Acrylic Reinforcement with Off the Shelf Perforated Metal Plates

ABSTRACT

To evaluate the effect of Dentaurum Grid Strengthener on flexural strength and modulus of two types of PMMA, 24 beams (75 mm x 10 mm x 2.5 mm) containing bonded and flattened Grid Strengthener and 24 beams without Grid Strengthener were subjected to a 3-point bending test at 5 mm/min. Flexural strength and modulus were calculated. Data were analyzed with a 2-way ANOVA. The highest mean strength and flexural modulus was measured for reinforced high impact resin (96.2±14.3 MPa and 3425±779 MPa, respectively). For flexural strength and modulus, resin and reinforcement had a significant effect. Clinical Relevance: Independent of the resin used, the incorporation of a grid strengthener increases the strength and modulus, thus the fracture probability of dentures is reduced.

Keywords

PMMA
Reinforcement
High Impact
Metal Plate

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INTRODUCTION

The introduction of polymethacrylate resin (PMMA) has dramatically improved the esthetics of removable dental prostheses. After its invention it took several years until it became practical for manufacturing individually dentures when prepolymerized PMMA spheres were incorporated in the resin that reduced the polymerization shrinkage to a few percentages. However, being a rather brittle material with modest mechanical properties dentures made of PMMA based resin are still prone to fractures, which occur in stress concentration areas such as a large frenal notch[1] mainly due to fatigue.[2] Typically, the ratio of upper to lower denture fractures is about 2:1 with the most common causes of fracture appearing to be poor fit and lack of balanced occlusion.[3] For the patient this is annoying, but for the clinician it must be seen as a positive effect, since misfit and lack of balanced occlusion may lead to ridge resorption[4-7] Darbar *et al.*[8] surveyed three dental laboratories and reported that 33% of the repairs were due to debonded teeth, and 29% were repairs to mid-line fractures most commonly seen in the upper denture. The remaining 38% were other types of fractures. The repair of denture fractures is a significant economic problem. The British Dental Practice Board[9] reported in the late 90's that the cost of repairing 1.2 million dentures annually is £18 million. Fractures of dentures may among others be correlated to the mechanical properties of the base material and have been discussed in details.[10]

Therefore, over the years, various approaches to strengthening acrylic resin have been suggested. Basically these efforts can be divided into two ways. The first way is to incorporate strengthening scaffolds which could be made out of metals in the form of mesh, wires, cast plates or frameworks, or materials, such as glass, carbon, polyamide, or polyaramid, made in the form fibers.[11] The strengthening effect of preformed

perforated gold plated stainless steel plates (Dentaurum Grid strengthener), which are sold as strengthener for full dentures has been studied in combination with a PMMA based denture base material (IvoBase Hybrid), in a previous investigation[12] and yielded a significant increase in flexure strength and especially flexure modulus. The other way is to modify the resin composition in order to become tougher (high impact resins).

PMMA base resins with higher impact strength can be obtained by incorporating rubber,[13] e.g. butadiene-styrene rubbers.[14,15] The addition of rubber to PMMA creates kind of a composite which can be described as a matrix of PMMA within which an interpenetrating network of rubber and PMMA is integrated. The strengthening mechanism is that cracks propagating in the PMMA matrix are stopped or at least slowed down, when they hit the rubber–PMMA interface.[16] This means that the cured resin can absorb more energy at a higher strain rate before fracture.[11] Another way to obtain high impact resins is using acrylic-elastomer copolymers. These are typically methyl methacrylate–butandiene or methyl methacrylate-butandiene-styrene copolymers.[17] Crosslinking agents such as glycol dimethacrylate may also be used.[18]

In the present study we were interested if a strengthening effect could be achieved by incorporating such grid strengtheners into a high impact resin. Therefore, the purpose of the study was to evaluate the effect of Grid Strengthener on two different denture base resins, one being a conventional PMMA resin (IvoBase hybrid) and the other being a high impact denture base resin (IvoBase High Impact).

Specifically, the null hypotheses to be tested were, that (1) the metal grid strengthener does not strengthen acrylic resin, and (2) the different acrylic resin do not affect the strength.

MATERIALS AND METHODS

Six Grid Strengthener (0.4mm-thick stainless steel gold plated with ø 2.5mm perforations were purchased and pressed in a hydraulic laboratory press at 9800 N for 2 days until flat. Using wax plates of different thicknesses (0.5mm for bottom, 1.6mm for top) "sandwiches" of 2.5mm thickness were produced, positioning the metal plate at 0.5mm from the bottom side. At three peripheral sites the wax was removed, so the samples could be repositioned into the flask after boiling out of the wax. Using flasks for the injection technique and the appropriate spruing *(Figure 1)* and yellow Microstone, type III a two part form was created, which allowed a defined 3D reposition of the grid before injecting the resin. For control specimens, six wax plates 2.5mm thick without grid strengthener were flasked and processed as described above.

The following four test groups with three flasks each were included in this study:

- Group IH-C: IvoBase Hybrid, no strengthen grid (control 1).
- Group IH-G: IvoBase Hybrid, with strengthening grid.
- Group IHI-C: IvoBase High Impact no strengthening grid (control 2).
- Group IHI-G: IvoBase High Impact with strengthening grid.

Before being repositioned into the flasks the strengthening grids were primed with Monobond Plus. The primer was applied to the flattened grid strengthener with paint brush, allowed to react for 30 s and then the solvent was evaporated for 10 s by blowing with an air syringe. The next step was to injection mold the IvoBase material using the Ivomat Polymerization unit with program #1 for 35 minutes for IvoBase Hybrid and program #2 for 50 minutes for IvoBase High Impact.

After removing from the flasks the resin/metal plates and the control plates were sectioned with a diamond saw under water cooling into rectangular beam shaped specimens approximately 75mm x 10mm x 2.5mm. For testing purposes the thickness and width of each bar was measured individually using a caliper. It yielded four beams per plate for a total of 12 beams per group. The bars were stored in water for 10 days prior to perform the mechanical testing.

The beams were subjected to a 3-point bending test according to ISO standard 1567 at 5 mm/min. The surface having 0.5mm of denture resin between the surface and the grid strengthener, which was described as the bottom of the processed denture base described earlier, was placed face down during flexure test. The load was applied from the top size, which has 1.6mm of denture resin between the surface and the grid strengthener. The flexural strength (σ) was calculated using the following formula:

$$\sigma = \frac{3FL}{2wh^2} \quad (1)$$

The flexural modulus (E) was calculated according to:

$$E = \frac{L^3F}{4wh^3d} \quad (2)$$

In equation 1 and 2, F is the load at fracture or peak load of bars not broke, L is the span between the two supports (50 mm), w is the width of the bar, h is the thickness of the bar and d is the deflection of the bar due to the load F.

Data were analyzed with two-way ANOVA; significance level was set at $p< 0.005$.

RESULTS

Table 1, Figure 2, and Figure 3 show that incorporation of grid strengthener improves significantly both the flexural strength and modulus of the denture base resin. However, as seen on Table 1 for strength there is a significant interaction, which means that the increase in strength is not the same with both resins. Note that the high impact resin had significantly lower flexure strength and modulus of elasticity than the hybrid material. For high impact resin, three beams of the control group and five beams of the grid-strengthened groups did not break after passing peak load on the load-displacement curve. The experiments of these specimens were terminated and the peak loads were used to calculate flexural strength and modulus.

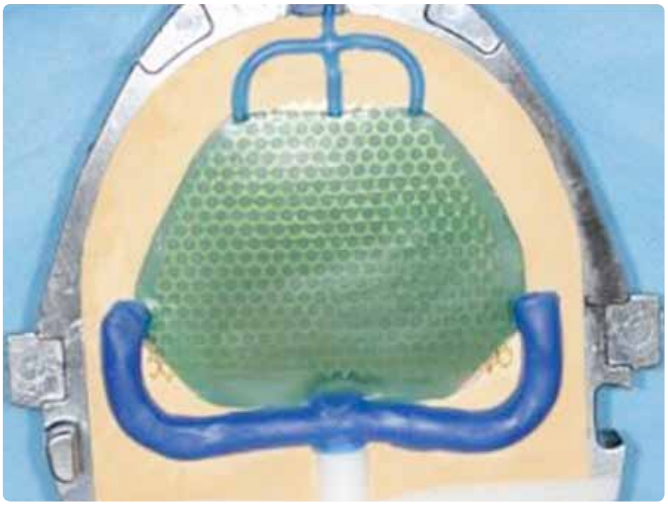

Figure 1: Wax/grit strengthener plate in injection molding flask with sprues. Arrows show reposition area without wax covering the grid.

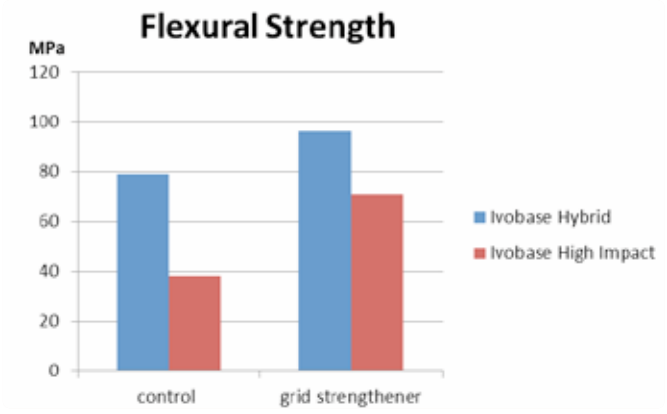

Figure 2: Flexural strength of two resins with and without strengthening grid (p< 0.005)

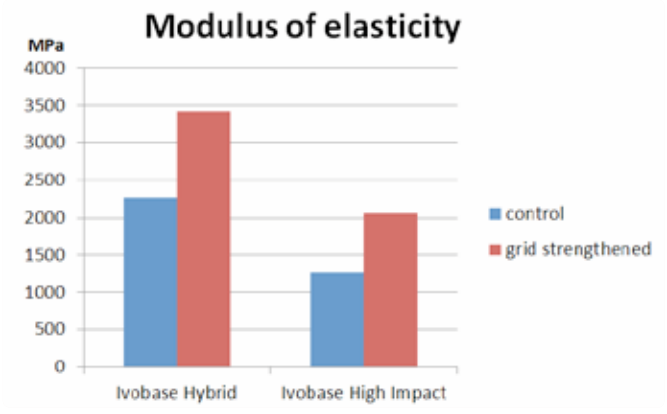

Figure 3: Flexure modulus of two resins with and without strengthening grid (p< 0.005)

Table 1. Results for Flexural strength and modulus

Materials	Flexural strength (MPa ± SD)	
	Control	Grid strengthener
IvoBase Hybrid	78.8 ± 5.9	96.2 ± 14.3
IvoBase High Impact	38.2 ± 6.9	70.9 ± 8.3
Interaction: resin*grid strengthener p = 0.0076		
Materials	Flexural modulus (MPa ± SD)	
	Control	Grid strengthener
IvoBase Hybrid	2262 ± 261	3425 ± 779
IvoBase High Impact	1262 ± 229	2059 ± 234
Interaction: resin*grid strengthener p = 0.1584		

2-way ANOVA; p<0.005

DISCUSSION

The purpose of the study was to investigate if the grid strengthener had a strengthening effect on the flexural strength and modulus of two PMMA based denture base resins (IvoBase Hybrid and IvoBase High Impact). The results showed that grid strengthening and resin type had a significant effect on the values of flexural strength and modulus. Therefore, both null hypotheses can be rejected. The present study could confirm the positive effect of the strengthening grid reported in a previous study.[12]

The injection molding technique was chosen, because it allowed better precision in positioning the metal grids within the PMMA plate and the resin injection does not subject strengthener to vertical forces during processing keeping the grid to stay in place. Traditional compressive molding technique, which requires multiple trial flasking, would likely cause drift of the grid during processing. The grids were positioned close to the bottom of the bars (~ 0.5 mm), where the bar is under tension during testing and fractures of the denture resin were expected. Thus it could be expected to have the best possible strengthening of a metal plate to a PMMA structure.

The IvoBase Injector was used according to the manufacturer's instructions. As most practitioners would, the system was used without the RMR (remaining monomer reduction) option, because the curing times were shorter. The manufacturer's scientific document reports that MRM reduces the residual monomer contents from 1.3 – 1.4% to 0.7%.[19] The effect of RMR on flexural strength and the modulus is not known as the values provided in the report are based on the specimens prepared without RMR option. Specimens made of IvoBase High Impact

material were so flexible that some specimens during testing reached a peak load and continued to deflect at a lower load without fracture. We terminated the test when it occurred and took the peak load for calculating the flexural strength. Same phenomenon was also observed with the grid reinforced beams. Because of the incorporation of grid, the reinforced beams did not break into two pieces but showing plastic deformation of the grid at the point of loading with fracture lines within the resin.

When metallic inserts, such as plates, meshes, wires or fillers, are used to strengthen denture resins, a metal bonding adhesive resin is needed to improve the adhesion between the metal surface and acrylic resin.[20] Improved adhesion makes these inserts integral parts of the denture resin resulting in greater transverse strength.[11] Metal grid used in this study is a perforated stainless steel sheet with staggered pattern of ø 2.5mm holes and 1.25mm between adjacent perforations. When this grid is incorporated during the processing described earlier, the resin fills the perforated spaces *(Figure 1)*. The result is an interpenetrating structure between the metal grid and denture resin that interlocks the resin and grid mechanically. Therefore, as the resin component is being stressed during testing, the metallic component is subjected to the same stress simultaneously. Practically, the perforation on the grid makes the grid an integral component of the processed denture resin. In other words, metal grid strengthener exhibits strengthening effect without the need of bonding between the metal grid and the resin. However, microleakage can still occur from lack of bonding or poor bonding between the denture base resin and metal grid as observed at the cast metal framework and resin base of removable partial dentures. It can cause discoloration and staining of the margins at the metal–resin interface over time.[21] Therefore, the need of a durable bonding between the metal grid and the denture resin remains critical with respect to prevention of staining over time. A multi-functional bonding agent, which is an ethanol solution of silane methacrylate, phosphoric acid methacrylate and sulphide methacrylate and have been shown to bond to gold plated surface of the strengthening grid,[22] was then used in this study.

The powder phase of IvoBase Hybrid contains PMMA beads, plasticizer, initiator and pigments, while IvoBase High Impact consists additional PMMA copolymer and modified PMMA copolymer for improving impact toughness.[19] Such construct is known to decrease the flexural strength and modulus of processed denture resins.[11] Comparing with the published data,[19] our results of IvoBase Hybrid material are lower by 3% (78.8 MPa vs. 81 MPa) in flexural strength and by 16% (2262 MPa vs. 2700 MPa) in flexure modulus. The results of IvoBase High Impact material are lower as indicated but much lower than expected; is substantial the flexural strength is 48% lower (38.2 MPa vs. 73.8 MPa) and the flexure modulus is 47% lower (1262 MPa vs. 2361 MPa). The cause of such discrepancy is not known as the specimens were prepared using the same protocol and the testing parameters were the identical using the same instrument. Nonetheless, the data have validated the positive effect of the grid strengthener.

The analyses show that the influence of the types of resins and grid strengthener on the flexural strength and modulus is statistical significant *(Table 1)*. Looking closer at the data, the percent of the flexural strength improvement by the metal grid was the highest with the IvoBase High Impact material at 86%, and was only 22% increase with IvoBase Hybrid material. For the flexural modulus, the percent of increase resulted from the grid strengthener is comparable between the two materials; 51% for IvoBase Hybrid and 63% for IvoBase High Impact. That explains why ANOVA show there is significant interaction between resin type and grid strengthener with flexural strength but not with flexural modulus *(Table 1)*.

Improving flexural strength and modulus through metal grid strengthener is proven. Since impact strength increase is through the inclusion of elastomeric fillers[19] and embedding grid inserts in processed denture resin means partial loss of elastomeric fillers, one question may be raised is whether the improvement of flexural strength and modulus is achieved at the cost of impact strength rendered by the elastomeric fillers. A study of impact strength of maxillary complete dentures by falling weight impact testing has shown 110% increase of complete denture reinforced with metal grid.[23] Other studies by Charpy-type impact tester using notched beam specimens also show significant increase of impact strength with glass, polymeric or metallic fibers.[24-26] These results indicate that impact strength of high impact resin should not suffer from incorporating metal grid for strengthening.

CONCLUSIONS

Within the limitation of this study, we can conclude that:

1. Metal grid as-received with adhesive resin coating can strengthen the denture base resin in the flexural strength and modulus.
2. The highest strength and modulus were measured for the grid strength reinforced beams made of the IvoBase Hybrid material.
3. Both null hypotheses were rejected.

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MANUFACTURERS DETAILS

- Grid strengthener, Article No. 318-104-00, Dentaurum GmbH &Co, KG, D-75228 Ispringen, Germany,
- IvoBase hybrid, Ivoclar Vivadent, FL 9494 Schaan, Liechtenstein

- IvoBase High Impact, Ivoclar Vivadent, FL 9494 Schaan, Liechtenstein
- Hydraulic laboratory press, Carver Lab press, Wabash, IN, USA
- Wax plates, Truwax, USA
- Injection technique, IvoBase, Ivoclar Vivadent, FL 9494 Schaan, Liechtenstein
- Microstone, type III, Whip mix, Louisville, KY, USA
- Monobond Plus, Ivoclar Vivadent, FL 9494 Schaan, Liechtenstein
- Ivomat Polymerization unit, Ivoclar Vivadent, FL 9494 Schaan, Liechtenstein
- Diamond saw,Buehler Isomet 100, Lake Bluff IL, USA
- Caliper, Model 06-664-16, Fisher Scientific, Pittsburgh PA, USA.
- ANOVA, SAS 9.4, Cary, NC, USA.

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