## Failure strengths of denture teeth fabricated on injection molded or compression molded denture base resins

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TITLE: Failure strengths of denture teeth fabricated on injection molded or compression molded denture base resins

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RUNNING TITLE: Failure strength of denture teeth/denture resins

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**ABSTRACT**

**Purpose:** Denture tooth fracture or debonding remains a common problem in removable prostheses. This study explored factors determining failure strengths of different denture tooth designs on injection or compression molded denture base resins.

**Materials and Methods:** Three central incisor denture tooth designs were tested: nanohybrid composite (NHC; Ivoclar Phonares II), interpenetrating network (IPN; Dentsply Portrait), and microfiller reinforced polyacrylic (MRP; Vita Physiodens). Denture teeth of each type were processed on an injection molded resin (IvoBase HI; Ivoclar) or a compression molded resin (Lucitone 199; Dentsply) (n=11-12). The denture teeth were loaded at 45° on the incisal edge. Failure load was recorded and analyzed with two-way ANOVA (α=0.05). Fracture mode was categorized as cohesive, adhesive, or mixed failure.

**Results:** Failure loads (mean±SD) were: NHC/injection molded 280±52N; IPN/injection molded 331±41N; MRP/injection molded 247±23N; NHC/compression molded 204±31; IPN/compression molded 184±17N; MRP/compression molded 201±16N. Injection molded resin yielded significantly higher failure strength for all denture teeth, among which IPN had the highest strength. Failure occurred predominantly cohesive in the teeth, with exception of mixed mode for IPN/compression group.

**Conclusions:** When good bonding is achieved, the strength of the tooth/base resin combination is determined by the strength of the denture teeth, which may be affected by the processing technique.

**KEYWORDS:** denture tooth; denture base resin; acrylic resin; failure strength; prosthesis
INTRODUCTION

The evolution of implant dentistry and current clinical trends towards providing more implant supported over-dentures and metal-acrylic hybrid restorations have increased the need for prostheses with high impact resistance. Implant born restorations are required to endure heavy occlusal forces due to lack of proprioception around dental implants, which can lead to a 7 to 10 fold increase in biting force as compared to natural dentition.\textsuperscript{1,2}

Denture tooth fracture and debonding from denture base resins is a common complication in implant-supported prostheses as well as other types of removable dental prostheses.\textsuperscript{3,4} Various factors have been implicated in denture tooth fracture and debonding. Surface contamination with wax during the denture fabrication and modification of denture teeth by mechanical and chemical means are known to affect bonding between denture teeth and denture base.\textsuperscript{5-7} Chemical make-up of the denture base and denture teeth also plays an important role in the strength and durability of prostheses.

The majority of denture bases are made from polymethylmethacrylate (PMMA, acrylic resin). Despite its polymerization shrinkage, traditional PMMA (Type 1) dentures fabricated using a compression molding technique with hot water bath process remains the conventional method for fabricating dentures.\textsuperscript{8} Another PMMA denture base resin system was introduced in the 1940s by Pryor that uses an injection molding technique for fabrication to minimize polymerization shrinkage.\textsuperscript{9} Injection molding resins (Type 2) are self-curing polymers with a polymerization temperature lower than 65 °C.\textsuperscript{10} Literature abounds with evidence that heat-processed acrylic resins have stronger bonds to denture teeth as compared to self-curing resins.\textsuperscript{5,11,12} However, the manufacturer of a recently engineered injection molding resin developed for impact performance and superior bonding to denture teeth found only cohesive failure in denture teeth during bond tests,\textsuperscript{10} which implies a strong interface between denture base and denture teeth.

Denture teeth have also been made mainly from PMMA resin. Manufacturers continue to introduce new denture tooth designs that tout better wear resistance and improved mechanical properties, or better esthetic quality. These types of denture teeth often incorporate fillers or are layered with filled bis-GMA, similar to restorative composite
materials. However, anecdotal experience from practitioners is that filled bis-GMA layered
denture teeth often debond from PMMA denture bases.\textsuperscript{13} Newer generation denture teeth
use nanohybrid composites layered over the PMMA tooth core, which is reported to
improve the bonding to conventional denture base resins.\textsuperscript{14}

Resistance to fracture or debonding is not an inherent characteristic of denture teeth alone,
nor is it solely a reflection of the denture base resin. The strength of the prosthesis should
be approached as a combination of the properties of the denture teeth and the denture
base resin. The aim of this study was to compare failure strengths of three denture tooth
designs fabricated on injection molded or traditional compression molded heat cured
denture base resin and to explore which factors determined the strengths of their
combinations.

**MATERIALS AND METHODS**

Failure resistance of a single denture tooth fabricated on a denture base resin was tested.
Central incisors from three types of denture teeth — a nanohybrid composite NHC
Phonares II from Ivoclar Vivadent, an interpenetrating network (IPN) Portrait from
Dentsply, and a microfiller reinforced polyacrylic (MRP) Physiodens from Vita (Figure 1A)
— were processed using injection molding or compression molding. The two respective
denture base resins were IvoBase High Impact from Ivoclar Vivadent and Lucitone 199
from Dentsply. Product descriptions and manufacturer information are listed in Table 1.

**Standardization of bonded area**

Before fabrication, bonding surface areas were standardized to be the same for all denture
teeth without cutting or modifying the ridge-lapped area and thus preserving the original
shape and layer integrity. A black line was scribed around the ridge lap portion to indicate
a finish line (Figure 1B). The ridge-lap was scanned (Comet xS 3D Optical Digitizing
System, Steinbichler Vision Systems, Neubeuern, Germany) and the surface area below the
black line was determined (Figure 1C). The black lines were adjusted until surface areas
for the three denture teeth were within 1 mm² of one another. These black lines determined the stopping point for adding baseplate wax onto the ridge-lapped surface during sample fabrication (Figure 1D). The wax was shaped into a cylindrical mold, which was the shape of the fixture used in the loading test.

**Sample fabrication**

Jigs were fabricated from polyvinylsiloxane (PVS) impression material (Aquasil Ultra Monophase and LV Dentsply, Milford, DE, USA) for each denture tooth/wax sample. The jigs controlled the placement of baseplate wax to make exact replicas in each group. The waxed base portion was invested in denture flasks with type III dental stone (Microstone, Whipmix, Louisville, KY, USA). The crown portion of the denture tooth was embedded in PVS, leaving the exposed incisal edge to be a stop during injection or compression technique. Type III microstone was poured around the PVS/exposed incisal edge of the samples in the flasks as a second pour following standard flasking techniques. Samples underwent standard boil out procedure by immersing the molds in boiling water for 5 minutes, opening the flasks and removing the molten/softened wax. The stone/PVS molds were then cleaned with soapy water (Dial Antibacterial liquid handsoap, Henkel, Scottsdale, AZ, USA), followed by clean non-soapy water to ensure no waxy residue was left on the teeth/stone/PVS. The ridge-lapped cervical area of the teeth were then lightly air abraded with 50 micron aluminum oxide under 20 bar pressure (Renfert Basic Quattro Air Abrasion Unit, Hilzingen, Germany) and steam-cleaned prior to processing. No primers or adhesives were applied to the cleaned/abraded tooth surfaces. Ivobase samples were invested within proprietary processing flasks designed for the Ivobase injector unit and processed under the Ivobase high impact program settings. Lucitone samples were flasked in traditional compression molding flasks and processed at 165 F for 8 hours with a 1 hour terminal boil at 212 F.

A total of 67 samples were fabricated: 34 samples using injection molded resin (Ivobase High Impact Ivoclar Vivadent) and 33 samples using compression molded resin (Lucitone 199). Sample size for each tooth/denture base combination was 11 (with the exception of...
12 for NHC/injection molded resin). After processing, samples were divested and stored on
bench top for 2 weeks at room temperature prior to testing.

**Failure test**

Samples were loaded with a flat tip stainless steel rod on the incisal edge at 45° to the long
axis of the tooth in a universal testing machine (Instron Electromechanical Testing System,
Series 5567, Instron, Norwood, MA, USA) at a crosshead speed of 0.5 mm/min (**Figure 2**).
Failure load (N) was recorded. Differences between groups were statistically analyzed with
two-way ANOVA and pairwise comparisons at 0.05 significance level. Type of failure
(cohesive, adhesive, or mixed) was categorized for each sample using a stereomicroscope.

**RESULTS**

Mean failure loads and standard deviation are shown in **Figure 3**. Two-way ANOVA
showed significant effect of denture base resins (P=0.0001) and denture teeth (P=0.0063)
on the failure load. Significant interaction effect between denture base materials and
denture tooth type was also observed (P=0.0001). Samples using injection molded resin
had significantly higher failure loads than samples using compression molded resin,
regardless of denture tooth type (**Table 2**). IPN teeth had significantly higher failure load
than MRP and NHC teeth when processed to the injection molded resin (**Table 2**, pairwise
comparisons). However, there was no significant difference in failure load among the three
types of denture teeth when they were processed to the compression molded resin.

The predominant failure mode was cohesive failure in the denture tooth (**Table 3**). All NHC
teeth exhibited cohesive failure regardless of denture base resin (**Figure 4AB**). The
majority of IPN teeth processed to injection molded resin also underwent cohesive failure
in the tooth (**Figure 4C**), except for 2 samples exhibiting a small area of adhesive failure on
the palatal side with the remaining fracture surface being cohesive in the denture tooth.
The IPN/compression molded group had 10 samples with a mixed failure mode, showing
small areas of adhesive failure at the palatal side (**Figure 4D**). The majority of
MRP/injection molded samples failed cohesively in the denture teeth (Figure 4E), with 4 samples exhibiting a mixed failure mode. Two cohesively failed MRP/injection molded samples broke in the middle-third of the teeth; the fracture loads of both samples were coincidentally 261 N. The majority of MRP/compression molded samples also exhibited cohesive failure of the teeth (Figure 4F), with 3 samples showing presence of small areas of adhesive failure (i.e., mixed mode).

**DISCUSSION**

The results of this study showed that denture teeth fabricated to the injection molded denture base resin failed at higher loads than the same type of denture teeth processed to the compression molded resin. No purely or predominantly adhesive failure between the teeth and the denture base was observed, which indicated proper sample processing techniques. Failure loads ranged from 247 to 331 N for the injection molding groups compared to 184 to 204 N for the compression molding groups. Another notable result was that failure loads were significantly different among the three denture teeth when fabricated to the injection molded resin, but they were not different when fabricated to the compression molded resin.

Heat processed acrylic denture base resins have usually been found to have stronger bonds to denture teeth as compared to traditional self-curing resins. However, the contemporary injection molded resin (classified as self-curing resin) in this study resulted in significantly higher failure strengths than the compression molded resin samples. Unlike bond strength, which tests the strength of the interface between denture tooth and base resin, the failure strength tested in this study is the strength of the combination of interface, substrates, shape, as well as fixation and loading conditions. Strength in this study was thus determined by the ‘weakest link’, which may not be the bond strength. Only in the IPN/compression molded combination showed evidence of adhesive failure in 10 out of 11 samples, suggesting that bond strength was its limiting factor. IPN denture teeth processed to the injection molded resin failed cohesively in the denture teeth and obtained
the highest failure strengths, suggesting high bond strengths. The quality of bond is thought to depend on the availability of free monomer during processing. To create bonding between polymerized denture teeth and polymerizing denture base resin thus requires sufficient monomer availability to penetrate and be incorporated into the existing polymer chains of the denture teeth. Denture teeth are therefore often painted with priming agents or monomers prior to processing to dissolve or swell existing polymer chains and thus expose available bonding sites to new polymers.\textsuperscript{15-19} The injection molded resin (powder/liquid ratio 3:2) can be expected to have a higher content of free monomers than compression molded resin (powder/liquid ratio of 2:1) for it to flow or be injected into a mold. More available free monomer should improve the chances for links to form between polymerized denture teeth and the polymerizing denture base.

Although all denture teeth that were processed to the injection molded resin had higher failure strengths, not all the results could be explained by differences in bond strength. For the NHC denture teeth all fracture surfaces were cohesive in the tooth substrate regardless of denture base type, yet failure strength was significantly lower in the compression molded resin samples. Sample loading and denture tooth shape were the same for both base resin types, bonding areas were the same, and no evidence of differences in bond failure were found at the fracture surfaces. Differences in mechanical properties between denture base materials could potentially alter the loading conditions and thus stress distributions in the denture teeth. However, the mechanical properties of both denture base resins have been shown to be quite similar (flexural modulus 2.4 and 2.5 GPa for Ivobase and Lucitone 199, respectively)\textsuperscript{20} and are therefore unlikely to create substantial differences in the stress conditions. Since there is no obvious explanation for the significantly lower failure strength of the NHC/compression molded samples suggests that the mechanical properties of the NHC denture teeth may not have been the same after the fabrication process. Fracture surface appearance was slightly different between the two combinations, with failure in the NHC/compression molded samples occurring slightly closer to the tooth/base interface than the NHC/injection molded samples (Figure 4AB) and thus potentially in different layers (see next paragraph). Maybe the elevated temperature during compression molding weakened the denture teeth. The same
hypothesis could apply for the MRP denture teeth, which also failed predominantly cohesively and with significantly lower failure strengths when processed to the compression molded base resin. To our knowledge there is no published information published about the effect of elevated processing temperature on the strength of denture teeth.

Strength properties of denture bases and bonding of denture teeth have been well researched. However, the strength of denture teeth themselves has received less attention in the literature. No studies were found that tested the strength properties of individual teeth, even though cohesive failure in denture teeth is commonly found when tested in conjunction with denture base materials. Such prevalence of cohesive denture tooth failure suggests that when the bonding is good, failure strength is determined by the strength of the denture teeth. This study used denture teeth with different designs. NHC teeth were composed of layers of nanohybrid composite materials and traditional PMMA to ensure proper bonding to denture base resins. IPN teeth were composed of an interpenetrating polymer network, in which polymers of similar chemical and physical natures become intertwined during the manufacturing process. MRP teeth had a homogeneous structure of PMMA matrix with inorganic microfiller particles incorporated into the polymer network. These design differences as well as differences in shape can be expected to result in different tooth strengths among the three denture teeth, which are likely reflected best in the teeth fabricated to the injection material because they failed mostly cohesively and revealed significant differences in their failure strengths. Based on this argument, our results suggest that IPN design teeth were the strongest denture teeth and MRP teeth the weakest under this test loading.

We also observed characteristic failure patterns among the three denture teeth. Mixed mode fracture surfaces showed the adhesive failure always on the palatal side where the load was applied (Figure 4D), but soon transformed into the denture teeth (cohesive failure). Even samples with all-cohesive failure had thinner denture tooth remnants at the palatal side than at the facial side (Figure 4AB). The fragmented fracture surface of MRP
samples (Figure 4EF) might be an indicator that the teeth themselves were more brittle compared to the other two denture teeth (Figure 4A-D).

Finally the manufacturer effect on the failure loads of denture tooth/base resin combinations is worth noting. Colebeck et al (2015) reported that denture teeth and denture base resin from the same manufacturer provided stronger bond strength. They found that NHC teeth (Ivoclar Vivadent) did not bond well to Lucitone (Dentsply), especially after gross ridge-lap reduction. The present study also found that NHC performed better when processed to IvoBase (Ivoclar Vivadent) than to Lucitone. However, we found that denture teeth processed to the same manufacturer’s denture base resin did not always outperform their counterparts. The highest failure load from this study was IPN/IvoBase (teeth from Dentsply and resin from Ivoclar) whereas the lowest failure load was IPN/Lucitone (both from Dentsply).

In summary, the results of this study imply that when manufacturer instructions are followed correctly, good bonding can be achieved between denture teeth and base resins. When good bonding is achieved, the strength of the tooth/base resin combination is likely determined by the strength of the denture teeth, whereas the strength of denture teeth could be affected by the processing technique. To explore the latter hypothesis requires further research to be conducted on the strength properties of denture teeth.

**CONCLUSION**

The choice of denture base resins plays an important role in providing failure resistance to the denture tooth/denture base complex. All three denture teeth processed to a contemporary injection molded resin failed at higher loads than those processed to a compression molded resin. IPN teeth processed to the injection molded resin, despite being from different manufacturers, exhibited the highest failure strength.
ACKNOWLEDGMENTS

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2012;40:210-221


22. IPN Teeth Mould Chart


Table 1 Materials used in this study

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<th>Description</th>
<th>Product name</th>
<th>Company</th>
<th>Information</th>
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<tr>
<td>Denture base resin, injection molding</td>
<td>IvoBase High Impact</td>
<td>Ivoclar Vivadent AG, Schaan, Liechtenstein</td>
<td>Type 2 Class I (self-curing) Lot R75730</td>
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<td>Denture base resin, compression molding</td>
<td>Trubyte Lucitone 199</td>
<td>Dentsply International Inc, York, PA, USA</td>
<td>Type 1 Class I (heat-curing) Denture base resin Lot 150130; Lucitone liquid Lot 140812</td>
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<td>Denture tooth, layered nanohybrid composite (NHC)</td>
<td>SR Phonares II</td>
<td>Ivoclar Vivadent AG, Schaan, Liechtenstein</td>
<td>Mold S73 Lot 028876</td>
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<tr>
<td>Denture tooth, interpenetrating network (IPN)</td>
<td>Portrait IPN</td>
<td>Dentsply International Inc, York, PA, USA</td>
<td>Mold 11H Dentsply Trubyte P4</td>
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<tr>
<td>Denture tooth, microfiller reinforced polyacrylic (MRP)</td>
<td>Vita Physiodens</td>
<td>Vita Zahnfabrik, Bad Sackingen, Germany</td>
<td>Mold 04L Lot T6</td>
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Table 2 Failure loads in Newton (mean ± standard deviation)

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<td>NHC (nanohybrid composite)</td>
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<tr>
<td>Injection molded</td>
<td>280 ± 52 B</td>
</tr>
<tr>
<td>Compression molded</td>
<td>204 ± 31 D</td>
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Different capital letters indicate significant differences between groups (two-way ANOVA followed by pairwise comparisons; adjusted significance level 0.05/2)
Table 3 Failure modes. All cohesive failures were in the denture teeth.

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<td></td>
<td>NHC (nanohybrid composite)</td>
<td>IPN (interpenetrating network)</td>
</tr>
<tr>
<td>Injection molded failure in all samples (n=12)</td>
<td>Cohesive failure in 9 samples.</td>
<td>Mixed failure in 2 samples (predominantly cohesive, less than 1/4 of the total area was adhesive failure).</td>
</tr>
<tr>
<td>Compression molded failure in all samples (n=11)</td>
<td>Cohesive failure in 1 sample.</td>
<td>Mixed failure in 10 samples (predominantly cohesive, less than 1/4 of the total area was adhesive failure).</td>
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</table>
FIGURE LEGENDS

Figure 1. **A** Three types of denture teeth used; **B** Denture teeth with demarcation ready to be scanned; **C** Scanned surfaces and calculated bonding areas of the denture teeth; **D** Wax addition following the demarcated line.

Figure 2. Loading with flat tip stainless steel rod on the incisal edge at 45° angle to the long axis of the tooth.

Figure 3. Failure loads (mean and standard deviation) of the three denture teeth processed to injection molding or compression molding denture base resins.

Figure 4. Characteristic fracture surfaces. Arrows indicate the loading direction (palatal side). All cohesive failures were in denture teeth. **A** NHC/injection molded, cohesive failure; **B** NHC/compression molded, cohesive failure; **C** IPN/injection molded, cohesive failure; **D** IPN/compression molded, mixed mode failure showing area of adhesive failure on palatal side; **E** MRP/injection molded, cohesive failure; **F** MRP/compression molded, cohesive failure.
A Three types of denture teeth used; B Denture teeth with demarcation ready to be scanned; C Scanned surfaces and calculated bonding areas of the denture teeth; D Wax addition following the demarcated line.

145x119mm (300 x 300 DPI)
Loading with flat tip stainless steel rod on the incisal edge at 45° angle to the long axis of the tooth.

127x90mm (300 x 300 DPI)
Failure loads (mean and standard deviation) of the three denture teeth processed to injection molding or compression molding denture base resins.

127x127mm (300 x 300 DPI)
Characteristic fracture surfaces. Arrows indicate the loading direction (palatal side). All cohesive failures were in denture teeth. A NHC/injection molded, cohesive failure; B NHC/compression molded, cohesive failure; C IPN/injection molded, cohesive failure; D IPN/compression molded, mixed mode failure showing area of adhesive failure on palatal side; E MRP/injection molded, cohesive failure; F MRP/compression molded, cohesive failure.

142x160mm (300 x 300 DPI)