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Physico-mechanical characteristics of materials and methods for provisional non-removable prosthetic constructions - Part 1. Contemporary literature review

M. Dimova-Gabrovska[1]*, S. Rangelov[1], E. Kirilova[2], K. Kirilov[3,4]

[1]*Department of Prosthetic Dental Medicine, Faculty of Dental Medicine, Medical University – Sofia, Sv. Georgi Sofiysk, Str., 1, Sofia 1431, Bulgaria*

[2]*Institute of Chemical Engineering, Bulgarian Academy of Sciences, Acad. G. Bonchev Str., Bl.103, Sofia 1113, Bulgaria*

[3]*Institute of Molecular Biology, Bulgarian Academy of Sciences, Acad. G. Bonchev Str., Bl. 21, Sofia 1113, Bulgaria*
[4]*Department of Natural Sciences, New Bulgarian University, Montevideo Str., 21, Sofia 1618, Bulgaria*

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In prosthetic dental medicine rehabilitation prior to definitive prosthesis placement there is an important step in clinical treatment plans. Different materials and methods for fabrications have been developed over the years, with still no universal solution for all cases. The knowledge of contemporary available options for dental provisionalization, all of which have their pros and cons regarding different clinical scenarios is crucial for any dental medic practicing prosthetic dentistry.

Keywords: Preliminary dental prosthetics, mechanical characteristics, dental polymers, preliminary non-removable prosthetics, interim dental materials

INTRODUCTION

According to several contemporary authors, interim fixed prostheses are essential in fixed prosthetic treatment, because for a certain period they provide protection and healing of dental, periodontal, and mucous tissues, improvement of aesthetic and phonetic functions, disclosure of data for assessment of hygiene control, stabilization of position of teeth [1-3], restoration of occlusal function [4-6].

It is considered that when making interim fixed prostheses, the clinician and dental technician should take into account the physical and mechanical characteristics of the materials used [1-3, 7] as well as whether they are biocompatible with all oral tissues [3, 8-10].

Rosenstiel *et al*. summarize their understanding that depending on their chemical composition, the materials used to make interim prostheses can generally be divided into four groups: polymethyl methacrylate (PMMA), polyethyl or butyl methacrylate, microfilled bisphenol A-glycidyl dimethacrylate (Bis-GMA) composite resin, and urethane dimethacrylate (light-polymerizing resins) [11, 12]. The primary monomer determines many of the material's properties such as polymerization shrinkage, strength, and exothermic heat of reaction [8, 11]. There is no material used to make interim prosthesis that meets all requirements of the patients and the clinicians [13-15]. Typically, clinicians select materials based on factors such as ease of manipulation, cost effectiveness, aesthetics, strength, and marginal accuracy.

The production of interim prostheses is carried out by applying the following basic techniques: (1) direct provisionalization in the mouth, on the abutments, or on the prepared teeth; (2) provisionals made indirectly; and (3) a mixed technique of indirect-direct provisionalization [16]. One of the most popular and frequently used techniques for making prostheses, which belongs to the group of indirect techniques, is CAD/CAM (computer-aided design–computer-aided manufacture) technology. The latter overcomes many of the problems of direct techniques associated with dosage, mixing, and material states. With CAD/CAM workflow systems, a high-quality interim prosthesis is obtained [17]. CAD/CAM applies two types of techniques - subtractive and additive to make interim prostheses. In subtractive methods, prostheses are obtained from a monolithic block of a certain material by applying milling and grinding processes. In additive methods, the final product is obtained by successively accumulating layers of material, a.k.a. the 3D printing method [18, 19]. In recent years, the 3D printing method has gained popularity, being applied with a variety of polymer materials [20].

It has been found that the success of prosthetic treatment performed with digital technology depends to a large extent on the choice of material

* To whom all correspondence should be sent:
E-mail: marianadimova@abv.bg

for making the prostheses. Most often, polymer-based materials, such as PMMA, are used in the CAD/CAM workflow [20].

When performing prosthetic treatment, interim fixed prostheses have a limited life. Some complex cases of oral rehabilitation, prosthetic treatments dedicated to children, adolescents or the elderly, the presence of some systemic diseases that require the termination or postponement of dental procedures, as well as the extension of the sequence of provisionalization require their prolonged use, in which this period increases significantly [11, 16, 21-23].

The latter requires the achievement of in-depth knowledge of mechanical properties of materials such as flexural strength, stiffness, impact resistance and stability [24-26] to be used for the development of new materials with higher strength properties to withstand the high functional loads.

AIM

The aim of the article is to present contemporary terminological positions and systematize contemporary materials and methods for preliminary non-removable prosthetics in prosthetic dental medicine.

Definition and essence of contemporary preliminary non-removable prosthetics

The definition of a preliminary (interim) prosthesis, as stated in The Glossary of Prosthodontic Terms [27], is as follows:

"...a fixed or removable dental prosthesis, or maxillofacial prosthesis, designed to enhance esthetics, stabilization, and/or function for a limited period of time, after which it is to be replaced by a definitive dental or maxillofacial prosthesis; often such prostheses are used to assist in determination of the therapeutic effectiveness of a specific treatment plan or the form and function of the planned for definitive prosthesis…"

As synonyms of an interim prosthesis are presented [27]: provisional prosthesis, provisional restoration.

In 2003, M. Dimova [28] introduced the term "preliminary constructions" for the first time in our country. She argued that these constructions should not only be temporary (remaining in the mouth for a specific short period) but also serve as prototypes for the final prosthetic constructions. The clinical stage of preliminary prosthesis plays an important role for the dental practitioner, as it has periodontal prophylactic and caries prophylactic significance, prevents tooth migration, and significantly contributes to determining the design of the permanent construction. The definition provided by M. Dimova for preliminary constructions is as follows:

"Preliminary constructions are prototypes of the final constructions in terms of the three medical-biological parameters (MBP) - preventive, functional, and aesthetic. They serve as the material carrier of the mutual informed consent between the dental practitioner and the patients regarding the type of final construction. They are planned in advance and fabricated in the laboratory prior to preparing the prosthetic field in the patient's mouth and long before the fabrication of the final constructions. They retain the potential for unlimited additional adjustments."

This definition of preliminary constructions was proposed and supported by M. Dimova [28]. It is based on the analyzed theoretical frameworks and requirements presented in her dissertation work, which outline the criteria that these constructions should meet.

In his textbook from 1992, Acad. N. Popov [29] proposes a classification of preliminary constructions in implant prosthodontics based on their fabrication technique. This classification based on the protocol used for their fabrication is generally applicable even in non-implant prosthodontics.

"... - *fabricated in clinical conditions (direct technique) using the techniques of conventional prosthodontics,*

- *fabricated in the laboratory on working models (indirect technique),* and

- *fabricated in a combined manner - using a direct-indirect technique, where pre-made shell crowns are fabricated, significantly reducing the clinical working time*..."

Preliminary prosthetic constructions, whether supported by natural teeth or implants, are preferred as a method for restoring missing teeth and dental tissues, satisfying both aesthetics and function. In the past, interim fixed prosthetic constructions were perceived as a substitute for the final construction during its fabrication in the dental laboratory. Preliminary prosthetics during the course of prosthetic treatment, intended to be completed with a fixed construction, are considered by many authors [1, 25, 28, 30-37] as an essential stage and should fulfill multiple tasks - preventive, functional, and aesthetic.

MATERIALS AND METHODS FOR FABRICATING PRELIMINARY NON-REMOVABLE PROSTHESES

Materials

The classification of conventional materials used for fabricating interim fixed prosthetic constructions (IFPC) can be divided into materials that are individually preformed, according to a report by Burns *et al.* for the Committee on Scientific Development in Fixed Prosthodontics of the Academy of Fixed Prosthodontics in 2003 [38].

I. *The materials for custom made* preliminary non-removable prosthetic constructions can be categorized based on their polymerization mechanism [38]:

1) Chemically activated self-polymerizing plastics;
2) Heat-activated plastics;
3) Light-activated plastics;
4) Dual-curing plastics;
5) Others (alloys and hybrid materials).

The most commonly used conventional materials for interim constructions are acrylic plastics [28, 34, 39]. According to some authors [25, 38, 40, 41], a disadvantage of acrylic plastics is their susceptibility to fracture [42]. However, they offer the advantage of adjustability through addition and subtraction [43, 44].

Burns *et al.* [38] divide acrylic resins into several types for provisional prosthesis materials:

A. Polymethyl methacrylate (PMMA) - first introduced in the 1940s, it still is the most widely used material for provisional restorations [34]. Iy possesses strength, affordability, and is easily polished, but its monomers are cytotoxic [45], and the polymerization reaction in self-polymerizing acrylics is highly exothermic, which carries the risk of sensitizing or devitalizing prepared vital teeth [28]. Therefore, in the literature, they are recommended as materials for indirect or direct-indirect methods of fabricating provisional restorations.

B. Polyethyl methacrylates (PEMA) - this category includes vinyl, ethyl, and butyl methacrylates which have similar chemical behavior. They are characterized by lower toxicity and exothermicity compared to PMMA, but they have inferior mechanical properties. They are recommended for short-term provisional restorations and rebase procedures in the indirect-direct technique [32].

C. Other acrylic resins or combinations of methacrylates without fillers - urethane dimethacrylate (UDMA) and others.

D. Composite materials - Representatives of this group commonly contain a polymer resin called bisphenol A glycidyl methacrylate (Bis-GMA) and inorganic fillers such as alumino-silicate, quartz, or acrylic particles. Depending on their polymerization mode, they can be:

- Self-polymerizing;
- Light-cured;
- Dual-cured (light- and self-polymerizing).

They are characterized by affordability, strength, ease of use in clinical conditions, good polish ability, and color stability. They have low toxicity, sensitizing potential, and allergenic potential compared to PMMA [28].

Most composite materials are supplied with a dispensing gun and mixing tips, similar to those used for addition of silicone corrections. This makes them significantly faster and more convenient for clinical use (direct and direct-indirect methods), although the cost of the materials is slightly higher [15].

II. *Preformed options* for preliminary non-removable prosthetic constructions - this category includes pre-made crowns, which are most commonly used in pediatric dentistry [46-49]. They can be made of metal, composite, zirconium dioxide, and other materials. This category also includes blanks for subtractive CAD/CAM milling - discs and blocks made of polymerized materials under ideal conditions [50].

In 2021, Benli *et al.* [51] tested and compared the mechanical properties of twenty subtractive manufactured crowns made of polylactic acid (PLA) - an organic, biodegradable material that is increasingly being used as a substitute for non-biodegradable industrial polymers and in the production of prototypes through thermoplastic extrusion printing. The other materials used in the study were the same number of subtractive manufactured crowns made of PMMA and polyetheretherketone (PEEK). Despite showing the lowest fracture strength, the PLA material exhibited similar values of marginal fit, which, combined with its ability to degrade in the environment without causing harm, ranks it among the materials suitable for provisional prosthetic crowns.

Methods

1) Conventional (analog) methods

Conventional methods for fabricating provisional prosthetic constructions involve taking an impression of the patient's dentition, creating a prototype of the future provisional restoration, and fabrication.

Laboratory methods refer to the techniques used to fabricate provisional restorations on a model. This includes waxing up a prototype, investing, pressing, and thermocycling in flasks or a polymerizer using heat-polymerizing resin [52]. It also involves injecting thermoplastic polymers into molds or direct modeling using self-polymerizing resin and thermocycling in a polymerizer.

On the other hand, *clinical methods* involve fabricating provisional restorations directly in the patient's mouth or using direct-indirect techniques with the help of matrices prepared in the laboratory on diagnostic wax patterns [53].

A *combined method* for fabricating thin-walled precise provisional restorations: In order to meet the three objectives of prevention, function, and aesthetics (PFA) in our country, Dimova [28] introduced a combined method for fabricating precise preliminary restorations with thin-walled frameworks. The laboratory preparation for fabricating the frameworks of provisional restorations precedes the preparation of the abutment teeth.

2) Digital methods

Digital technologies (CAD/CAM) for provisional prosthetic constructions have significantly entered everyday practice and have greatly reduced the fabrication time in the clinic and laboratory. They can be divided into two main types of methods:

I. Subtractive methods: These methods involve obtaining the desired construction by subtracting material from prefabricated CAD/CAM blocks.

II. Additive methods: These methods involve creating the desired construction by adding material for CAD/CAM purposes.

In terms of historical development, initially, the methods of fabricating provisional restorations through subtracting (milling) material from prefabricated blocks, which were polymerized under ideal conditions, found wide application in dental medicine [54]. The predominant material used was PMMA, with some manufacturers offering products with enhanced mechanical properties achieved through additional cross-linking in the polymer network, known as cross-linked polymers [55].

The more recent method is the additive method, which allows for the fabrication of constructions with more complex geometry but has a more sensitive workflow protocol [56]. In 2015, Rayyan *et al.* [57] conducted a comparative study on the color stability, imbibition, wear resistance, surface hardness, fracture strength, and microindentation between crowns fabricated on identical replicas of the upper first premolar using epoxy resin. The materials included in the study were PMMA CAD/CAM blocks, self-polymerizing PMMA, self-polymerizing Bis-GMA, and thermoplastic resin for provisional restorations. The conclusion of the study was that CAD/CAM-fabricated provisional crowns using PMMA outperformed the other constructions made from different materials in terms of their color [10], mechanical, and physical characteristics [57].

The results of the study conducted by Alt *et al.* [25] in 2011 comparing the mechanical properties of materials for direct and indirect fabrication of FPDs are similar. The authors note the superior qualities of the experimental specimens fabricated using the subtractive CAD/CAM method and highlight the absence of composite materials (discs or blocks) for this fabrication technique, despite their advantages.

In another study by Yao *et al.* [58], the compressive strength and marginal fit between Bis-GMA materials for direct (clinical) fabrication of FPDs and PMMA materials for subtractive CAD/CAM fabrication method were compared after thermocycling for 5000 thermal cycles (from 5°C to 55°C). Once again, the results favored the experimental specimens fabricated using the subtractive method, particularly after undergoing thermocycling.

In a study by Al-Dwairi *et al.* in 2020 [30], the flexural strength, fracture toughness, and modulus of elasticity (E) of two PMMA materials (AvaDent and Tizian) for subtractive CAD/CAM technology and one heat-polymerized PMMA material (Meliodent by Heraeus Kulzer) were investigated. Each group of 15 specimens was stored in distilled water at 37 ± 1°C for 7 days. The results demonstrated better mechanical properties for materials used in the subtractive fabrication method, although there was some variation among different brands.

In a laboratory study published in 2019, Alp *et al.* [20] investigated three groups of CAD/CAM PMMA polymer blanks for the subtractive manufacturing method (Telio CAD [T]; M-PM-Disc [M]; Polident-PMMA [P]), one Bis-GMA clinical composite material (Protemp 4 [PT]), and one cold-polymerizing clinical PMMA material (ArtConcept Artegral Dentine [C]). The test specimens were prepared with dimensions of 2 × 2 × 25 mm according to ISO 10477:2004 standard (Dentistry - Polymer-based crown and veneering materials). Test specimens (N=15 of each type) were subjected to 10,000 thermal cycles (5 to 55°C). A three-point bending test was conducted on a universal testing machine at a crosshead speed of 1.0 mm/min. The results showed the highest values for the subtractive manufacturing materials, intermediate values for the Bis-GMA clinical material, and the lowest values for the self-polymerizing PMMA clinical material for dental prostheses.

Milled PMMA disc preliminary structures are not characterized by the toxicity, heating, and shrinkage described [8, 28, 40] with self-polymerizing and dual-polymerizing plastics for clinical use. Other advantages include increased mechanical resistance [20, 25, 30, 57, 58] fit [57, 58], and color stability [57].

3D printing setups are becoming increasingly accessible, where manufacturing after digital design is accomplished through material addition (additive method), allowing for material savings and reduced production time compared to subtractive methods (milling) [59-61]. According to several studies, printed preliminary structures are not inferior to milled ones in terms of accuracy and strength [62].

Reinforcing preliminary non-removable prosthetic constructions

Reinforcing preliminary non-removable prosthetic structures is a method aimed at increasing mechanical resistance and reducing the likelihood of fracture, which is a common issue in clinical practice, especially in bridge constructions. The reinforcement method can be applied during the fabrication of the prosthesis or after intraoral use, when repairing a fractured structure.

In 1991, Larson *et al.* [63] conducted an experimental study on specimens made of three types of polymers for fixed dental prostheses: one methyl methacrylate (PMMA) and two polyether methacrylate (PEMA) materials, with and without carbon fiber reinforcement. The groups were further divided based on the storage medium, with half of the specimens being immersed in water. The results showed a significant increase in the elastic modulus of the specimens in the reinforced groups, regardless of the storage condition. Immersion in water did not cause statistically significant changes in the results.

In a study conducted in 2003 by Pfeiffer and Grube [64], the fracture resistance of fixed dental prostheses made from various materials with and without reinforcement was compared. The experiments involved identical long-span bridge structures with 2 abutments and varying numbers and lengths of pontics (3-unit: 12 mm, 4-unit: 19 mm, and 5-unit: 30 mm), and the central part of the pontics in the occlusal region was subjected to loading. The researchers found that reinforcement with impregnated fibers significantly increased the fracture resistance for different lengths of pontics.

In 2004, Kim and Watts [65] investigated the influence of glass fiber reinforcement on polymers for fixed dental prostheses. They compared three dimethacrylate-based materials and one methyl methacrylate material, and also examined the effect of water storage on the specimens. The study revealed a significant increase in the flexural strength values for the groups reinforced with glass fibers and lower values for specimens stored in water, although the differences were not statistically significant.

In a similar study conducted in 2004, Hamza *et al.* [66] compared the mechanical properties of three types of materials for fixed dental prostheses (PMMA, PEMA, and composite), reinforced with two types of glass fibers and four types of polyethylene fibers (Kevlar). The authors examined the fracture strength and flexural strength of the specimens according to ASTM no. E 399-83 and ISO 14077, respectively. For both tests, they used non-reinforced specimens as a control group.

DISCUSSION

A brief discussion of the new trends in materials and methods and their practical significance is presented.

Reinforcement of polymer materials for FPDs is a method used to create medium-term (1 to 6 months) and long-term (6 months to 2 years) provisional prosthetic restorations [67] in cases where their use is necessary within complex, multidisciplinary treatment plans. The methods for their fabrication can be direct (clinical), indirect (laboratory), direct-indirect (clinical-laboratory), or indirect-direct (laboratory-clinical).

Clinical methods

Clinical or direct methods save time and resources for both the clinician and the patient. For their fabrication, factory-made or individual matrices (external formers of provisional restorations) are most commonly used, thus avoiding the time-consuming direct modeling of tooth forms. However, direct methods have some drawbacks. These include the allergenic potential of unpolymerized provisional restorative materials placed on oral tissues, thermal trauma and sensitization of vital prepared teeth [28, 68], poorer marginal adaptation of the restorations due to the need for removal during the impression phase from the prepared abutments to prevent blockage in potential subgingival spaces, the need for training of the dental practice staff in the fabrication, finishing, and polishing of the restorations [15]. Reinforcement of such restorations can be achieved through the use of polyethylene or glass fibers adapted intraorally onto the preparations and subsequently placed in the individual matrix along with the provisional restorative material, as described by Hammond and Hodd in an article from 2016 [69], or they can be fixed without bonding using a liquid composite on dried abutments before placing the matrix with the provisional material, similar to the fiber-splinting technique often used in the fabrication of a retentive splint following orthodontic treatment or in cases of periodontal mobility [70].

Laboratory methods

In laboratory methods of provisional prosthetics, reinforcement can be achieved using all known materials directly onto the prepared tooth abutments, with the polymerization of the plastic materials under ideal conditions, better finishing and polishing of the restorations [15]. The only drawback can be the period between preparation and fabrication of the provisional restorations when the patient has to be either with clinically fabricated restorations or without any [53].

Clinical-laboratory methods

Reinforcement of provisional restorations fabricated in clinical conditions in the laboratory is achieved by integrating fibers into prepared channels in the restoration, filling them with polymers [40], and performing finishing and polishing. We believe that this technique combines the drawbacks of both clinical and laboratory methods.

Laboratory-clinical method. This method involves the fabrication of preliminary laboratory "shells" based on preliminary models, diagnostic modeling, and laboratory pre-conservative preparation of the tooth abutments on the model intended for prosthetic treatment in the mouth [8, 67]. In the clinical phase, the teeth are prepared, the reinforcing fibers are adapted to the preparations, and the restorations are reseated along with them. These restorations possess all the advantages of laboratory methods but also avoid some of the drawbacks of clinical methods, such as compromised marginal adaptation and exposure of the preparations to elevated temperatures during polymerization and the cytotoxicity of unpolymerized provisional restorative materials [28].

CONCLUSION

The presented variety of modern materials and methods for preliminary (provisional) non-removable prosthetics in dental medicine, as well as the options for reinforcement through armament, require a thorough analysis and a wide range of *in vitro* and *in vivo* studies to provide recommendations for daily dental practice. They are also the subject of detailed scientific research in a dissertation entitled "Reinforcement of preliminary restorations - a laboratory and clinical study."

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