimed to present a 3D printing digital workflow to manufacture an occlusal splint for sleep bruxism using a rigid PMMA material and the advantages of the digital occlusal splint.

MATERIALS AND METHOD

The study included a patient diagnosed with probable bruxism after assessment using the STAB (Standardized tool for the assessment of bruxism) criteria [2,26], who received an indication for occlusal splint for treatment. Participant gave a written informed consent before the start of the study.

The occlusal splint was manufactured following a workflow involving 3D printing [27,28].

Working steps
1. Digital impressions of the dental arches and occlusion were obtained after
conventional impressions, pouring of plaster casts, mounting of dental casts in articulator and digital scanning of the casts.

1. Digital impressions of the dental arches and occlusion

Maxillary and mandibular arches were impressed with standard perforated trays (Moldeira, Spain) and Zetaplus with Oranwash condensing silicones (Zhermack, Italy) (Figure 1a). Maximum intercuspation occlusion impression used Occlufast Rock occlusion silicone (Zhermack, Italy). The impressions were disinfected (Zeta 7 Spray, Zhermack, Italy) and sent to the dental laboratory where grade IV plaster casts were cast. The dental casts were positioned in maximum intercuspation according to the interocclusal records. (Figure 1b, 1c). Later, an intraoral scanner (Medit I600, Medit, Korea) was used to scan the dental casts and the STL files were transferred to the computer design program.

2. Computer aided design (CAD)

Computer aided design of the dental appliance included STL file importing in a software and occlusal appliance design. For the design, the steps were: creating the digital database, establishing the design, mounting of virtual casts in virtual articulator and adjusting of occlusal contacts.

The design of the occlusal splint with a specific software for Exocad splints (Exocad 3.1. Rijeka, Exocad GmbH Darmstadt, Germany) followed the next steps: choosing the splint parameters, uploading the scanned files, mounting the digital casts in the Artex digital articulator, the occlusal splint design (Figure 2, Figure 3, Figure 4).

For the case studied, the design of the occlusal splint was as follows: all maxillary teeth covered, flat and smooth occlusal surfaces, similar and balanced bilateral contacts, and canine guidance with lateral disocclusion and bilateral incisal contacts during mandibular protrusion.
Figure 2. Creating the digital database
a. Preparing the patient file, b. Choosing the parameters of the future occlusal splint, c. Uploading the scanned files, d. Orienting the working cast with visualization from the occlusal side.

Figure 3. Establishing the design of the occlusal splint
a. Establishing the necessary parameters for the interior design of the occlusal splint, b. Design of the splint – drawing the limits, c. Design of the splint – occlusal aspect, d. Design of the splint – installation in the Artex CR articulator.
Figure 4. Virtual dental casts mounted in the Artex virtual articulator for adjustment of occlusal contacts in maximum intercuspation and during anterior and lateral guidance.


3. Computer aided manufacturing involved 3D printing of the occlusal appliance and postprocessing and finishing.

After obtaining the occlusal splint design, the splint project was transferred to the printer software.

Figure 5. a. Resin for occlusal splint b. Asiga Max printer.
The occlusal splint was printed from an ester-based photopolymer resin, NextDent Ortho Rigid Blue (3D Systems, NextDent B.V., Soesterberg, The Netherlands) (Figure 5a) at an angle of 45° and in layers of 50 μm thickness. NextDent Ortho Rigid Blue is a commercially available 3D printing UV-curable acrylate-based resin material intended for the manufacture of 3D printed dental splints. The resin is a monomer based on acrylic esters that presents as a viscous liquid (1.1 to 1.6 Pa) with a relative density (water) of 1.1 to 1.2, and better solubility in organic solvents than water (MSDS). The properties that the company presents are flexural strength: 78 MPa; flexural modulus: 2075; elastic modulus: 1596 MPa; stress intensity factor 1.1 MPa m1/2; total fracture work 262 J/m2; sorption 20 µg/mm3; solubility 0.8 µg/mm3; residual monomer below 0.1% (w/w).

The Asiga Max 3D printer (3D MAX UV 385 Asiga, Alexandria, Australia) was used, which allows the use of over 500 resins for 3D printing, including NextDent resins, such as NextDent OrthoClear (https://www.asiga.com/ open-material-library/) (Figure 5a). Asiga Max is a 3D printer that works with DLP technology, having a pixel size of 62 µm, and an LED wavelength of 385 nm UV or 405 nm, which works with STL, PLY, SLC, STM type files (Figure 5b).

After printing, the occlusal splint was post-processed with isopropyl alcohol for 5 min in the BB Wash chamber (Rimas Engineering S.R.L., Pescara, Italy) and exposed to UV light for 10 min in the Led BB Cure Plus photopolymerization oven (Rimas Engineering S.R.L., Pescara, Italy). The occlusal splint has been finished and polished. After polishing, the occlusal splint was kept dry and delivered to the dental office (Figure 6a).

4. Intraoral application and adjustments of the occlusal appliance were followed by a period of occlusal splint wearing and evaluation.

After printing and finishing of the occlusal splint, a clinical evaluation was performed to verify the distribution and stability of the occlusal contacts and adjustments were done (Figure 6b). Red Occlusion Foil articulation paper (Blue Radar, 65µ, Nordin, Montreux, Switzerland) was used to check the occlusion. Insertion and removal of the occlusal splint were performed, and instructions were given to the patient. Participant was instructed to use the occlusal splints daily, at night, no more than 12 h per day, for 2 months.

Figure 6. a. Finished occlusal splint. b. Occlusal splint in the oral cavity

The Ethics Committee of University of Medicine and Pharmacy of Craiova approved the study by Decision no. 156/25.07.2022.

RESULTS
The workflow for occlusal splint manufacture established included clinical and technical steps: conventional impressions of the upper and lower dental arches and occlusion, casting of the plaster casts and their mounting in the articulator, scanning of the dental casts, digital design of the occlusal splint, 3D printing of the occlusal splint, adjustment of the occlusal splint. Participant had to wear the occlusal splint at night, daily and to report any discomfort.

After two weeks a dental check for minor adjustments was made. After 9 weeks of wearing the occlusal splint, the final dental control performed, and participant was invited to assess the performance of the occlusal splint.

For the 9 weeks period of observation, the participant wear daily the occlusal splint by night and observed the behaviour of the splint. There were no complaints of mismatch of the bite splint or inconvenient. After the 9 weeks the bite splint presented vague signs of wear.

**Figure 7. Occlusal splint aspect after 9 weeks of wearing. a. Exterior aspect. b. Interior aspect. †The arrows show signs of wear.**

**DISCUSSIONS**

The results of the study showed good behaviour of the printed occlusal splint overall and good compliance of the participant with a rigid PMMA occlusal appliance for sleep bruxism. After wearing the occlusal splint daily at night for 9 weeks, according to participant declaration, the occlusal appliance behaved well.

The conversion of dental laboratory technology to digitalization has brought about a transformation of all techniques for obtaining dental prostheses, as well as other intraoral devices, such as occlusal splints. For the occlusal splints production, digital technologies must provide predictable and reproducible results [6]. Regulatory organizations in the United States and Europe have recently approved the use of these products in vivo [29]. According to several authors [6,29,30], the design and manufacture of occlusal splints by digital scanning and CAD-CAM technology have several benefits, including reproducibility, good internal adaptation of the occlusal splint to the dental arch and accuracy of occlusal contacts, better resin polymerization, no deformation or polymerization contractions and less time required for the manufacture and intraoral adaptation of the occlusal splint. Although additive manufacturing, also known as 3D printing, first proposed in 1986 for use in dentistry, it took time for the dental industry to accept it [6,31]. The main advantage of 3D
printing over milling is the reduction of waste [20]. Other advantages of the 3D printing technique are the ability to create projects with complex geometry, offering remarkably high design flexibility, reproducibility, simple and fast use, high productivity, and profitability, being efficient, with low material consumption [6,9].

Occlusal splints used in bruxism made of rigid polymer resins or resins with a certain flexibility can be manufactured through additive CAD-CAM technology. 3D printing involves the use of a 3D printer and special resins for printing and is a more affordable and efficient technology [32]. The mechanisms of action of the occlusal splint in bruxism are several: reduction of the EMG activity of the mandible elevator masseter and temporalis muscles [33-36], pain reduction for muscles and temporo-mandibular joint [37,38], reduction of cortisol levels and stress levels in patients with nocturnal bruxism [39], cognitive awareness [40]. Although there are studies that claim that the effectiveness of treatment with occlusal splints in bruxism is controversial [33], it is generally accepted that occlusal splints contribute to the preservation of natural teeth, protecting them from excessive wear. The occlusal splints can dissipate the additional stress generated by bruxism, where forces occur and create a biomechanical balance between the physiological occlusal stress and the excessive stress created [41]. The occlusal splints are also useful as a diagnostic device for bruxism as they provide information to the dentist about grinding or clenching while the patient is wearing the splint [42].

To obtain occlusal splints through digital workflow, complete digital impressions of the dental arches, CAD software to design the splint and a computerized milling or 3D printing device are required [6]. The advantages of this technology are the ability to correctly reproduce the digital project, the digital control of the splint design and occlusion by using a digital articulator, the control of the production flow with a high manufacturing speed [29,43]. Berntsen et al., 2018 [44] compared the conventional technique of creating occlusal appliances with the digital one, giving significant importance to the intraoral scan, which was considered by patients to be more pleasant. However, the impression time was longer for intraoral scanning compared to the conventional alginate impression. Scanning longer arches and erupting teeth was more difficult. Another disadvantage of the digital technique was given by the remarkably high costs of the devices (intraoral scanner, printer) and software compared to the conventional technique [45]. However, the manufacturing technique of the splint did not influence its results [44].

Another important aspect to point out regarding the type of technique used to obtain the occlusal splints is the fact that after printing, the occlusal splints must go through several finishing steps, which involve positioning the splint on the dental cast for a better fit. Through digital scanning, the digital impression is obtained, and a cast can be printed, but its cost is higher than that of the conventional cast and the accuracy may be affected.

Digitalized occlusal splints manufacture uses diverse types of materials such as self-polymerizing acrylates, soft or hard hardness, heat-softening acrylates, or light-curing materials. Researchers believe that the mechanical properties of occlusal splints depend mainly on the type of material and less on the manufacturing technology [16,20,46]. However, the materials used for additive manufacturing of occlusal splints differ from conventional and subtractive/milled ones. Recent studies [14,16,25] have shown that the properties of materials used for additive manufacturing of occlusal splints (e.g.,
bending strength, surface hardness and wear resistance) are in general inferior compared to conventional PMMA or milled materials. The materials used for the occlusal splint must be able to simulate the micro-hardness of the dentin (250 and 800 MPa) and the modulus of elasticity of the dentin, which varies between 10-20 GPa [9]. These values compensate for the hardness of the tooth enamel with the ability to neutralize the impact of mastication, have good wear behaviour and good surface finishing properties, which prevent the alteration of the device by changing the colour, micro-porosity, the rapid formation of biofilm on the surface [9,47]. Regarding the resin used in this study, Next Dent OrthoRigid Blue, according to Mangal et al 2020 [48], the main component of the resin is methacrylic oligomers (>90% w/w) with a small percentage of phosphine oxides [48]. This material showed a smooth surface and lower bacterial adhesion [49].

In an in vitro study, Abad-Coronel et al [9] compared 4 types of polymer occlusal splints: splints obtained by the classical technique (acrylic splints), rigid resin printed splints, flexible resin printed splints and milled splints. The fracture resistance of these splints was, on average, 1303.9 N for conventional splints, 1489.9 N for rigid printed splints, 1943.4 N for flexible printed splints and 3051.2 N for milled splints [9]. Milled splints had the highest fracture resistance, followed by flexible printed ones and rigid printed ones. Between the digital splints and conventional ones was a statistically significant difference. From the fractograph analysis, the two materials (conventional resin and rigid printed resin) showed a brittle fracture. Once the critical stress value reached, brittle materials exhibit unstable cracks, so they do not require an increase in stress for crack propagation, which is why catastrophic fracture occurs. Flexural strength for the four resins studied by Abad-Coronel et al. [9], was much lower in the study compared to the values given by the manufacturer. Thus, if the manufacturer considers a fracture strength of more than 100 MPa, the strength resulting from the research was much lower, being almost 4 times lower for conventional acrylic resin, 3 times lower for printed resins and 2 times lower than milled resin [9].

Although 3D printers have a lower cost than milling devices, they have not penetrated the direct technological flow of obtaining occlusal splints in the dental office, with dentists being reluctant to accept innovative technologies that require a longer learning curve. The benefits of additive manufacturing are the reduction of waste, the reduction of energy consumption and of the number of steps required to obtain the finished product and predictable costs without compromising details [50,51]. Another benefit of 3D printing technology is that it can create multiple objects at the same time, which is indicated for creating objects with complex geometry [6]. 3D printing is an efficient, profitable, and predictable manufacturing method with capacity for further development [52].

**CONCLUSIONS**

Occlusal splint is an important therapeutic tool in sleep bruxism. Digital workflow for bruxism occlusal splint of rigid acrylic materials obtained through 3D printing technology is a rapid and precise technology. Digital technologies offer a new perspective in occlusal splints manufacture, making them readily affordable.

**Clinical significance**

Rigid 3D printed polymer material was used for 3D printing of occlusal splints in a digital workflow. This study provides evidence that this material is a viable alternative to conventional occlusal splint for at least two months of clinical use. Further evidence of long-term use of occlusal splints
in bruxism needs to be obtained.

**Authors’ contributions**

All authors read and approved the final manuscript. All authors have equally contributed to this work.

**Ethical statement**

Written informed consent was obtained from participant in the study. The study was conducted in accordance with the Declaration of Helsinki. We obtained the approval of the Ethics Committee of University of Medicine and Pharmacy of Craiova (No. 156/25.07.2022).

**Conflict of interest statement**

The authors declare no conflict of interest concerning this study.

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