Evaluation and comparison of transverse and impact strength of different high strength denture base resins

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ABSTRACT

Aim: The present study was undertaken to evaluate and compare the impact strength and transverse strength of the high-impact denture base materials. A conventional heat polymerized acrylic resin was used as a control.

Materials and Methods: The entire experiment was divided into four main groups with twenty specimens each according to denture base material selected Trevalon, Trevalon Hi, DPI Tuff and Metrocryl Hi. These groups were further subgrouped into the two parameters selected, impact strength and flexural strength with ten specimens each. These specimens were then subjected to transverse bend tests with the help of Lloyds instrument using a three point bend principle. Impact tests were undertaken using an Izod–Charpy digital impact tester.

Results: This study was analyzed with one-way analysis of variance using Fisher f-test and Bonferroni t-test. There was a significant improvement in the impact strength of high-impact denture base resins as compared to control (Trevalon). However, in terms of transverse bend tests, only DPI Tuff showed higher transverse strength in comparison to control. Trevalon Hi and Metrocryl Hi showed a decrease in transverse strength.

Conclusions: Within the limits of this in vitro study, (1) There is a definite increase in impact strength due to the incorporation of butadiene styrene rubber in this high strength denture base materials as compared to Trevalon used as a control. (2) Further investigations are required to prevent the unduly decrease of transverse strength. (3) It was the limitation of the study that the exact composition of the high-impact resins was not disclosed by the manufacturer that would have helped in better understanding of their behavior.

Key words: High-impact denture base resin, impact strength, transverse strength

Rehabilitation of stomatognathic system by removable prosthodontics can be considered satisfactory when the prosthesis can give effective and efficient service to the patient. Fracture of a denture base is a common problem and is a major limitation for the effective service expected from the prosthesis.[1]

Various materials like vinyl resins and vulcanite, etc., have been used in the past to fabricate dentures, however, they all had a variety of disadvantages.[2] Polymethyl methacrylate (PMMA) resins have dominated the denture base market since its introduction in 1937.[3] It satisfies most of the requirements of denture base materials in terms of good esthetics, ease of processing and repairability, reasonable cost, etc., However, it has a relatively poor resistance to impact and flexural forces that may affect denture design and lifespan.[4]

A study conducted in England and Wales found about that nearly one million denture repairs were made every year. Fractures in dentures usually result from two different types of forces, namely, flexural fatigue and impact. Flexural fatigue occurs after repeated flexing of a material and is a
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 mode of fracture whereby a structure eventually fails after being repeatedly subjected to loads that are so small that one application apparently does nothing detrimental to the component.[1] This type of failure can be explained by the development of microscopic cracks in areas of stress concentration. With continued loading, these cracks fuse to an ever growing fissure that finally ruptures the material.[9] The midline fracture in a denture is often a result of flexural fatigue. Impact failures usually occur out of the mouth as a result of a sudden blow to the denture or by accidental dropping.

There have been two approaches to strengthen PMMA. The first is to increase the impact strength by incorporating a rubber phase in bead polymer.[6,7] The second approach is a reinforcement of PMMA resin denture base with high modulus fibres, for example, carbon fibers, glass fibers, ultra-high modulus polyethylene, titanium derived fillers, hydroxyapatite whiskers, etc.[8‑15]

The purpose of this study was to evaluate three new high strength denture base materials available in the market and select the best possible material that can serve clinical situations in terms of strength and service. This study aims to investigate transverse and impact strength of a range of high strength acrylic denture base materials like DPI Tuff, Metrocryl Hi and Trevalon Hi. Conventional heat cure acrylic resin (Trevalon) was used as a control.

MATERIALS AND METHODS

This study was conducted on a series of polymerized blanks produced by mixing the appropriate amount of polymer with a monomer according to manufacturer’s instructions.

In this study, a total of eighty specimens were prepared, with twenty specimens each for Trevalon (Dentsply, Weybridge, UK), Trevalon Hi (Dentsply, Weybridge, UK), DPI Tuff (Dental Products of India Ltd., Mumbai, India) and Metrocryl Hi (Metrodent, Huddersfield, UK) acrylic resins. Each group was further subgrouped into two parameters, flexural strength and impact strength with ten specimens each.

All the specimens were polymerized using standard protocols of acrylation.[16] These polymerized blanks were carefully finished to the dimension of $64\,\text{mm} \times 10\,\text{mm} \times 2.5\,\text{mm}$[17] for the transverse bend test and $50\,\text{mm} \times 6\,\text{mm} \times 4\,\text{mm}$[17] for the impact tests; as specified in the International Standard Organisation ([ISO] 1567: 1988) and British standards for testing of denture base resins (BS 2487: 1989).[18]

All the specimens were stored in water-bath for $50 \pm 2\,\text{h}$ at $37 \pm 2\,\text{C}$ until fully saturated.[19] The impact specimens were taken from water-bath and stored in air for $1\,\text{h}$ prior to testing.

Experiment

A. Transverse bend test: It was performed using three point loading method, i.e., the loading nose at the centre with the two supports around 7 mm away from the end[19] to prevent slipping of the specimen from both the ends as the specimen deflects about 5 mm at the centre during load application of the specimen. A Lloys instrument testing machine was used capable for manufacturing deflection within 0.01 mm at the center of the specimen. A crosshead speed of 5 mm/min[17] was adjusted which means that 5 mm deflection of the specimen at the loading point was allowed in 1 min. The loading nose and two supports were made parallel, and the load is applied at the center within 0.1 mm variation over a 10 mm length of the specimen.[19] The loading nose came over the center of the specimen with preadjusted speed, and the deflection of each specimen at the center was measured.

B. Impact test: On each specimen, a V-notch was cut to a depth of 0.8 mm leaving an effective depth of 3.2 mm under the notch.[17] This was carried out with the help of a Zwick notch cutter. The purpose of the notch was that it produces a stress concentration that promotes a brittle, rather than a ductile fracture. The impact strength was measured using an Izod–Charpy digital impact tester. This machine with its pendulum type hammer has been standardized, such that they must comply with certain requirements including a fixed height of hammer fall which results in substantial fixed velocity of hammer at the moment of impact. Impact tests were undertaken in air at 20 $\pm 2\,\text{C}$.[17]

Statistical analysis

The data set constituted a total of eighty specimens, with twenty specimens each for Trevalon, Trevalon Hi, DPI Tuff and Metrocryl Hi acrylic resins. They were further subgrouped into two parameters, flexural strength and impact strength with ten specimens each. Mean values and standard deviations of ten specimens were calculated for each group, and the results of this study were analyzed by one-way analysis of variance using Fisher f-test and Bonferroni t-test.

RESULTS

Figure 1 shows the mean flexural strength of all the denture base material used in the present study. The results obtained were very highly significant. DPI tuff reported the transverse strength of 79.04 N as compared to 72.38 N of Trevalon (control). There was a decrease in transverse strength of Trevalon Hi (65.84 N) and Metrocryl Hi (68.01 N) as compared to the control.

Figure 2 shows the mean impact strength of all the denture base material used in the present study. The results obtained were very highly significant. DPI tuff showed the highest
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Impact strength of 22.20 kJ/m². Trevalon Hi and Metrocryl Hi showed impact strength of 17.12 and 12.89 kJ/m² respectively as compared to 9.036 kJ/m² of Trevalon (control group).

Figure 3 shows the mean flexural modulus of all the denture base material used in the present study. The results obtained were very highly significant. DPI tuff and Metrocryl Hi reported flexural modulus of 2202.2 MPa and 1918 MPa respectively as compared to 1641.7 MPa of Trevalon (control). There was a decrease in flexural modulus of Trevalon Hi (1485.7 MPa) as compared to control.

DISCUSSION

The fracture of acrylic resin denture remains an unresolved problem, and failure is probably because of a multiplicity of factors rather than intrinsic properties of denture base materials. Because no single property can give a true measure of the quality of denture, it is essential to understand the principles involved in a variety of mechanical properties if maximum service is to be obtained. Quantities of force, stress, strain, strength, hardness and others can help identify the properties of a material.[5]

Improved polymers are being developed to overcome the inherent deficiency of the material and to serve the subjective demands of oral environment. The chemical form of butadiene styrene has been successful, but it has detrimental effects on the modulus of elasticity and hence the rigidity of denture base.[8]

The autoclave processing technique in comparison to conventional water-bath processing technique is also one of the methods to improve physical and mechanical properties of high-impact acrylic resins.[20]

Transverse bend test

The transverse (flexural) strength of a material is a measure of stiffness and resistance to fracture. Results of the study were very highly significant ($P < 0.001$).

DPI tuff reported the transverse strength of 79.04 N, which was slightly higher than 72.38 N of Trevalon (control). There was a decrease in transverse strength of Trevalon Hi (65.84 N) and Metrocryl Hi (68.01 N) as compared to the control [Figure 1].

Jagger et al.[17] compared the transverse strength of rubber reinforced denture base materials with conventional denture base material. Except sledgehammer (65.2 N) all the other materials lucitone 199, Enigma Hi-base, Metrocryl Hi and N.D.S Hi reported a decrease in transverse strength when compared to 52.5N of Trevalon (control). The results of this study were similar to present study where DPI tuff showed a higher transverse strength than control (Trevalon) whereas all other materials reported lesser values than control. The (ISO 1567) (1988) and British standard specification 1989 (BS2487)[18] for denture base resins have specified transverse deformation limits that are from 1 to 2.5 mm for a force of 15–35 N and 2–5 mm for a force of 15–50 N. The average breaking force of acrylic resin should not be < 55 N. In this context all the four materials selected in the present study satisfied this requirement as compared to study of Jagger et al.[17] where the only sledgehammer satisfied the requirement. Johnston et al.[1] they compared and tested flexural fatigue properties of ten different denture base resins of four different types. The four different categories used were PMMA pour type, PMMA – thermosetting, PMMA-grafted and vinyl resins. The resins type listed in order of increasing resistance to flexural fatigue are PMMA pour resins, PMMA thermosetting resins, vinyl resins and a PMMA-grafted resins. PMMA-grafted resin (Lucitone 199) rubber reinforced tended to withstand repeated flexure when compared with other resins. The results of this study were similar to the present study.
Shibat Al Hamd and Dhuru compared the physical (processing shrinkage) and mechanical properties (bending deflection, flexure strength, and flexure modulus) of pressure-molded (Lucitone 199 and ProBase Hot) and injection-molded (SR-Ivocap) denture base materials in different conditions. ProBase Hot exhibited significantly less bending deflection and greater flexural strength values than the other two materials ($P < 0.05$). Within the load range of 9–10 kg, 5% of the lucitone specimens, 25% of the SR-Ivocap specimens, and all of the ProBase Hot specimens fractured. Lucitone (PMMA-grafted resin) exhibited the least flexural strength and more bending deflection than Probase Hot among all the three materials tested.

Ajaj-Alkordy and Alsaadi compared the elastic modulus and the flexural strength between two heat-cured acrylic resins used in denture bases: A high-impact resin (Lucitone 199) and traditional resin (Rodex). The high-impact acrylic resin (Lucitone 199) exhibited a lower elastic modulus ($P = 0.000$) and higher flexural strength ($P = 0.001$) compared to the traditional acrylic resin (Rodex). The results of this study were similar to the present study.

Reduction in transverse strength of the high-impact resins used in the present study as compared to the control Trevalon may be due to the incorporation of rubber to improve the impact strength. The manufacturers may have used a different percentage of macromer copolymer (butadiene styrene rubber) in the optimum formulation for high-impact acrylic resins. It was the limitation of the study that the exact composition of the high-impact acrylic resins was not disclosed by the manufacturer. This would have helped in better understanding of the behavior of these high-impact resins.

Impact tests

The impact strength of a material is a measure of the resistance of a material to sudden application of load. This type of fracture is typical of brittle fracture behavior characterized by a lack of distortion of the broken parts. The results obtained were very highly significant ($P < 0.001$) with a definite increase in the impact strength of rubber reinforced acrylic resins as compared with the conventional heat cure acrylic resin. DPI Tuff showed the highest impact strength of 22.20 kJ/m². Trevalon Hi and Metrocryl Hi showed impact strength of 17.12 and 12.89 kJ/m² respectively as compared to 9.036 kJ/m² of Trevalon (control group) [Figure 3].

Jaggers et al. compared impact and transverse strength of five “high strength” denture base acrylic resin with a conventional heat cured resin. The results demonstrated that there were significant differences between some materials. The impact fracture energies range from 11.45 kJ/m² for the highest value recorded for Metrocryl Hi to 4.94 kJ/m² (Trevalon) used as a control. Metrocryl Hi, Lucitone 199, and N.D.S Hi used in this study showed significantly higher impact strength than control (Trevalon). The results of this study were similar to the present study where rubber reinforced acrylic resins showed higher impact strength than conventional heat cure acrylic resin. Murphy et al. in an investigation of some mechanical properties of three denture base materials, a conventional heat cure acrylic resin, a rubber reinforced heat cure acrylic resin and an injection molded rubber reinforced acrylic resin. They reported a considerable improvement in the impact strength for the rubber reinforced polymers that was similar to the present study. Rodford in his study stated that an optimum blend comprising about 25% w/w “macromer” copolymer with D-80 (standard PMMA) gave a reasonable increase in impact strength without unduly decreasing the modulus of elasticity. Impact strength recorded for this blend was 0.61 J/cm² with Young’s modulus of 2140MPa. The mechanism of reinforcement has been discussed in more general terms Rodford. In his study, he conducted various mixing trials of a blended material of rubber reinforced acrylic resins to increase the impact strength. He formulated an optimum blend that had an impact strength of 0.83 J/cm² and young’s modulus of 2270 MPa. The mechanism of reinforcement described was acrylic terminated butadiene styrene copolymers of relatively low molecular weight and narrow molecular range together with nonacrylate terminated block copolymers. Bucknall stated the reinforcement of glassy polymer is a well-established concept, and the mechanism of reinforcement has been discussed. The addition of rubber to PMMA produces a resin that consists of a matrix of PMMA within which is dispersed an interpenetrating network of rubber and PMMA. A developing crack will propagate through PMMA but will decelerate at rubber interface.

Various clinical implications of the study can be the use of rubber reinforced resins for patients who had a past history of repeated denture fractures, shallow palate cases, and patients with high labial frenal attachments and long span provisional fixed partial denture, etc.

CONCLUSION

This study gives an insight of the impact and flexural strength of some commonly available high strength denture base material. DPI Tuff, Trevalon Hi, Metrocryl Hi all had an impact strength significantly higher than the conventional heat cured acrylic resin control material (Trevalon). For the transverse strength, DPI tuff produced the highest value followed by control. The remaining two material had a transverse strength less than control. For flexural modulus, only Trevalon Hi produced the value less than control as compared to DPI Tuff and Metrocryl Hi, which had values more than control.
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Conflicts of interest
There are no conflicts of interest.

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