Mechanical properties of a polymethyl methacrylate block for CAD/CAM dentures

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Abstract: This study compared the mechanical properties and molecular distribution of a polymethyl methacrylate (PMMA) block (Dry) with specimens that were fabricated by a conventional method and cured in a wet environment (Control). Two specimen types were fabricated with heat-curing denture base resin. Dry specimens were polymerized at high pressure and in a dry system, while Control specimens were polymerized with a heat-curing method, in accordance with the manufacturer’s recommended procedures. Specimens from each group were evaluated for three-point bending, water sorption, and color change, and by gel permeation chromatography (GPC). Mean values for the flexural strengths and moduli of the Dry specimens were significantly higher than those of the Control specimens (P > 0.05). Water sorption and discoloration values of the Dry group were significantly lower than those of the Control group. Mean weight-average molecular weights of the Dry group were higher than those of the Control group. As compared with the conventional method, the present method of fabricating PMMA blocks under high pressure yields superior mechanical properties for the denture base.

Keywords: CAD/CAM, denture base, mechanical properties, molecular distribution, PMMA

Introduction

Since its introduction in 1936, polymethyl methacrylate (PMMA) has become the most common essential material for fabricating removable prostheses [1,2]. However, although ideal as a denture base material, PMMA lacks mechanical strength [3-6], is sometimes polluted by stain [7,8] and candida [9], and has limited biocompatibility [10]. These deficiencies are mainly related mainly to the polymerization process [11,12]. With the conventional method, problems related to the technical process, such as swelling of the investment material and resin shrinkage, cannot be avoided. The advanced technique used by dental technicians is necessary in order to compensate for errors in the process and improve denture precision. However, this technique is not easy, because of the residual ridge in each patient. In addition, nonuniformity of the resin results in inadequate material strength and susceptibility of the denture base to bacterial invasion, which decreases biocompatibility [13].

To address these problems, computer-aided design/computer-aided manufacturing (CAD/CAM) systems have been developed for fabricating complete dentures [14]. With these methods, a new denture can be designed as a three-dimensional template with CAD software. A new denture base is then cut from a PMMA block with a computerized numerical control machining center, after which the artificial teeth are bonded [15] and the new denture is completed. This method is unlimited by a flasking process similar to that used in the conventional method. The denture base can thus be milled from a highly accurate PMMA block polymerized under rigorously controlled conditions, which solves the problems described above. The CAD/CAM method differs from conventional methods for cutting the denture base. The PMMA block used for the CAD/CAM method is fabricated at high pressure and temperature, which improves PMMA polymerization, decreases free monomers and porosity, and enhances mechanical properties [16-22]. Furthermore, because this method is not limited to particular denture base materials, materials more suitable than PMMA can be used for dentures [9]. The number of studies of denture fabrication with CAD/CAM methods is growing [23-25]. However, to the authors’ knowledge, no study has investigated the mechanical properties of a PMMA block for a denture created with CAD/CAM methods.

This study compared the mechanical properties and molecular distribution of the PMMA block (Dry) with specimens fabricated by the conventional method (Control). The null hypothesis tested was that there would be no difference between the Dry and Control groups.

Materials and Methods

Two specimen types were fabricated with heat-curing denture base resin (Acron; GC, Tokyo, Japan). One was polymerized in a metal mold under high pressure, to achieve a final diameter of 98 mm and thickness of 30 mm in a dry system (Dry), while the other was polymerized, according to the manufacturer’s recommended procedures, in a gypsum mold by using a heat-curing method without air pressure and with immersion in 100°C water (Control).

Flexural test

Five rectangular specimens were prepared for each group in accordance with ISO 20795-1: 2013 standards [2]. The specimens were cut and polished with 1,200-grit waterproof SiC paper ( Fuji Star; Sankyo Rikagaku, Okegawa, Japan) and rinsed with tap water to achieve a final size of was 65 × 10 × 3.3 mm. Specimen sizes were measured with a micrometer (293-421-20; minimum reading, 0.001 mm; Mitutoyo, Kawasaki, Japan) before flexural testing. Specimens were then stored in 37°C distilled water for 48 h. To measure flexural strength and modulus values, a three-point bending test was performed with a universal testing machine (5500R; Instron, MA, USA) at a temperature of 23°C. The support span distance was 50 mm, and the crosshead speed was 5 mm/min [26]. Flexural strength and modulus values were calculated with statistical software (Series IX; Instron) using the following equations:

\[
FS = 3Fl/2bh^2
\]

\[
FM = 3F/l(F/4bh^3)
\]

where \(F\) is the maximum load (N), \(l\) is the width of the support span (mm), \(b\) is the width (mm) of the specimen, \(h\) is the height (mm) of the specimen, \(F_s\) is the load (N) at a point in the straight-line portion of the trace, and \(d\) is the deflection (mm) at load \(F_s\).

Water sorption and solubility tests

Five disc-shaped specimens were prepared in each group, in accordance with ISO 1567 standards. They were cut and polished with 1,200-grit waterproof SiC paper, rinsed with tap water, and polished with 0.3-μm aluminum powder to achieve a final diameter of 20 mm and a thickness of 1 mm. The specimens were dried in a desiccator with silica gel at 37°C (±1°C) for 7 days. After that, each specimen was removed from the water and dried with a Kimwipe (Kimtex; Kimberly-Clark, TX, USA). Then, each specimen was weighed in a balance at 1 min after being removed from the water, to an accuracy of 0.1 mg.
Control groups. The high-Mw polymer separated at a very early stage in the Dry group (arrow).

Results

Table 1 shows the values for flexural strength, modulus, water sorption and solubility, and discoloration of Dry and Control specimens. A high-Mw polymer separated at a very early stage in the Dry group (arrow).

Statistical analysis

Flexural strength, modulus, water sorption and solubility, and discoloration values were presented as means (SD). Values for the Dry and Control groups were compared by analysis of variance (ANOVA), and the means differences were compared by Student t-test with a significance level of \( P < 0.05 \), following a Shapiro–Wilk test of normality. All analyses were performed with JMP 10 statistical software (SAS, Cary, NC, USA).

Discussion

The present results support rejection of the null hypothesis, as the Dry and Control groups differed in mechanical properties and molecular distribution. Flexural strength, modulus, and Mw were greater in the Dry group than in the Control group, while water sorption and discoloration were lower in the Dry group than in the Control group. Thus, PMMA can be uniformly polymerized from the inner area to the surface by dry, and heat polymerizing systems under high pressure enhanced the mechanical properties of the PMMA polymer. A high flexural strength and modulus are important requirements of denture base materials, to prevent denture fracture and resist denture deformation during mastication. Prior studies on strengthening of denture base materials reported that flexural strength was increased by about 10% to 30% by adding various reinforcing agents [4-6]. Although these methods present challenges related to polishing, aesthetics, and technical procedures, the present findings indicate that the denture base can be improved by using conventional PMMA with different polymerization conditions.

The present finding of greater flexural resistance was consistent with the result of a previous study, which reported that resin polymerized under high pressure (250 MPa) [18]. The increase in mechanical strength resulted in increased higher-Mw polymers because of the high-pressure polymerization process [19,22]. In free-radical polymerization, high pressures greatly increase polymerization rate, with an enhanced propagation rate constant and reduced termination rate constant [19]. In this study, Mw was higher in the Dry group than in the Control group, as were flexural strength and modulus. These results are consistent with those reported in a previous study of high-pressure PMMA polymerization [22]. The pres-
ent results suggest that the high-Mw fraction, which separated at a very early stage in the GPC trace, increased Mw in the Dry group. Because the properties of polymers depend on the proportion of Mw, this high-Mw polymer observed in the Dry group might have an effect on the increase in the mechanical properties of the Dry group.

The increase in the mechanical strength of the polymer may be attributable to a reduction of internal voids and defects during the polymerization of acrylic resin [20]. Furthermore, reduction of porosity and voids in PMMA may decrease water sorption and affect color stability [11,21]. During polymerization of acrylic resin, porosity and voids can develop between polymeric chains [11]. Water absorption by the resin is influenced by porosity and voids in the resin. The use of high pressure during polymerization improves conversion of monomer to polymer and increases crosslinks between polymer chains [21]. The finding of decreased water sorption in this study was consistent with a possible reduction in porosity and voids in the Dry group. Moreover, resin discoloration could be related to the uptake property of the surface [7]. The finding of lower discoloration in the Dry group suggests that the polymerized state of the surface in Dry group specimens was superior to that in Control group specimens. This suggests that the Dry group was well polymerized from the surface to the inner area, thus yielding a homogeneous polymeric structure. The degree of conversion depends on the site of the PMMA block, which is the subject of a future study.

With traditional denture-fabricating technique, the acrylic base resin dough is packed and pressed into an investment gypsum mold. However, the thickness of the denture base is irregular, as it depends on the shape of the residual ridge and degree of ridge resorption. In a denture base, insufficient pressure may result in an inhomogeneous polymer. In addition, water from the investment gypsum could be a curing inhibitory factor in the conventional method [12], because most of gypsum is composed of water.

However, by using a PMMA block uniformly polymerized at high pressure and eliminating water, a high-quality denture base can be fabricated, regardless of denture shape. This increases durability and ensures long-term denture use.

The present findings indicate that the enhanced polymerization procedure improves the mechanical properties of the denture base. In the future, denture bases will be fabricated with various characteristic features, consistent with their milling from resin blocks. However, the association between pressure conditions and polymerization extent was not investigated in detail in this study. Future studies should attempt to develop new resin blocks for CAD/CAM dentures and optimize the conditions during the process. In the present mechanical test, the shapes of the specimens were prepared for specific tests. However, in mechanical testing of denture base materials, previous studies reported differences between denture base and specimen shapes [21]. Moreover, previous studies evaluated only the short-term effects, even though dentures must perform satisfactorily for many years. Therefore, future studies should investigate real denture base shapes and long-term use. In addition, the fitness of the denture base is an important requirement for dentures. Evaluation of the fitness and accuracy of a denture base cut from a resin block and fabricated with the present method is a task for future studies. Within the limitations of this study, the present results suggest that a dry, heat polymerizing system under high pressure enhances the mechanical properties of denture base resin. The PMMA block produced with this method could yield superior mechanical properties for a denture base, as compared with the conventional method, and might thus be a suitable material for CAD/CAM dentures.

Conflicts of interest
None.

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