Review Article

PROPERTIES OF 3D-PRINTED COMPLETE DENTURES – CLARIFIED AND UNCLARIFIED ASPECTS

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ABSTRACT

In recent years, the elaboration of complete dentures via the additive method of tri-dimensional (3D) printing has become more and more popular. This is a relatively new technology and while the technical aspects have been elaborated in detail, the clinical aspects of its application are undergoing development. The goal of this review was to analyze the data available up to now in dental literature about the quality of the 3D-printed complete dentures and outline the clear and unclear aspects, given their clinical application. E-search was performed in three databases: Web of Science, Scopus, and PubMed. The results show that the properties of complete dentures elaborated via the additive technology of 3D printing have not been sufficiently analyzed from a clinical point of view. The mechanical properties of materials for 3D-printed removable dentures and the optimal technical parameters for the technology application are widely discussed. Yet prosthetic rehabilitation of fully edentulous patients with 3D-printed dentures still faces numerous challenges. Among them are the determination of precise vertical dimensions of occlusion when using fully digital clinical methods, achievement of optimal fitting to the denture bearing area, and sufficient masticatory function, respectively. Achievement of foreseeable aesthetical results is not a solved problem yet. Additional research is necessary to clarify these aspects of 3D-printed complete dentures' clinical performance.

Key words: 3D-printed complete dentures, 3D-printing materials, Denture base accuracy, Patient satisfaction.

Introduction

The main purpose of prosthetic treatment of completely edentulated patients is the optimal restoration of masticatory and speech function and aesthetic appearance of the patient. Patients' satisfaction with complete dentures is predefined by a set of factors that have been widely discussed in dental literature. Patients demonstrate their utmost dissatisfaction when dentures cause pain, have no good retention, get relocated, or fall during mastication thus limiting the ability to chew, especially hard food [1, 2]. The research on patients' complaints shows that between 15 and 20% of them communicate issues with denture retention and stability [3]. The recovery of the aesthetical appearance given the patient's requirements is also an essential factor for the success of denture treatment after complete loss of teeth [2]. To achieve good aesthetical results, we have elaborated clinical protocols that include individual dentures' characterization.

To some degree, the functional qualities of complete dentures depend on the technology of their elaboration. At present, we know these issues are mainly based on clinical research of patients treated with conventional complete dentures that have been elaborated according to traditional technologies. In contemporary dental medicine, thanks to the digital technologies that develop with ever-increasing speed, the clinician could prefer some innovative digital methods compared to conventional ones. We have proposed various approaches towards elaborating complete dentures including computer-assisted methods [4, 5]. In the interest of choosing the digital protocol for the elaboration of complete dentures, there are several advantages about which the scientific community has arrived to consent. The most important advantages of conventional methods are the lower number of clinical visits and reduced time for working with the patient [6].

In recent years, the elaboration of complete dentures via the additive method with the help of tri-dimensional (3D) printing has become more and more popular [7]. This is a relatively new technology and while the method's technical aspects have been elaborated in detail, the clinical aspects of its application are undergoing development. Numerous contemporary types of research are devoted to looking for an opportunity to create a product that is clinically foreseeable given quality and functional fitness.

It is believed that complete dentures that have been elaborated according to digital technology have better mechanical properties, uniform plate thickness in their different sections, and better conformity with the denture field [8, 9]. This results in fewer traumatic lesions of mucous membranes related to denture use [10]. Nevertheless, in the opinion of other authors, the retention, adaptation, and stability of dentures that have been elaborated according to the digital technologies are not satisfactory. The reason behind the versatile opinions is that in the case of dentures made via computer-assisted methods oftentimes were found imprecisions in the denture edge positioning [11].

Another debatable issue is the precision with which we could reproduce occlusal contacts in the different occlusal schemes when complete dentures are being elaborated via digital technologies [12]. We have reported results with comparable precision for milled and 3D-printed complete dentures. Another issue being discussed is the degree to which clinical protocols based on a completely digital approach and additive technology ensure the satisfaction of patient's aesthetical preferences [13].

Even though numerous researches confirm some advantages of digital technologies, there are essential questions about the quality of complete dentures made via additive technology of 3D printing which have still not been fully clarified.

The goal of this review was to analyze the data available up to now in dental literature about the quality of the 3D printed complete denture and outline the clear and unclear aspects, given their clinical application.

Materials and Methods

E-search was performed in three databases: Web of Science, Scopus, and PubMed. The keywords used were "3D-printed denture accuracy," "3D-printed dentures base properties," "3D-printed dentures biocompatibility ", "3D-printed dentures aesthetics", "Patient satisfaction with 3D-printed dentures."

It was performed screening of the extracted articles based on the inclusion and exclusion criteria as follows:

Inclusion criteria

1. Research with a focus on 3D-printed dentures.
2. In Vivo and In Vitro studies.
3. English language of publication.
4. Articles published between 2018 and 2023.

Exclusion criteria

1. Publications other than the English language
2. Articles published out of the period 2018-2023

Results and Discussion

To clarify the advantages and disadvantages of additive technology, we have analyzed different properties of complete 3D-printed dentures while comparing them to the properties of dentures prepared according to traditional and other digital methods [11, 14].

Retention and stability of 3D-printed dentures

The precision of denture base fitting to the denture bearing area is beyond doubt among the most important factors for the retention and stability of complete dentures. Numerous studies contain comparative results about the denture base precision of 3D-printed dentures with the precision of denture bases prepared via other technologies.

Hwang *et al*. [15] compare the adaptation of upper dentures' internal surfaces prepared via three different technologies. The internal denture surfaces have been scanned and compared via the method of computer superimposing with the surface of the corresponding casts. The group of 3D-printed dentures demonstrates better trueness (0.074 ±0.005) and adaptation of mucous surface compared to the group of Compression moulding (0.165 ±0.056) and the milled dentures (0.177 ±0.003).

Other researches confirm that the denture base resulting from the additive technology has better retention than the one prepared via thermal polymerization. Analysis of the experimental bases of maxillary complete dentures demonstrates trueness values of 0.02 ±0.08 for the ones prepared via Compression moulding and 0.03 ±0.01 for the ones prepared via 3D printing [16]. Lee *et al*. [17] compare the accuracy of maxillary dentures prepared via Compression moulding, milling, and 3D printing. The precision of the denture base is higher in the case of milled and 3D-printed dentures compared to the injection molding method.

We could accept that most authors share the opinion that 3D-printed denture bases demonstrate higher trueness compared to the ones prepared via Compression moulding. Nevertheless, if it comes to comparing milled and 3D-printed dentures there is no unanimous opinion on the technology that guarantees better trueness of the denture base.

Comparing of upper complete dentures – 10 milled and 10 3D printed, whose intaglio surface has been scanned via laboratory scanner, shows that trueness is higher in 3D-printed dentures [18].

Lo Russo *et al*. [19] report different results. They have compared the trueness of the intaglio surface of complete dentures that have been prepared according to an entirely digital protocol and two technologies – via milling and 3D printing. The dentures have been scanned with the same intraoral scanner with which scanning of edentulous jaws was performed. Comparative measurements were performed at points set in advance that mark the zones of interest. According to the authors [19] the milled dentures demonstrate in general better trueness of the complete internal surface (0.002 mm) than the 3D-printed dentures (0.018 m) with fewer variations in the examined zones of interest.

The significance of the denture base' adaptation to the denture-bearing area is even greater when it is about the retention and stability of a complete lower denture. Most of the patient's complaints are related namely to using complete lower dentures mainly due to the lack of stability during the mastication which causes pain and discomfort while trying to process food [20].

Yoon *et al*. [21] compare the accuracy of lower dentures prepared via Compression moulding, milled and 3D-printed. The internal surfaces were scanned and the adaptation degree was assessed via superimposition over the corresponding models via 3D software (3D comparison software Geomagic Verify, 3D Systems). The milled dentures have demonstrated better trueness (0.104±0.015) than the 3D printed dentures (0.101±0.011), yet there is no statistically significant difference in terms of adaptation to the denture bearing area.

To achieve objective results when evaluating the quality of the 3D-printed dentures it is essential to research in greater detail the precision of some key areas that directly impact dentures' retention and stability.

Masri *et al*. [14] compare the adaptation of complete denture bases that were prepared in 3 ways: conventional technology, milling, and 3D printing. The research of 5 functional areas - posterior palatal seal, anterior border seal, the crest of the ridge, maxillary tuberosities, and palate, demonstrates that the milling technique provides the best adaptation in most areas. 3D-printed bases have the best adaptation in the distal palatal sections which is essential for the good retention of the complete upper denture.

Another research does not establish a difference in the adaptation of the 3D-printed dentures compared to the adaptation of the milled and Compression moulding dentures. The silicone replica technique was used for measuring dentures' fitting, whereas the thickness of the silicon layer was measured via a stereo microscope. Via this methodology, there are no statistically significant deviations in the measurement points [22].

Another parameter studied about the quality of the denture bases is their flexural strength. In in vitro research, we have compared the flexural strength of trial specimens prepared via milling and the ones prepared via 3D printing – with the printer recommended by the manufacturer and with a third-party 3D printer [23]. The milled dentures demonstrate higher flexural strength than the 3D-printed ones. The dentures prepared with the printer recommended by the producer have higher flexural strength compared to the ones produced with the assistance of a third-party printer.

Technological aspects influencing the quality of 3D-printed dentures

In a systematic review, Gad and Fouda [24] analyze the factors that influence the flexural strength of 3D-printed resins and summarize that this property could be improved via one or more of the following factors: addition of nanofillers, printing orientation, angulation, or directions; printing layer thickness; post-polymerization time and temperature.

How the 3D printing is performed could also impact the precision of the denture base and the retention and stability of complete dentures. In this light, essential factors were discussed in different build orientation settings and layer thickness.

Gao *et al*. [25] compare the trueness of the base of 3D printed mandibular dentures prepared via different build orientation settings – 0°, 45°, 90° and found out that the dentures prepared with 45° build orientation demonstrate the best trueness of fit. Hada *et al*. [26] also confirm that 45° build orientation displays the highest accuracy.

We have also researched the impact of layer thickness on the accuracy of denture bases prepared via 3D printing via a DLP 3D printer (Pro95, SprintRay, USA) and denture base material DENTCA Denture Base II, Dentca, USA, [27]. They have analyzed the results in seven build orientations (0°, labial 45°, labial 90°, posterior 45°, posterior 90°, buccal 45°, and buccal 90°) and two types of layer thickness - 50 µm and 100 µm. It was found that the denture bases that have been printed with the labial orientation of 45° and 90° demonstrate the highest accuracy and the optimization of this parameter could increase the precision of the 3D-printed dentures. The layer thickness impacts only the printing time without influencing precision.

Most authors sustain the thesis that to achieve maximum precision of the 3D-printed dentures, these should be elaborated with 45° build orientation. On the other hand, Jin *et al*. [28] believe that build angle settings do not impact denture adaptation. The authors research the effect of various build angle settings: 90°, 100°, 135°, 150° onto mucous surface's adaptation of 10 upper and 10 lower complete dentures and they do not find statistically significant differences when evaluating the adaptation of the various denture groups to the application build angle.

The quality of the 3D-printed denture base could be influenced by some other technological peculiarity. Lee *et al*. [29] highlight that the application of various (vat) polymerization techniques could also influence the mechanical and biological properties of 3D-printed dentures. They research the NextDent denture bases printed via stereolithography, digital light processing, and light-crystal display techniques that are subjected to the same post-polymerization procedures. The authors have evaluated flexural strength and modules, strength to fractures, water absorption and solubility, and fungi adhesion. The highest flexural strength is demonstrated by the bases printed with stereolithography. The water absorption and solubility are significantly higher during printing via digital light processing, and the highest fungi adhesion was found in the case of stereolithography. The authors conclude that with a suitable length of light wave 3D- 3D-printed resins could be processed via different polymerization techniques for 3D printers.

Another researched factor is the impact of the post-polymerization onto a 3D-printed polymer (V-Print database, VOCO) for denture base. It studied the effect of the post-curing methods with different light-curing devices (Otoflash G171, Labolight DUO, PCU LED, and LC-3D Printbox) on the surface characteristics, flexural strength, and cytotoxicity. The different post-curing methods do not significantly influence the surface topography and roughness yet these could increase the flexural strength and effectively decrease the cytotoxic effect of the 3D-printed polymers [30].

We have also analyzed the results of the application of different post-polymerization regimes: time – 15 and 30 minutes and temperature - 40°C, 60°C, 80°C, onto 3D printed specimens that simulate complete maxillary dentures. It was established that the optimal post-polymerization time and temperature for 3D printing is 30 minutes and 40°C, correspondingly [31]. These conditions are prerequisites for high denture base conformity with the denture-bearing area and good adaptation.

Al-Dulaijan *et al*. [32] study the influence of printing orientation and the post-curing time on the surface roughness and the hardness of the conventional heat-polymerized material and two materials for 3D-printing (NextDent and ASIGA). Printing was performed with different orientations - 0°, 45°, and 90°, then every group of samples was subjected to the 4 post-curing regimes (30, 60, 90, 120 min) and thermocyclic processing of 10.000 cycles. The printing orientation and the post-curing time do not influence the surface roughness of the 3D-printed specimens. In general, the 3D-printed materials demonstrate lower hardness compared to the conventional ones which could be improved with the increase of the post-curing time to 120 min.

Properties of the materials for elaboration of 3D-printed dentures

In addition to technological conditions, dentures' quality depends on the properties of the material chosen for their elaboration. Casucci *et al*. [33] compare flexural strength of 11 different materials for the denture base: 6 conventional PMMA(Acrypol R, Acrypol LL, Acrypol HI, Acrypol Fast, Acryself and Acryslef P), 2 for milled dentures (Ivotion disk and Aadva disk, two 3D-printed PMMA NextDent Denture 3D+, and SprintRayEU Denture Base) resins and one 3D-printed composite resin (GC Temp Print). The materials for milled dentures demonstrate the highest flexural strength, followed by the 3D-printed composite resins. Given all the 3D-printed materials established a high correlation between the polymerization technique and flexural strength, the choice of optimal option could be decisive.

In vitro research compares the flexural strength and surface hardness of different materials and technologies for the elaboration of denture base: heat-polymerized (ProBase Hot, Paladon 65 and Interacryl Hot), for milled dentures (IvoBase CAD, Interdent CC disc PMMA and Polident CAD/CAM disc), for 3D-printing (NextDent Base), and one polyamide material (Vertex ThermoSens), [34]. It was found significant differences in terms of the researched parameters. The material for 3D printing demonstrates the lowest flexural strength**.** The authors [34] conclude that in general the materials for milled dentures demonstrate better mechanical properties compared to the heat-polymerized ones and those for 3D printing. Another research compares printing accuracy and flexural properties of 3 experimental 3D-printed materials DentaBASE (ASIGA, Erfurt, Germany), Denture Base Resin LP (Formlabs Inc, Somerville, MA, USA), and Denture 3D+ (NextDent B.V., Soesterberg, Netherlands) to the properties of the specimens from heat-polymerized resin [35]. Changes in length depending on the used material vary between 1.3% and 2.4%, in width - between 0.2% and 0.7%, and in thickness – between 0.2% and 0.6%. The 3D-printed specimens have lower values of flexural strength and module of elasticity compared to the heat-polymerized ones. It was established that the choice of material influences the printing precision and to a lesser degree the flexural strength, yet it does not change the module of elasticity.

Biological and antimicrobial properties

The mechanical properties of materials used for the elaboration of complete dentures additionally impact their biocompatibility and antimicrobial properties. The low surface roughness of the denture base is an important prerequisite for reducing bacterial biofilm, as well as improving aesthetics and denture reception by the patient [36].

It is well-known that denture stomatitis is caused most often by the formation of Candida albicans colonies and its main symptom is persistent inflammation of denture denture-bearing area's mucous membrane [37]. This impacts oral health as well as the general health status of the patient. The low porosity and superficial roughness are essential for reducing the adhesion capacity of Candida albicans to the denture surfaces [38]. The conventional dentures even after exact cleaning and polishing create prerequisites for better adhesion of Candida albicans compared to the dentures made via computer-assisted technologies [39]. It was proven that CAD/CAM and 3D-printed dentures have lower porosity compared to the conventional ones made of PMMA [39, 40].

The most up-to-date studies demonstrate that the modification of the materials for 3D printing with different agents in the pattern of nanoparticles significantly improves their mechanical and antimicrobial properties, correspondingly. Gad *et al*. [41] evaluate flexural strength, impact strength, surface roughness, and hardness of 3D printed resins incorporated with Silicon dioxide nanoparticles. The results demonstrate that this modifying agent improves the examined properties without increasing the surface roughness. Khattar *et al*. [42] report that the addition of ZrO_2 NPs in low concentrations (0.5%) significantly reduced C. albicans adhesion and proliferation whereas did not affect the surface roughness of the 3D-printed resins.

They have evaluated the effect on flexure strength, elastic modulus, impact strength, hardness, and surface roughness of specimens that were prepared from two types of 3D-printed resins modified with the addition of nanoparticles of zirconium dioxide (ZrO_2NPs), [43]. The nonmodified 3D-printed resins demonstrate a significant decrease in all the researched properties compared to the heat-polymerized resins. The modified 3D-printed materials show increased flexure strength, impact strength, and hardness whereas the surface roughness and elastic module were not significantly changed.

The definition of optimal occlusal parameters is essential for dentures' functional fitness. Most CAD/CAM systems provide the opportunity to use a virtual articulator. The question about the precision of the entirely digital method for defining the occlusion parameters in the case of complete edentulation is yet to be discussed and the research results in this direction presented in dental literature are contradictory. The most significant problem is the probability of an imprecise definition of the vertical dimensions of occlusion. The precise reproduction of occlusal contacts according to the selected occlusal scheme is also an essential issue.

We have researched the differences in occlusal forces reproduced by CAD-CAM and 3D-printed complete dentures that have been elaborated with different occlusal schemes - bilateral balanced, lingualized, and mono-plane [44]. In the case of 3D-printed dentures was established better retention compared to CAD-CAM dentures, irrespective of the applied occlusal scheme. The bilaterally balanced occlusion and the lingualized occlusion provide the best centralization and alignment of forces, as well as the reproduction of higher occlusal forces during the masticatory function [44]. The opportunity for uniform distribution of occlusal contacts that are provided by cutting-edge technologies is essential also for ensuring comfort and prevention of the temporomandibular joints.

Aesthetical aspects

According to the available data, 3D-printed dentures limit the opportunity for satisfaction of patient's aesthetic preferences since clinical trials are not included in the digital protocols [13]. This can result in a less predictable aesthetic effect. Additionally, even though digital technologies have several ways to individualize dentures, these are far more limited compared to the opportunities to characterize the dentures prepared according to conventional laboratory methods [13].

Tasaka *et al*. [45] compare the teeth dislocation that occurred after the completion of dentures with the original teeth arrangement onto wax with 5 dentures elaborated via the Injection-moulding method and 5 – via 3D printing. The greater teeth relocation was observed in the case of 3D-printed dentures compared to the heat-polymerized ones.

Mugri *et al*. [46] research the effect of two commercial tobacco products on color stability and the surface roughness of denture bases prepared via milling, 3D printing, and conventional heat-polymerization. The greatest changes in color and surface roughness were found in 3D-printed bases compared to the other researched groups.

Sustainability of complete denture properties

The sustainability of complete denture properties throughout time is an important prerequisite for the long-term success of the prosthetic treatment. When using dentures, various factors could impact their qualities. Daily contact with food and beverages of various compounds and temperatures, cleaning and disinfection means, etc. could result in changes in the denture base which would deteriorate retention, denture stability aesthetics, and in general its functional fitness. Hence it is essential to analyse the impact of various factors on 3D-printed dentures to foresee the potential changes.

Wemken *et al*. [47] compare the maxillary dentures prepared according to 3 methods - Injection-moulding, milled, and 3D-printed. Dentures are "aged" via hydrothermal processing and subjected to microwave sterilization. Milled dentures demonstrate the lowest surface deviation followed by injection-molded and 3D-printed dentures before the "aging" process. The hydrothermal processing does not impact the milled group's trueness compared to the injection-molded and 3D-printed. Microwave sterilization does not impact the measurable trueness of the 3D-printed dentures yet it results in significant deformations of injection-molded and milled dentures that would be of clinical significance.

We have evaluated the strength of the connection between two types of artificial teeth and 3D-printed plates when using two types of connecting agents [48]. They have found out that for Biotone tooth the bond strength is significantly higher when using MMA + Cosmos TEMP and similar to the control group when using only Cosmos TEMP. Given a 3D-printed tooth (Cosmos TEMP) the use of both connecting agents yields results similar to the control group.

Alharbi *et al*. [49] in invitro research compare the failure load of 3D-printed denture resin material and teeth before and after dynamic loading, with those of conventional heat-polymerized materials and commercially available denture teeth. Ten specimens from each group were subjected to a dynamic load of 50 N for 250,000 cycles in a chewing simulation The processing technology impacts the mode of failure between acrylic teeth and resin base material. Cohesive failure in teeth was predominant in the conventional group. Both technologies demonstrate satisfactory strength of the connection between the base material and teeth during dynamic loading.

Other in vitro research compares the mechanical properties, surface roughness, and color stability of the 3D-printed and heat-polymerizing denture base materials [50]. The 3D-printed materials show higher impact resistance and lower surface roughness compared to the heat- heat-polymerizing acrylic resin, but lower flexural strength, hardness, and color stability.

It also examined water absorption, solubility, and transparency of three 3D-printing materials for denture bases (NextDent, FormLabs, and Asiga) [51]. The measurements were performed before and after thermally processing the specimens for 5000 cycles. The three 3D-printed materials demonstrate higher water absorption and solubility and lower transparency compared to the heat-polymerized ones. The thermal processing negatively impacts all the surveyed properties with all the researched materials.

The reparability of 3D-printed denture base materials is an important quality related to the opportunity to provide patients with comfortable dentures for long-term use. The percentage of patients who use their dentures for more than 5 years according to Pavlova [52] is 54.17%. Precisely elaborated dentures could lose their good functional properties under the influence of different factors in tame. The violated conformity with denture bearing area could result in injuries of the underlying tissues. Unfortunately, the information about this issue is very limited. One research evaluates the effect of hard-reline procedures on the flexural strength of materials for digital elaboration of denture bases [53]. They have compared traditional PMMA resin; three types of PMMA for milled dentures and 3 types of materials for 3D printed dentures. All the materials for milled dentures demonstrate lowered flexural strength after rebasing, whereas conventional and 3D-printed materials show significantly higher results. According to results, hard relining influences the flexural strength of most digitally elaborated materials for denture bases.

We have also evaluated the opportunity for repairing 3D printed material (FREEPRINT denture) for the denture base [54]. They have examined the effect of surface treatment and artificial aging on shear bond strength. The 3D-printed material demonstrates good reparation capacity. Given the rebased surface, the shear bond strength is satisfactory and we do not need additional treatment. In the case of aged dentures, shear bond strength could be significantly decreased and additional processing is recommended.

Clinical evaluation of 3D-printed dentures

Limited numbers of research were performed to evaluate patients' satisfaction after the real use of 3D-printed dentures**.** Liu Y-X *et al*. [55] surveyed the opinion of 30 edentulous patients separated into two groups – wearing traditional complete dentures and the ones with 3D printed dentures. Patients' satisfaction was measured with a 0-10 visual analog scale (VAS) 4 times – after insertion of the dentures and after 1, 3- and 6-month periods. The satisfaction of all examined people demonstrates higher values after 3 months of using the dentures. The evaluations of both groups concerning the aesthetics, speech function, masticatory capacity, dentures' stability, and comfort do not demonstrate statistically significant differences.

Another clinical research also studies patients' satisfaction with conventional complete dentures and with the dentures elaborated via 3D printing [56]. We have evaluated a high number of indicators: masticatory effectiveness, present pain, stability, retention, comfort while using the dentures, aesthetics, phonetics, possibility for easy cleaning, and general satisfaction. Higher satisfaction is expressed by the patients with the conventional dentures given phonetics, stability, comfort, and possibility for easy cleaning. Even though patients' satisfaction is generally lower given the digitally prepared dentures around 20% of them prefer them due to the shortened time for elaboration and the fewer number of clinical visits.

Al-Kaff *et al*. [57] compare the satisfaction of 20 patients wearing three types of complete dentures: conventionally manufactured with conventional impression, additively manufactured with intraoral scanning and additively manufactured with cast digitization. Patients' satisfaction with both types of 3D-printed dentures in general is comparable to the one with the conventional. The 3D printed dentures prepared according to entirely digital impressions are of lower clinical quality and retention compared to the others, especially the ones of the mandible. Teeth arrangement with both types of 3D-printed dentures gets lower approval compared to the conventional ones.

Cristache *et al*. [58] surveyed the opinion of 35 patients wearing complete dentures prepared according to an innovative protocol via additive technology and modified PMMA via the incorporation of TiO_2 nanocomposite. The evaluation was performed at 3 stages – 1 week after insertion of the dentures and in 12-, and 18-month period of use. It uses used Visual Analogue Scale (VAS, 0-10) and Oral Health Impact Profile for Edentulous Patients (OHIP-EDENT). The innovative material provides the opportunity to prepare dentures of good functional properties that preserve their improved properties during the research period.

Alhallak *et al*. [59] in a review analyze the clinical application of CAD/CAM and 3D-printed dentures in modern dental practice. In addition to the generally recognized advantages such as lowered preparation time and relatively good clinical results, they highlight that many studies recommend additional clinical trials given achieving better results concerning aesthetics, retention, and vertical dimensions of occlusion.

The comparative research of properties inherent to the digitally elaborated dentures via 3D-printing with the ones elaborated via traditional methods makes it possible to assess the degree to which innovative technologies would help in achieving higher satisfaction of patients after rehabilitation of masticatory systems with complete dentures [14-19]. Although the opinions about the retention and stability of 3D-printed dentures are not unambiguous, a lot of studies report better or comparable results with those obtained for conventional complete dentures.

In recent years numerous studies were performed to establish the aquracy of the denture base of 3D-printed dentures. The reported results provide us with grounds to accept that they have better precision than the ones elaborated via Compression molding [15-17]. Nevertheless, the opinions concerning this property compared to milled dentures are not unanimous. Some research states that the most accurate 3D-printed denture bases are [15] and according to others, the milled ones have higher precision [19, 21].

The reason behind the ambiguous opinions concerning these issues could be the application of various research methods and the fact that the prevailing part of the studies was performed in vitro on experimental specimens and not in clinical conditions of real patients. These confirm the opinion that the faults of 3D-printed dentures are strength aesthetics and biocompatibility and there is still a shortage of information about the clinical behavior in the real circumstances of the oral cavity [60].

Even though the results confirm some advantages of new technologies, there are significant issues about elaborating complete dentures that still have not found their unanimous answer. One such issue is the one about the reliability of digital imprecisions and the opportunity to get foreseeable results [61]. The implementation of different clinical protocols could impact the results concerning the properties of the 3D-printed dentures. When we implement fully digital protocols, we need to take into consideration the opportunity for imprecisions in denture base fitting as a result of imprecisions of intraoral scanning and not of 3D printing. The results of similar studies assist the doctor of dental medicine in making an informed decision on whether the application of a specific method is suitable for the particular patient.

The highest number of researches is devoted to the examination of mechanical properties of 3D-printed complete dentures. We have examined the influence of various factors on these properties and have defined the optimal parameters of performing 3D printing to get dentures of good quality [24-29].

Several comparative researches on 3D-printed materials for denture bases comment on their advantages and disadvantages and facilitate the choice of material when elaborating dentures via the additive technique [24, 34, 35]. We have clarified the issue that modified 3D-printed materials with nanoparticles from different modifying agents demonstrate better mechanical properties and most of all they have higher antimicrobial properties [41, 43, 45]. This advantage is to be used for the elaboration of 3D-printed dentures given oral disease prevention such as denture stomatitis.

Very few studies discuss other aspects of the elaboration of 3D-printed dentures such as defining the vertical dimensions of occlusion and aesthetics. According to the prevailing opinion, the reproduction of different occlusal schemes via digital technologies could be precise enough, yet clinical research that verifies the definition of optimal restoration of masticatory and speech function and intermaxillary relation is missing [44].

The achievement of satisfactory aesthetical results via 3D-printed dentures is also a disputable issue [13, 45, 46]. The lack of denture trials before their completion hinders taking into consideration the individual preferences of patients concerning aesthetics and decreases the foreseeability of denture treatment [59]. In this light, further examinations are needed to find opportunities to characterize the 3D-printed dentures.

Very few researchers report results from the clinical application of 3D-printed dentures [55-57]. The resulting data are diverse and more often favor the conventional and milled dentures than the 3D-printed ones [56, 57]. This confirms the opinion that the currently available information is not sufficient to draw reasoned conclusions about the qualities of 3D-printed dentures concerning rehabilitation of masticatory capability, speech function, and aesthetics.

Conclusion

The properties of complete dentures elaborated via the additive technology of 3D printing have not been sufficiently analyzed from a clinical point of view. The mechanical properties of materials for 3D-printed removable dentures and the optimal technical parameters for the technology application are widely discussed. Yet prosthetic rehabilitation of fully edentulated patients with 3D-printed dentures still faces numerous challenges. Among them are the determination of precise vertical dimensions of occlusion when using fully digital clinical protocols, achievement of optimal fitting to the denture bearing area, and sufficient masticatory function, respectively; foreseeability of the aesthetic results.

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