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Mechanical Properties of Polyamide Versus Different PMMA Denture Base Materials

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Keywords
Denture base materials; mechanical properties; polyamide.

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This work was previously presented at the 88th General Session of the IADR, 2010, Barcelona, Spain.

Accepted: May 15, 2011

doi: 10.1111/j.1532-849X.2011.00804.x

Abstract

Purpose: Polymethyl methacrylate (PMMA) resins are the most commonly used denture materials; however, they do not have a high flexural strength (FS). This study aimed to compare the mechanical properties of a polyamide-based, injection-molded denture material (Deflex) with another injection-molded PMMA base material (SR-Ivocap) and a conventional compression-molded PMMA (Meliodent).
Materials and Methods: Flexural properties (deflection, bending strength, and bending modulus) of denture base materials were evaluated ($n = 10$). Specimens meeting International Standards Organization (ISO) specification number 20795–1 requirements were prepared ($65 \times 10 \times 3$ mm^3). A three-point bending test was carried out on an Instron testing machine at a 5 mm/min crosshead speed. The Knoop hardness test was used to compare microhardness values. Data were analyzed using ANOVA, followed by REGWQ.
Results: The group results, standard deviations, and statistical differences ($p < 0.01$) for Deflex, SR-Ivocap, and Meliodent were (A) flexural strength (MPa: 78.3 ± 1.0,[a] 69.8 ± 1.4,[b] 81.1 ± 1[a]), (B) flexural modulus (GPa: 0.70 ± 0.13,[a] 0.85 ± 0.27,[a] 1.70 ± 0.23[b]), (C) Knoop Hardness (kg/cm^2: 7.5 ± 1.0,[a] 13.5 ± 1.4,[b] 16.9 ± 1.0[c]). Different superscript letters indicate significant difference. All Meliodent specimens fractured during flexural testing, but no Deflex specimens did.
Conclusions: While polyamide denture material produced good fracture resistance, its modulus is not yet sufficiently high to be equal to standard PMMA materials. *Clinical Implications*. Polyamide has some attractive advantages, but will require modification to produce consistently better properties than current PMMA materials.

Even though different materials have been used for denture construction,[1] polymethyl methacrylate (PMMA) resins are the most commonly used.[2] However, PMMA resin fracture strength is not high.[2] Denture wearers are generally older with potentially less muscle control,[3] resulting in accidents causing denture fractures.[1,4] Using metal frameworks within dentures increases the strength of the denture; nevertheless, concerns like corrosion of the metal framework, allergic reactions, permanent deformation following dropping of a denture, unesthetic appearance of the metal clasps, and difficulties encountered during casting remain problems for metal-supported dentures.[1] Continuous efforts to increase material strength to decrease the risk of denture fractures can be listed as: (1) reinforcement of denture materials by adding filling materials,[4,5] (2) changing the chemistry of the denture base polymer by copolymerization and cross-linking of resin materials, (3) incorporation of techniques new to the dental field; and (4) manufacturing new materials with increased resistance to fracture.

One technique that improves the physical properties of dentures is injection molding.[6] The SR-Ivocap system (Ivoclar AG, Schaan, Liechtenstein) is one of the current systems used for making injectable PMMA dentures.[7] Anderson et al[8] and Strohaver[9] reported that the dimensional stability was improved with the injection-molding technique compared to the compression-molding technique, in addition to the decreased polymerization shrinkage and diminished changes in vertical dimension. Results by Huggett et al[10] demonstrated that dentures produced by the injection molding procedure exhibit less shrinkage than those produced by conventional press-pack procedures.

Polyamides, known as "nylon," are thermoplastic polymers produced by condensation reaction between a diamine and a dibasic acid. Yunus et al[11] reported that nylon was not found to be successful for denture construction because of the tendency to color deterioration, staining, and high water sorption. Hence, it was used only in certain circumstances like repeated denture fractures and orthodontic appliance construction. It was reported that with the incorporation of glass fibers in nylon, stiffness of the material was increased, and the flexibility was improved.[11] Flexural properties of a nylon-based denture material (Lucitone FRS, Dentsply, York, PA) were compared with PMMA denture materials processed with different methods and polymerization modes, and inferior flexural properties of nylon material were reported. Parvizi et al[7] evaluated the linear dimensional accuracy of chemically different injection-molded materials (PMMA, nylon, and styrene) to that of conventional pressure-pack acrylic resin (PMMA) and reported that the greatest overall distortion occurred with nylon (Valplast, Valplast Int. Corp., Oceanside, NY) while the least with styrene (Northern, Rapid Injection Systems, Mineola, NY).

Deflex (Nuxen S.R.L, Buenos Aires, Argentina), is another high impact thermo-injection molded polyamide material used for manufacturing dentures. Although there are reports of the mechanical properties of some nylon denture materials like Lucitone FRS[11] and Valplast,[7] the authors of the current study were unable to find published data about Deflex, which has been on the market for the past ten years. The purpose of this study was to evaluate and compare the mechanical properties of a polyamide-based, injection-molded denture material with another injection-molded PMMA base material and a conventional compression-molded PMMA denture material. The null hypothesis was that there would not be any difference between the mechanical properties of the different denture base materials.

Materials and methods

Several mechanical properties of an experimental polyamide material (an injectable material) were evaluated (flexural strength (FS), flexural deflection, flexural modulus, hardness) in comparison to a conventional compression-molded PMMA and an injectable PMMA. Information about the materials is reported in Table 1. The polyamide chemistry of this material is based on a condensation reaction between a diamine and a dibasic acid.[11] Ten specimens ($65 \times 10 \times 3$ mm^3) meeting the requirements of International Standards Organization (ISO) specification number 20795–1 were prepared for each group.

To prevent any deformation that might occur on the wax pattern during preparation, premature specimens were prepared using a wooden stick coated with inlay wax (Dip-wax; BEGO, Bremen, Germany). The conventional compression molding technique using metal flasks was employed to prepare Meliodent specimens. Pre-dosed, injection-molded PMMA resin, SR-Ivocap high impact denture base material, was injected into the Ivocap flask under pressure as recommended by the manufacturer. Constant pressure was applied during polymerization. Details of the technique are presented in the literature.[7] For the polyamide specimens, the wax patterns were flasked according to the manufacturer's instructions. Following the isolation of the pre-packed cartridge and placement in the equipment, the flask was also placed in the system, and the polyamide material was injected into custom-fabricated stainless-steel molds.

Table 1 Denture base materials used in this study and their manufacturers

	Lot & batch no	Manufacturer	Material	Manufacturing method
Deflex	2469	Nuxen S.R.L, Buenos Aires, Argentina	Polyamide	Injection molded
SR-Ivocap	N10685	Ivoclar AG, Schaan, Liecten-stein	PMMA	Injection molded
Meliodent	10JAN051	Bayer Co. Lev-erkusen, Germany	PMMA	Compression molded

Specimens were kept in room temperature distilled water for 100 days. Tests were done immediately after removing the specimens from distilled water without drying the specimens. A three-point bending test was carried out on an Instron testing machine (Testometric M500, 25 kN; Testometric Co, Rochdale, England). A custom-made stainless steel device with a 50 mm span distance between the two supports was used and the crosshead speed was set at 5 mm/min (Fig 1).

Maximum load exerted on the specimens was recorded, and flexural strength values were calculated according to the following formula (Yunus et al[11]):

$$S = 3PL/2bd^2$$

where S is the flexural strength, P is the maximum load applied to the specimen, L is the span length, b is the width and d is the height (thickness) of the specimen.

Flexural modulus (E) was computed from the equation;

$$E = FL^3/4ybd^3,$$

where y is the deflection corresponding to load F at a point in the straight-line portion of the load–deflection curve, L is the

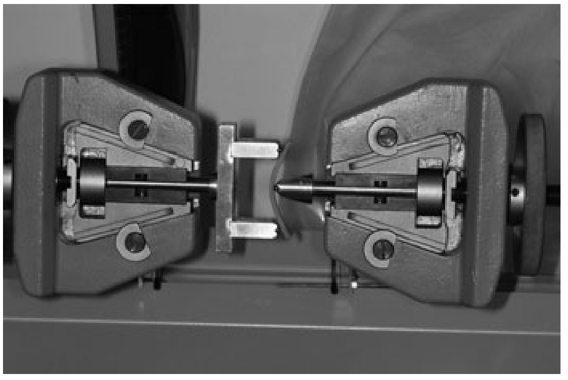

Figure 1 The 3-point bending test assembly.

Table 2 Means and standard deviations of mechanical properties for three groups (n = 10) with results of REGW-Q multiple comparison test

	Flexural modulus (GPa)	Flexural strength (MPa)	Knoop hardness (kg/mm^2)
ISO 20795–1 Values	>2	65	–
Deflex	0.70 ± 0.13^a	78.3 ± 1.0^a	7.5 ± 1.0^a
Ivocap	0.85 ± 0.27^a	69.8 ± 1.4^b	13.5 ± 1.4^b
Meliodent	1.70 ± 0.23^b	81.1 ± 1.0^a	16.9 ± 1.0^c

Different superscript letters within groups indicate significant differences ($p < 0.05$).

length between the jigs, b is the width, and d is the thickness of the specimen.

Fractured specimens were used for the hardness test. Knoop hardness number (KHN) was determined for each specimen using a digital micro-hardness tester (Buehler MMT-3, Lake Bluff, IL). A 100 gf load was applied through the indenter with a dwell time of 15 seconds. Hardness was measured at five locations on each specimen, and the mean KHN was subsequently determined[12,13] for each specimen. ANOVA followed by Ryan, Einot, Gabriel, and Welsch Q (REGWQ) procedure was used for data analysis ($p = 0.05$) using statistical software (SPSS 17.0 for Windows; SPSS, Inc., Chicago, IL).

Results

The results of mechanical property testing for all three materials are reported in Table 2 along with statistical comparisons. All Meliodent specimens fractured during flexural testing, but no Deflex specimens did. Seven of the Ivocap specimens fractured (Fig 2).

Discussion

Results of the current study demonstrated higher flexibility of the Deflex group compared to the Ivocap and Meliodent groups. It was interesting to observe a simultaneously strong and highly flexible material. Although flexibility of a material is important for energy absorption when a patient drops the denture, the same property raises the question as to whether the denture will be rigid enough to distribute the forces equally over the dental arch. This is set as one main requirement for a major denture connector.[2,14] The major connector of a removable partial denture (RPD) should be rigid enough to evenly distribute the force applied on the denture. Therefore, a lower flexural modulus (higher flexibility) is often a disadvantage from the clinical standpoint. According to ISO 20795–1, flexural modulus of the processed modulus shall be no less than 2 GPa. According to the current study, all tested materials failed to pass the requirement. Flexural modulus of Meliodent denture base material was found to be slightly higher in another study (1969 MPa).

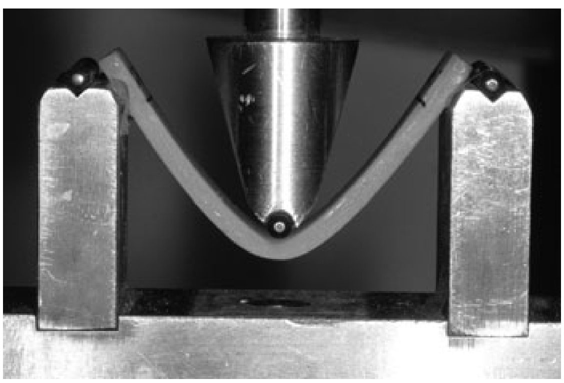

Figure 2 Enormous deflection of a specimen from Deflex group.

The mean flexural strength of all three materials tested in the current work was higher than required in ISO 20795–1. The mean flexural strength of Meliodent specimens found in this study was in agreement with the literature.[2] However, Yunus et al found lower flexural strength compared to the current project.[11] The difference between the two studies might be attributed to different testing conditions. Yunus et al carried out the test at 37°C. Tests of the current study were performed at room temperature. Ganzarolli et al reported higher flexural strength for the injection-molding technique.[6] However, a different brand was used in their study. On the other hand, specimens tested in the current study were kept in room temperature distilled water for 100 days while Ganzarolli's group stored the specimens in water for 30 days. Increased water absorption in 100 days might have decreased the flexural strength. The mean flexural strength of Deflex specimens was found to be lower than the manufacturer's value (89.2 MPa). The difference might be attributed to the different batches tested.

Knoop hardness test was found to be highly convenient for investigating the relative mechanical properties of the microstructural features.[12,13] Hardness results of three denture materials evaluated in the current study were consistent with their flexural properties. Even though the hardness of SR-Ivocap (13.48 ± 1.4) and Meliodent (16.9 ± 1.0) were consistent with the hardness results of denture base materials in the literature, the hardness of Deflex specimens (7.47 ± 1.0) were found to be much lower. Consani et al[13] reported KHNs for different acrylic resins ranging between 11.53 and 18.53. Whether the relatively lower hardness of Deflex materials might cause any clinical problems should be further investigated.

Flexural properties of different denture materials were evaluated. Even though flexibility is necessary for the clasps in an RPD, materials with high flexibility are not the material of choice for use as major connectors. Therefore, both higher flexural modulus and strength are more important than higher deflection rates. This study shows significantly higher deflection rates in polyamide material. Deflex might be an alternative for constructing complete dentures, but not for RPDs.

The flexural resistance of polyamide can be improved by including reinforcing fillers.[1,4,5] However, a more rigid material will not be flexible enough to be used as denture clasp. Even though the initial results on mechanical properties of Deflex seem promising, further research is needed to evaluate the water absorption and discoloration of the new material, the bond between the denture material and the prefabricated PMMA teeth, and microorganism and plaque accumulation.

The most important advantage of polyamide denture base materials is esthetics. A variety of colors is provided by all manufacturers. Especially when a more transparent selection is made, the material reflects the color of the base tissue, either the teeth or the mucosa. This result provides a more acceptable appearance of the clasps used for retention and the denture material, respectively. Nevertheless, the repair of a polyamide denture is more difficult than repairing PMMA dentures. It is difficult and expensive to fix the dropped teeth or clasps, repair fractures, and reline the denture when polyamide denture material is used. Most of the time, making a new denture is more convenient than repairing a polyamide denture.

Glass transition temperatures of PMMA and PEMA are 105°C and 65°C, respectively.[15] These temperatures are close to the higher end mouth temperatures. Hence, mechanical properties of denture base materials might be different at mouth temperatures (ranging between 5°C and 55°C). It will be interesting to observe the effect of thermocycling on mechanical properties of denture materials; however, this was not included in this study and is an important area for a future study. A three-point bending test was performed at room temperature. Whether testing materials at mouth temperature changes the results should be investigated.

A decision on denture material selection for clinical applications cannot be made only according to the mechanical properties of a material. This selection should be based on many factors, as mentioned above, that will affect the long-term use of a restoration.

A clinical long-term prospective study should be planned to evaluate if there is a clinical significance between the strength and long-term use of the materials. Further research should be done before clinical use of this material is common.

Conclusions

Within the limitations of this study, it can be concluded that:

1. Polyamide flexural strength was not significantly different from compression-molded PMMA ($p > 0.05$); however, injection-molded PMMA provided a significantly lower flexural strength compared to the other groups ($p < 0.05$).
2. The flexural modulus of polyamide was lower than compression-molded PMMA material ($p < 0.05$).
3. Polyamide was not as hard as the other materials.

Acknowledgments

The authors of the current project are highly grateful to Dr. Burak Ozcelik from the Dental Hospital of Baskent University, Ankara, Turkey for preparing the Ivocap and Meliodent specimens. We also acknowledge Maydental (Izmir, Turkey), for their contribution in preparing the Deflex specimens.

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