

Some Mechanical Properties of a Highly Cross-Linked, Microwave-Polymerized, Injection-Molded Denture Base Polymer

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Purpose: The impact strength and the flexural properties of denture base materials are of importance in predicting their clinical performance upon sudden loading. This study compares the impact and transverse strengths and the flexural modulus of three denture base polymers. **Materials and Methods:** The investigation included a relatively new microwave-polymerized polyurethane-based denture material processed by an injection-molding technique, a conventional microwave-polymerized denture material, and a heat-polymerized compression-molded poly(methyl methacrylate) (PMMA) denture material. Impact strength was determined using a Charpy-type impact tester. The transverse strength and the flexural modulus were assessed with a three-point bending test. The results were subjected to statistical analysis using a one-way analysis of variance and the Scheffé test for comparison. **Results:** The impact strength of the microwave-polymerized injection-molded polymer was 6.3 kJ/m², while its flexural strength was 66.2 MPa. These values were lower than those shown by the two compression-molded PMMA-based polymers. The differences were statistically significant. The flexural modulus of the new denture material was 2,832 MPa, which was higher than the conventional heat-polymerized polymer but was comparable to the other microwave-polymerized PMMA-based polymer. The difference in the flexural modulus was statistically significant. **Conclusion:** In terms of the impact and flexural strengths, the new microwave-polymerized, injection-molded, polyurethane-based polymer offered no advantage over the existing heat- and microwave-polymerized PMMA-based denture base polymers. However, it has a rigidity comparable to that of the microwave-polymerized PMMA polymer. *Int J Prosthodont* 2001;14:214–218.

Poly(methyl methacrylate) (PMMA) with a small quantity of cross-linking comonomers is the most widely used denture base material. The polymers are multiphase with a slightly cross-linked polymer matrix between the polymer beads, which are cross linked from the outermost layer only. The PMMA-based denture base polymer is far from being a satisfactory denture material in fulfilling the mechanical requirements of prostheses. One of the factors that influence the

mechanical properties is the type of polymer matrix,¹ and the plasticization effect of water on the polymer matrix is the reduction of the flexural properties of the material.² It is also generally recognized that the impact and fatigue strength of PMMA denture base polymer is not entirely satisfactory; this is reflected in the continuous efforts to improve these mechanical properties. The reinforcement of PMMA with rubber increased the impact strength, but at the expense of fatigue and flexural properties.³ Carbon graphite fiber-reinforced PMMA produced materials with higher fatigue resistance and flexural modulus as compared to unreinforced PMMA.⁴ Poor esthetics, however, can be unacceptable to some patients. Other materials that have been added for reinforcements include glass fibers,^{5–7} aramide fibers,⁸ and ultrahigh-modulus polyethylene.⁹ Alternative polymers, such as polyamide, nylon, and polycarbonate, have also been tested to overcome some of the mechanical deficiencies of

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Table 1 Materials Tested

Material	Manufacturer	Chemical composition	Processing method	Polymerization mode
Microbase	Dentsply/DeTrey	Polyurethane 44%, polymer beads 54%, initiator 2%, silicon dioxide, glass powder, fillers	Injection	Microwave oven 7 min at 750 W
Acron MC	GC	Powder: PMMA almost 100%, barbituric acid derivative Liquid: MMA 95%, difunctional MMA 5%, QAC trace	Compression	Microwave oven 3 min at 500 W
Meliodent	Bayer Dental	Powder: PMMA 97%, benzoyl peroxide initiator Liquid: MMA 95%, EGDMA 5%	Compression	Water bath 9 h at 73°C

PMMA = poly(methyl methacrylate); MMA = methyl methacrylate; QAC = quaternary ammonium chloride; EGDMA = ethylene glycol dimethacrylate.

PMMA. However, the tests have not resulted in the breakthrough of totally new denture base polymers.

Many different processing techniques have been proposed to simplify the technique and to reduce denture production time despite the long-time acceptance of compression molding with the water-bath polymerization method. The use of microwave energy to polymerize PMMA was first reported by Nishii.¹⁰ It is possible to process acrylic dentures in a very short time, as the surface and the deeper parts of the resin are uniformly and rapidly heated.¹¹

Another processing method that has been in use for some time is a continuous-pressure injection technique. The injection-molding technique for denture construction has less polymerization shrinkage¹² and produces a more accurate denture¹³ compared to that produced by the compression-molding method. The latest microwave-polymerized polymer with the injection-molding system for denture construction claims to have the advantages of both the injection-processing and microwave-curing methods. In addition, the one-component paste-form resin is packaged in a disposable plastic cartridge that eliminates mixing and direct handling. It is a polyurethane-based polymer and is claimed by the manufacturer to have high biologic compatibility. Basically, the chemical composition of the new resin corresponds to that of resin reported in the 1980s¹⁴ under the trade name of Triad (Dentsply). That resin did not obtain general acceptance from professionals because of some shortcomings, such as problems of adherence to the denture teeth. To the authors' knowledge, the impact and flexural strengths of this new polyurethane-based denture material have not been fully studied. Therefore, there is a need for these properties to be investigated before the material's use in clinical practice.

The purpose of this study was to compare the impact strength and flexural properties of a new

injection-molded, microwave-polymerized, polyurethane-based polymer; a compression-molded, microwave-polymerized, PMMA-based polymer; and a conventional compression-molded, heat-polymerized, PMMA-based denture base polymer.

Materials and Methods

The materials used in this study are shown in Table 1. Ten specimens of each material were fabricated for each test according to the manufacturers' instructions. Meliodent resin was mixed using a powder-to-liquid ratio of 23.4 g to 10 mL, and the doughing time was 6 minutes. The powder-to-liquid ratio of Acron MC resin was 30 g to 9 mL, and the doughing time was 15 minutes. Microbase resin was supplied in a single-paste form in a plastic cartridge. Dental stone molds were prepared by investing Perspex blocks (ICI) of the appropriate size into the respective denture flasks.

For the injection-molded method, Microbase specimens were prepared in special fiber-reinforced flasks, with the injection unit (Dentsply/DeTrey) maintaining a pressure of 550 kPa for 20 minutes during injection to allow complete outflow of the material into the molds. Polymerization was carried out in a microwave oven (AEG Micromat, model 115) using the recommended curing mode of 7 minutes of irradiation at 750 W.

For the compression-molded method, Meliodent specimens were prepared in conventional metal denture flasks and polymerized in a water bath for 9 hours at 73°C. The specimens of Acron MC were prepared in fiber-reinforced plastic flasks (FRP Flasks, GC) and microwave irradiated according to the manufacturer's instructions for 3 minutes at 500 W.

Each plate was of sufficient size to be cut into four specimens using a band saw and was reduced to the required size on a trimming machine. They were wet

Table 2 Impact Strength of Denture Base Polymers*

Material	Mean (kJ/m ²)	Standard deviation	Coefficient of variation (%)
Microbase	6.3	1.3	20
Acron MC	12.5	1.2	10
Meliodent	13.9	0.7	5

*n = 10 for each group.

Table 4 Flexural Modulus of Denture Base Polymers*

Material	Mean (MPa)	Standard deviation	Coefficient of variation (%)
Meliodent	2355	211.8	9
Acron MC	2753	106.1	4
Microbase	2832	146.2	5

*n = 10 for each group.

Vertical line indicates values that were not significantly different at the 95% level of confidence.

ground using a polishing machine (Struer Rotopole, Struers) with silicon carbide paper disks of 600 and 1,000 grit sizes. The specimens were immersed for 1 month in water at 37°C prior to testing.

Impact Strength Test

Rhombic specimens with dimensions of 50 mm × 6 mm × 4 mm were prepared as specified by the International Standards Organization (ISO) specification for the testing of denture base resins.¹⁵ The impact strength was determined with a Hounsfield Plastics impact testing machine (Monsanto Tensometer, model H-20), which is a Charpy-type test in which the specimen does not have to be clamped. The test was carried out with a pendulum of 453.6 g for Acron MC and Meliodent specimens and a pendulum of 226.8 g for Microbase specimens determined after trial fracture. Unnotched specimens were placed on horizontal supports with the midpoint in the path of the pendulum. The pendulum released from the rest position, and the reduction in swing of the pendulum immediately after breaking the specimen was indicated by the position of the pointer on the attached dial scale. Direct reading of the scale multiplied by the weight of the pendulum gave a value that was converted to kJ using the manufacturer's conversion chart.

Table 3 Transverse Strength of Denture Base Polymers*

Material	Mean (MPa)	Standard deviation	Coefficient of variation (%)
Microbase	66.2	4.1	6
Meliodent	83.6	7.2	9
Acron MC	84.0	5.0	6

*n = 10 for each group.

Vertical line indicates values that were not significantly different at the 95% level of confidence.

Transverse Bend Test

Ten rhombic specimens from each material measuring 64 mm × 10 mm × 2.5 mm, as specified by the ISO specification, were prepared.¹⁵ The test was carried out using an Instron machine (model 4466) using the three-point method, and the dimensions of each specimen were entered into the program for computation. The specimen was centered on the two wedges, which were 50 mm apart. The loading wedge was set to move at a speed of 5 mm/min and engage the center of the specimen until the specimen fractured. Ultimate transverse strength and flexural modulus were automatically calculated.

Statistical analysis was made using a one-way analysis of variance (ANOVA) and the Scheffé test for post hoc comparisons. All analyses were executed using the SPSS software (Microsoft Excel 97, Microsoft) for Windows statistical package.

Results

There was a significant difference between the three materials in terms of the impact strength ($P < .05$), with Microbase specimens exhibiting the lowest value, 6.3 kJ/m², about half the values of the other two materials (Table 2). The difference in the impact strength values between the two PMMA-based polymers (Acron MC and Meliodent) was significant according to the Scheffé test, but it was very small.

A one-way ANOVA demonstrated a significant difference in the transverse strength between the three groups of specimens ($P < .05$). Microbase specimens showed the lowest value, 66.2 MPa (Table 3). The difference in transverse strength value between Acron MC and Meliodent was not significantly different according to the Scheffé test.

A one-way ANOVA demonstrated a significant difference in the flexural modulus between the three groups ($P < .05$), with Meliodent specimens having the lowest value, 2,355 MPa (Table 4). The post hoc Scheffé test indicated that the values for Microbase and Acron MC were not significantly different.

Discussion

The results of the present study allow a comparison of the mechanical properties between the latest microwave-polymerized polyurethane-based material and the existing PMMA-based denture base polymers. The study did not investigate the actual composition of Microbase material, but the information was based on the description provided by the manufacturer. As in any dimethacrylate, polymerization of Microbase resin forms a highly cross-linked polymer matrix. Because it is different from the other two PMMA-based polymers with respect to the cross-linking degree, it is expected to exhibit different mechanical properties. To the authors' knowledge, no other studies have evaluated extensively this new material since its introduction to the market. Because of the limited information available, only an indirect comparison using another urethane-based light-polymerized denture base polymer is possible.

Impact strength is a measure of the energy absorbed by the material before fracture. Notching is normally employed in this type of test. However, the methods used to apply the notch can set up stresses, and be difficult, time consuming, and not reproducible. The currently used test specimens were unnotched because a better correlation was found between the impact strength and the energy absorbed in a flexural test with unnotched test specimens.¹⁶ Al-Mulla et al¹⁴ compared the impact strength of notched and unnotched denture materials and observed the same ranking order regardless of the types of specimen preparations. In the present study, Microbase was shown to have lower impact strength, indicating its comparative weakness and brittleness to the other two materials. According to Robinson and McCabe,¹⁶ surface defects or scratches as small as 16 μm can reduce significantly the impact resistance of acrylic resin. This may explain the low impact strength observed in Microbase, as the material was shown in another study¹⁷ to have the roughest surface among the denture base materials.

The transverse strength test again demonstrated Microbase material to have the lowest value, indicating its inferior strength and low resistance to fracture. This finding is in agreement with a previous study¹⁴ on a light-cured urethane dimethacrylate denture base polymer (Triad). Al-Mulla et al¹⁴ reported Triad to have the lowest values for impact energy and transverse strength when compared to some conventional PMMA denture base polymers. The brittleness of the Microbase polymer, which is chemically similar to Triad, is typical of many extensively cross-linked polymers. The transverse strength of the microwave- and heat-polymerized PMMA-based

polymers did not differ in this study, which is in agreement with other studies.^{18,19}

A comparison of the flexural moduli of the two PMMA-based polymers showed the heat-polymerized polymer to be less stiff, which can be explained by its relatively higher residual methyl methacrylate monomer content. Curing cycle at the temperature of 70°C without terminal boil produces a denture base with a higher residual monomer content,^{20,21} and the adverse effect of the residual monomer is to reduce the flexural modulus of the polymer.²⁰ Further support for the relatively higher monomer content in the heat-polymerized than the microwave-polymerized PMMA-based polymer comes from the higher impact strength of the former. It is normally observed that autopolymerized PMMA has higher impact strength than heat-polymerized PMMA because the higher level of residual monomer has a greater plasticizing effect on the polymer.²²

The high flexural modulus of the injection-molded polyurethane-based Microbase can be explained in terms of the highly cross-linked polymer structure. Again, this is in agreement with the previous study¹⁴ in which the flexural modulus of a urethane dimethacrylate polymer (Triad) was found to be higher than the conventional heat-polymerized PMMA. It is also assumed that the presence of pyrogenic silicon dioxide and microfine glass powder as inorganic fillers in the Microbase formulation further improves its rigidity. Whiting and Jacobsen²³ showed polymeric restorative material with a high filler content to have a higher modulus of elasticity than unfilled PMMA polymer.

It is undesirable to introduce any material into clinical practice whose mechanical properties are inferior to existing materials. The impact strength and the flexural properties are of some clinical relevance when evaluating denture base materials even though fatigue behavior is clinically more important. In terms of the flexural modulus, there appears to be some advantage in employing the new microwave-polymerized denture base polymer of the injection-molding system. The main claim by the manufacturer that the strength is comparable to PMMA-based denture base polymer resin does not seem to be substantiated by this finding. Furthermore, the injection-molding method requires additional expenditure for injection-molding equipment. However, an obvious advantage of using the new material is that it eliminates mixing and direct handling, as it is available in a cartridge in the form of a single paste. From the point of view of the health of workers, this material may have a great potential for future development. This is possible provided that further improvement can be made to the present formulation to improve the impact and flexural strengths.

The microwaveable injection-molded denture base material investigated had inferior impact and flexural strengths compared to the conventional compression-molded PMMA-based denture base polymers. However, in terms of the rigidity, the new material is better than the conventional heat-polymerized PMMA and comparable to the microwave-polymerized PMMA-based polymer.

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Literature Abstract

Long term results of telescopic crown retained dentures—A retrospective study.

The aim of this study was to examine the long-term success of telescopic crown-retained dentures and to relate their success to the number and position of the abutment teeth. The clinical data were collected from 250 telescopic crown-retained dentures provided for 175 patients. The reviewed dentures involved 617 different abutment teeth with telescopic crowns. The observation period varied from 1 year up to more than 20 years. All treatment was performed by either qualified dentists or dental students and checked by senior members of the staff. The dentures had various saddle arrangements. The survival rates were analyzed with the Kaplan-Meier method. During the observation period, 11% of the abutment teeth had been extracted. Of 250 dentures, 34 failed during the observation period. In 56%, this was a result of loss of abutment teeth. There were no significant differences in the survival time between maxillary or mandibular prostheses or between male and female patients. An increased number of abutments improved the survival rate of most denture designs. However, for bilateral free-end saddle dentures, there was no evidence that using more than two abutment preparations improved the survival rate. There was no evidence that using more than four abutment preparations resulted in a higher survival rate.

Eisenburger M, Gray G, Tschernitschek H. *Eur J Prosthodont Restorative Dent* 2000;8:87–91.

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