Flexural strength of heat-polymerized polymethyl methacrylate denture resin reinforced with glass, aramid, or nylon fibers

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Statement of problem. Despite the favorable properties of conventional PMMA used as a denture base material, its fracture resistance could be improved.

Purpose. This in vitro study was performed to determine whether the flexural strength of a commercially available, heat-polymerized acrylic denture base material could be improved through reinforcement with 3 types of fibers.

Material and methods. Ten specimens of similar dimensions were prepared for each of the 4 experimental groups: conventional acrylic resin and the same resin reinforced with glass, aramid, or nylon fibers. Flexural strength was evaluated with a 3-point bending test. The results were analyzed with a 1-way analysis of variance.

Results. All reinforced specimens showed better flexural strength than the conventional acrylic resin. Specimens reinforced with glass fibers showed the highest flexural strength, followed by aramid and nylon.

Conclusion. Within the limitations of this study, the flexural strength of heat-polymerized PMMA denture resin was improved after reinforcement with glass or aramid fibers. It may be possible to apply these results to distal extension partial denture bases and provisional fixed partial dentures. (J Prosthet Dent 2001;86:424-7.)

To overcome these shortcomings, experiments with alternate polymers were conducted, but the polymers failed to produce dentures of greater accuracy or better performance. Various modifications of PMMA also have been tested to improve the existing material; these modifications include chemical modification to produce graft copolymer high-impact resins and mechanical reinforcement through the inclusion of glass fibers, sapphire whiskers, aramid fibers, carbon fibers, stainless steel mesh, nylon, or (more recently) ultra-high-modulus polyethylene fibers.

Numerous studies have evaluated the use of individual reinforcing fibers to improve the strength of the denture base. In the absence of any single study comparing the properties of PMMA resin reinforced with different types of fibers, this in vitro study was performed to compare the flexural strength of commonly used PMMA resin and that of PMMA resin reinforced with glass, aramid, and nylon fibers.

MATERIAL AND METHODS

Forty dental stone molds were prepared using stainless steel dies of specific dimensions. The 4 experimental

CLINICAL IMPLICATIONS

This in vitro study demonstrated a significant improvement in the flexural strength of conventional acrylic resin when it was reinforced with glass or aramid fibers.

PMMA currently is the material of choice for denture base fabrication. Introduced in 1937 by Dr Walter Wright, PMMA continues to be used because of its favorable working characteristics, processing ease, accurate fit, stability in the oral environment, superior esthetics, and use with inexpensive equipment. Despite these excellent properties, there is a need for improvement in the fracture resistance of PMMA.

Most fractures of the denture occur inside the mouth during function, primarily because of resin fatigue. The denture base resin is subjected to various stresses during function; these include compressive, tensile, and shear stresses. Some of the factors responsible for denture fracture include stress intensification, increased ridge resorption leading to an unsupported denture base, deep incisal notching at the labial frenum, sharp changes at the contours of the denture base, deep scratches, and induced processing stresses.

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groups consisted of conventional acrylic resin and the
same resin reinforced with glass, aramid, or nylon fibers.
Ten specimens were fabricated in a standardized fashion
for each of the experimental groups. Flexural strength
was tested with a 3-point universal testing machine.

Forty dental stone molds were prepared in dental
flasks with preformed stainless steel metal dies (each
$65 \times 10 \times 3 \text{ min}$). Each die was coated with a thin
layer of petroleum jelly before being invested in dental
stone. After the final set of the dental stone, the flask
was opened, and the die was gently removed from the
investing material. The master die had a threaded hole
in the center to facilitate easy removal from the stone
mold. The prepared molds then were immersed in hot
water to remove any trace of impurities and to facili-
tate the application of separating medium. The mold
cavities obtained were used for the preparation of
acrylic resin test specimens.

The control group test specimens were made with
conventional heat-polymerized acrylic resin (Travalon;
Denstply International, York, Pa.). A mixture of
monomer and polymer in the ratio of 1:2.4 by weight
was allowed to reach dough stage, then kneaded and
placed in the mold. Trial closure was performed with a
hydropress at 40,000 N (KaVo EWL, Leutkirch,
Germany). The flask was clamped, and low pressure
was maintained for 30 minutes to allow proper pene-
tration of monomer into the polymer, even flow of the
material, and outward flow of excess material. The
flask was immersed in water in an acrylizer (KaVo
EWL) at room temperature. The temperature was
raised slowly to $73^\circ\text{C}$ and maintained for a half hour.
After completion of the polymerization cycle, the flask
was allowed to cool in the water bath to room tem-
perature before deflasking. The acrylic specimens then
were retrieved, finished, and polished.

The remaining 3 experimental groups consisted of
PMMA resin specimens of the same dimensions rein-
forced with glass (Ahlstrom Corp, Karhula, Finland),
aramid (Kevlar; DuPont, Wilmington, Del.), or nylon
(MRF Ltd, Chennai, India) fibers. These fibers had a
thickness of 10 to 15 $\mu\text{m}$ and were cut to 5 mm
length. The cut fibers were soaked in monomer for 10
minutes for better bonding with the acrylic resin;
after the fibers were removed from the monomer,
excess liquid was allowed to dry. The resin and fibers
(2% by weight) were mixed thoroughly to disperse
the fibers. On reaching dough stage, the mixture was
kneaded and packed into the prepared mold. The
specimens were polymerized and recovered in the
same manner as the control group. After deflasking, if
the specimens revealed exposed fibers at the peripher-
al border, trimming was performed with diamond burs
to avoid delamination of the reinforcement.

All specimens were stored in water at room tem-
perature for 1 week before testing. Specimens were
labeled on each end before testing so that fractured
pieces could be reunited and examined subsequent
to testing.

All samples were tested for flexural strength with a
3-point bending test with a universal testing machine
(WPM Leipzig, Leipzig, Germany) at a crosshead
speed of 2 mm/min. A load was applied by a centrally
located rod until fracture occurred. The flexural
strength was calculated with the following formula:

$$FS = \frac{3p}{2bd^2}$$

where $FS$ is flexural strength, $p$ is the peak load
applied, $l$ is the span length, $b$ is the sample width, and
d is the sample thickness. The results were analyzed
with a 1-way analysis of variance (ANOVA).

RESULTS

Figure 1 shows the mean and standard deviation
values of flexural strength for each of the experimental
groups. In group A (control), the force required to fracture the specimens ranged from 14 to 18.5 kg; the flexural strength of these specimens ranged from 624.6 to 825.4 MPa, with a mean of 696 MPa. In group B (glass fiber reinforced), the force required to fracture the specimens ranged from 18.5 to 23.5 kg; the flexural strength of these specimens ranged from 825.4 to 1048.5 MPa, with a mean of 979.2 MPa, the highest among all groups. In group C (aramid fiber reinforced), the force required to fracture the specimens ranged from 16.5 to 22 kg; the flexural strength of these specimens ranged from 736.2 to 981.5 MPa, with a mean of 849.9 MPa. Finally, in group D (nylon fiber reinforced), the force required to fracture the specimens ranged from 15 to 19 kg; the flexural strength of these specimens ranged from 619.5 to 847.7 MPa, with a mean of 733.4 MPa. Group B specimens had the highest flexural strength, followed by groups C, D, and A (in that order). The higher the load or force required to fracture the specimens, the higher the fracture resistance.

An analysis of the difference in flexural strengths was performed with a 1-way ANOVA, and the result was found to be significant ($P<.001$). The minimum significant value was 87.8 MPa. Only the control and nylon-reinforced denture resins did not differ significantly.

DISCUSSION

PMMA resin is the material of choice for the fabrication of denture bases. However, fracture of the base may occur during function because of the poor transverse, impact, and flexural strengths of PMMA. One of the most common causes for breakage of dentures is fatigue (namely, continued flexing of the base during function, which leads to crack development). Midline fracture of a denture base is a flexural fatigue failure that results from cyclic deformation of the base during function. This fracture stems from the initiation and propagation of a crack, and it requires the presence of a stress raiser or localized stress.

This study compared the flexural strengths of conventional PMMA resin and the same resin reinforced with glass, aramid, or nylon fibers in loose form. Glass is an inorganic substance that has been cooled to a rigid condition without crystallization. Different types of glass fibers are produced commercially; these include E-glass, S-glass, R-glass, V-glass, and Cemfil. Of these, E-glass fiber, which has high alumina and low alkali and borosilicate, is claimed to be superior in flexural strength.8

The flexural strength of a material is a combination of compressive, tensile, and shear strengths. As the tensile and compressive strengths increase, the force required to fracture the material also increases. Compared with conventional polymer materials, fiber-reinforced polymers are successful in their application primarily because of their high specific modulus and specific strength. Because the modulus of elasticity of glass fibers is very high, most of the stresses are received by them without deformation.23 Thus, in this study, glass-reinforced specimens exhibited better flexural strength than the other specimen groups.

Aramid is a generic term for wholly aromatic fibers. These fibers are resistant to chemicals, are thermally stable, and have a high mechanical stability, melting point, and glass transitional temperature. They also have pleated structure (molecules are radially arranged in the form of sheets) that makes aramid weak as far as flexural, compression, and abrasion behavior are concerned. This explains why aramid fiber-reinforced specimens demonstrated a lower flexural strength than specimens reinforced with glass fiber.

Nylon fibers are polyamide fibers and are based primarily on aliphatic chains. The chief advantage of nylon lies in its resistance to shock and repeated stressing. However, water absorption affects the mechanical properties of nylon. In this study, nylon-reinforced specimens bases had a higher fracture resistance than the control PMMA specimens.

Neither thermocycling nor fatigue testing was conducted in this study. Fatigue would be better simulated in intraoral conditions, which would also reveal any effect of water sorption on the properties of fiber-reinforced PMMA resins.

CONCLUSIONS

Within the limitations of this study, the reinforcement of denture base resin with glass, aramid, or nylon fibers improved the flexural strength of the resin. Which type of fiber is preferable depends on the type of prosthesis being fabricated. Glass and aramid fibers appear to be suitable for long-term use in complete dentures and distal extension partial denture bases, which are considered prone to fracture. Glass fiber reinforcement may also help prevent fracture in provisional fixed partial dentures by strengthening them at the connector sites.

REFERENCES


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Saliva in health and disease: an appraisal and update

Purpose. Saliva plays an extremely important role in oral health monitoring, as it regulates and maintains the integrity of the oral cavity’s hard tissue as well as some of the soft tissues. This article reviews the role of saliva in health and disease and highlights the current use of salivary tests and the use of saliva as a diagnostic fluid.

Discussion. This article reviews the prevalence of oral dryness (xerostomia) and its importance to the dental practitioner. The discussion includes the following topics: (1) stimulated and unstimulated salivary flow rates and how they are affected by aging; (2) the relationship between xerostomia and salivary gland hypofunction; (3) the causes of oral dryness, which include drug use, irradiation to the head and neck, decreased masticatory function, and xerostomia in the Sjögren’s Syndrome patient; (4) the role of saliva as a diagnostic fluid; and (5) the methods currently available for testing saliva.

Recommendations. The author, an acknowledged world-class scientist of salivary function, makes 12 major recommendations related to saliva education and treatment. Among other things, he suggests that reference values for saliva should be developed; that dental associations worldwide should be encouraged to promote media campaigns on the health benefits of saliva and the significance of dry mouth; that brochures about saliva, dry mouth, and Sjögren’s Syndrome should be published and given to patients by dentists; and that industry should be encouraged to develop salivary testing kits as well as develop products and drugs that do not promote dry mouth. 134 References. —RP Renner