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Failure Modes with Point Loading of Three Commercially Available Denture Teeth

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Abstract

Purpose: A common problem associated with implant-supported prostheses is the fracture of denture teeth. This study was designed to compare the fracture modes of three denture teeth by compressive load at a 30° off-axis angle.
Material and Methods: Three denture teeth (Vident Duostat, Ivoclar Vivadent, and Dentsply Trubyte) processed to two denture base processing systems [injection-molded (IM) SR-Ivocap system and compression-molded (CM) denture base resin] were evaluated. Each specimen was processed to a metal framework. Ultimate failure strength of each system when point loaded at a 30° off-axis angle was recorded, along with a visual inspection of each specimen.
Results: The average load fracture for each group was (in N): Vident CM 1106.97 ± 223.20, Vident IM 1168.18 ± 322.52, Dentsply CM 1098.08 ± 286.32, Dentsply IM 1023.80 ± 282.45, Ivoclar CM 1616.98 ± 204.87, and Ivoclar IM 1373.54 ± 282.58. There was a significant difference between the groups and the Ivoclar CM group. The Ivoclar CM group had the highest average load force, and the Dentsply IM group had the lowest average load force. On average, the teeth within the groups fractured at a higher compression force than the average maximum occlusal force in natural dentition. Dentsply and Vident denture teeth fractured more horizontally, and the Ivoclar denture teeth fractured more vertically within the groups. There was no significant difference among the groups between the IM and CM processing methods.
Conclusions: In the present in vitro study, all specimens were able to withstand 30° off-axis loading with the exception of one specimen. With these results, this would indicate that these denture teeth are able to withstand normal occlusal forces.

The outbreak of World War II and the resultant shortage of the raw material for vulcanite placed acrylic resin in the forefront of materials used for denture production. It has remained in that position to the present, and its continued popularity stems from relatively low cost and simple processing equipment for the fabrication process.[1]

Denture teeth made of acrylic resin are often preferred, because they chemically bond to denture base materials and are easier to adjust. The combination of acrylic resin teeth and denture base acrylic resin is mediated by polymethyl methacrylate (PMMA), which is copolymerized with a cross-bonding substance.[2] To reduce fracture of acrylic resin teeth, a cross-bonding substance, silica, is incorporated in the teeth. Barpal et al found that the bonding of highly cross-linked denture teeth to a denture base was influenced positively by modification of the ridge lap.[3]

Estimates show that approximately 20% of dentures produced in the National Health Service in the United Kingdom suffer from denture teeth detachment within 1 to 2 years.[4] The failure of the tooth–denture bond may be caused by excessive stress failure or by fatigue. With the increased use of implants and the increase in forces applied to prosthetic components, it is probable that tooth debonding or fracture will probably become an even greater clinical problem.[5,6] In a study of patients with

implant-supported prostheses, 6.5% had fracture of prosthetic teeth that were replaced.[7] Another study showed that of the 111 repairs of fixed implant-supported prostheses, patients had an 18% likelihood of fracturing a denture tooth and a 14.4% chance of fracturing the acrylic resin.[8] Jemt showed that 14% of maxillary implant-supported prosthesis failures had fractures of the resin tooth within the first year.[9] Fractures of the acrylic resin superstructure and/or artificial teeth occurred in 22% of the arches.[10] Studies that have evaluated the frequency of various denture repairs have found tooth debonding to be the most frequent repair for conventional prosthodontics.[11-13]

Excellent long-term treatment results have been reported for fixed prostheses supported by osseointegrated implants.[7] The reports have focused on the favorable reactions of the bone and the marginal soft tissues to the implants. A few studies have been performed on the prosthodontic maintenance required by implant-supported prostheses. They have identified a variety of clinical problems, including unstable occlusion, difficult access for oral hygiene, persistent cheek biting, speech difficulties, and mechanical problems such as fractured acrylic resin. Jemt's findings of denture tooth debonding in patients who wear implant-supported prostheses is in agreement with other investigators.[8,11] Worthington et al also note that resin veneer placed over the framework cannot be expected to improve prosthesis strength significantly.[14]

Maximum occlusal force has been shown to increase by a factor of two or three after insertion of a fixed implant-supported prosthesis in the mandible of a complete-denture wearer.[15] Due to these higher impact occlusal forces, denture teeth may be at a higher risk of fracture (Fig 1).

Debonding of denture teeth to the denture base can occur adhesively or cohesively. Adhesive failure occurs if there is no trace of any denture base resin on the tooth surface after the fracture. Cohesive failure occurs if there is a presence of any trace denture base resin on the surface of the denture tooth or remnants of the denture tooth on the denture base. Attempts to improve bond strengths of denture teeth to the acrylic resin denture base have involved mechanical and chemical means. Results have varied by way of creating a diatoric[13,16] and removal of the denture tooth glaze.[17,18]

Ivoclar Vivadent (Schaan, Liechtenstein) denture teeth are fabricated by layering techniques—a hardened, double cross-linked acrylic resin PMMA denture tooth made of three layers. Dentsply Trubyte Portrait IPN Bioblend (Dentsply, York, PA) denture teeth contain an interpenetrating polymer network acrylic resin, sustained life material (SLM). The molecular chains of the interpenetrating network (IPN) teeth are cross-linked and interlocked. This makes the SLM denture teeth 25% more wear resistant than IPN denture teeth. They are made of two layers. Vita Duostat Zahn fabric denture teeth (Vita Zahnfabrik Bad Sackingen, Germany) are made of a highly dense cross-linked PMMA, consisting of two acrylic layers, dentin and enamel.

Figure 1 Cohesive fracture of a maxillary implant-supported prosthesis.

The method that uses the SR-Ivocap system (Ivoclar Vivadent) has reported advantages, including less polymerization shrinkage, resulting in decreased tooth movement and decreased need for clinical remount.[19-21] Capsules of acrylic resin are triturated according to the manufacturer's recommendation and allowed to set for 10 minutes. Flasks are placed under 3 tons of pressure in a clamping frame. Acrylic resin is then injected under 6 bars of pressure for 5 minutes with the manufacturer's pressure apparatus. The flask is then placed in a bath of boiling water for 35 minutes and cooled for 30 minutes while maintaining 6 bars of pressure in accordance with the manufacturer's recommended procedures. By way of comparison, the conventional heat-polymerized processed denture in Lucitone 199 (Dentsply) is polymerized for 90 minutes at 70°C and 30 minutes in boiling water.

This study was designed to compare the fracture modes of three denture teeth: Vident Duostat Zahn fabric, Ivoclar Vivadent, Vivodent PE (Ivoclar), and Dentsply Trubyte Portrait IPN, processed to two denture base processing systems: injection-molded (IM) SR-Ivocap system and compression-molded (CM) denture base resin. Ultimate failure strength of each system when point-loaded at a 30° off-axis angle was recorded, along with accompanying visual inspection of each specimen. The null hypothesis was that there is no difference in the fracture modes of Vident Duostat Zahn fabric, Ivoclar Vivadent, Vivodent PE Dentsply Trubyte, and Portrait IPN with either processing system.

Materials and methods

The technique used to test the mechanical characteristics of Vident Duostat Zahn fabric (mold TC8), Ivoclar Vivadent, Vivodent PE (mold A24B), and Dentsply Trubyte Portrait IPN (mold 12E) involved two maxillary central incisors (#8, 9) and one maxillary lateral incisor (#10) of similar mold. Thirty specimens were processed with the IM system, and 30 specimens were prepared with conventional heat-polymerized denture base resin. Thus, there were six groups of ten specimens fabricated by one investigator in order to standardize the processing protocol.

Each tooth was modified by removing the glaze of the ridge lap with an acrylic bur #H77 (Brasseler, Savannah, GA). The metal portion for the fixed-detachable prostheses was fabricated through a master pattern block of methyl methacrylate acrylic resin GC Pattern LS (GC America, Inc. Alsip, IL), duplicated in a mold made with a vinyl siloxane system, Silflex III (Austenal, Chicago, IL, batch 061062), and cast with Techniq metal

(Ney Dental Int., Bloomfield, CT), which has physical properties similar to type III gold alloys. The space between the tooth and the gold framework was 2 mm, and a dental surveyor was used in placing the denture teeth off-axis, 30° directed labially, to embed the teeth in baseplate wax before processing. This was done through the fabrication of a jig from the master prosthesis to make each specimen identical. Thirty specimens were processed by injection molding with the SR-Ivocap Plus Preference (Ivoclar, Batch F68605) system. Thirty were processed by compression molding with denture base resin Lucitone-199 (Dentsply, Batch UN 1247) to manufacturer's instructions. The specimens were polished with acrylic burs, flour of pumice, and high shine. The processed specimens were selected at random and held in a vice assembly (Fig 2) and an Instron machine (MTS System Corp., Minneapolis, MN), with a point compressive load, 500 lb load cell, and crosshead speed of 5 mm/min, was used on the left maxillary central incisor (#9) (Fig 3). The Instron unit was calibrated by the operator before use. The size of the point compressing the teeth was 2.76 mm and directed toward the cingulum (Fig 4) of each tooth to be fractured. Upon failure, each sample was removed, and the maximum applied load and the mode of failure were recorded. Photographs were taken of the area between the denture base and the denture tooth. Observations were made to determine where the fracture occurred: tooth, resin, or tooth/resin (Figs 5-7).

SPSS 10 software (SPSS, Inc., Chicago, IL) was used for statistical procedures. Univariate two-way ANOVA was used to evaluate the compressive load data, followed by Tukey-HSD multiple comparisons test to determine significance at $p < 0.05$.

Results

The Univariate two-way ANOVA showed no interaction effect ($p = 0.212$). There was a strong main effect of the type of tooth used ($p < 0.001$), but no main effect of the way the acrylic resin was polymerized ($p = 0.225$).

The data for the compressive load experiments are shown in Table 1. There was a significant difference between the groups and the Ivoclar CM group. The Ivoclar CM group had the highest average load force, and the Dentsply IM group had the lowest average load force.

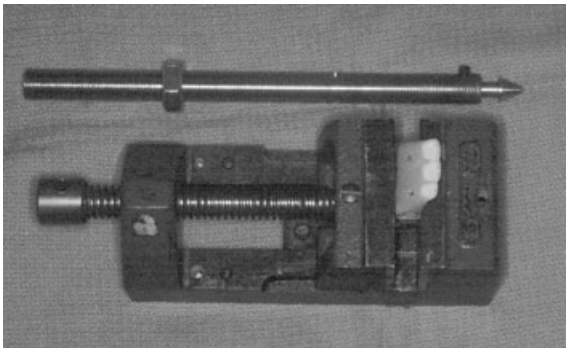

Figure 2 Specimen in vice assembly with a 2.78-mm point load.

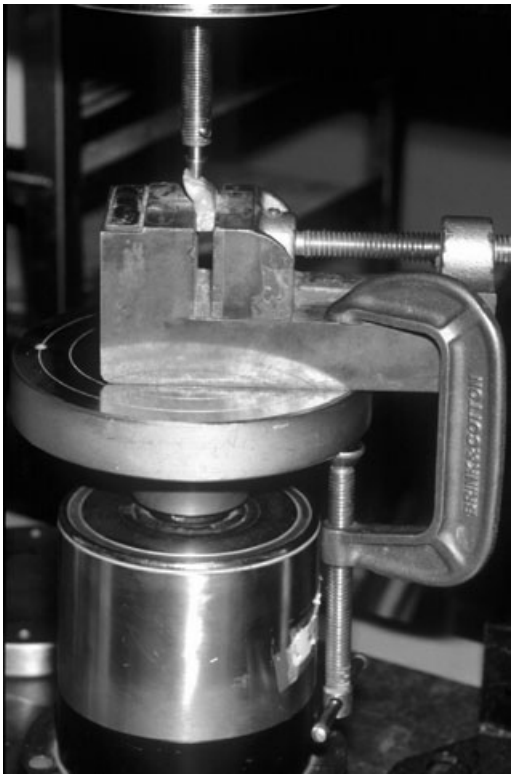

Figure 3 Specimen in vice assembly placed on an Instron unit with a point load on the cingulum of a maxillary left central incisor denture tooth.

Table 2 shows the maximum and minimum force values within each specimen. The highest maximum load force was from the Ivoclar CM group. The lowest minimum load force was from the Dentsply IM group. Table 2 also shows the average values of processing the specimen by injection or compression. In the Dentsply and Ivoclar groups, the force values were higher for the CM, whereas the Vident group had higher maximum force values for the injection system.

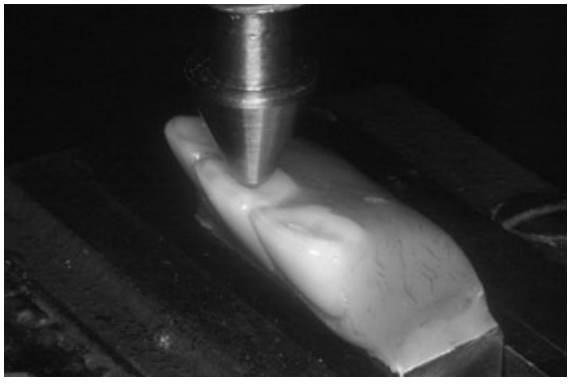

Figure 4 Point load on the cingulum maxillary left central incisor denture tooth.

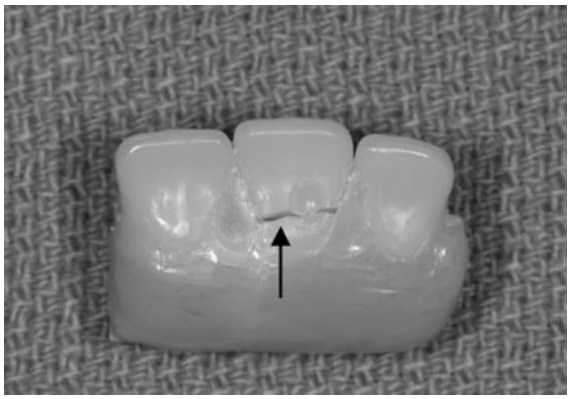

Figure 5 Grade 1 horizontal fracture of a Vident denture tooth.

Figures 8-11 detail the fracture analysis for the experiment. When the teeth were fractured, the fracture would occur either through the tooth or through the tooth and include the adjacent tooth/acrylic resin. All fractures were cohesive where the remainder of the tooth was embedded in acrylic resin. Figure 9 defines the grade in tooth fracture. The Ivoclar CM group had the most fractures (8) occurring with a single tooth and did not include the adjacent tooth/resin. Dentsply IM group had the fewest fractures (5) occurring with a single tooth. The

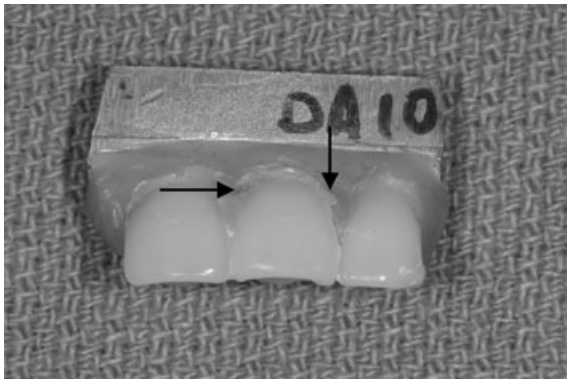

Figure 6 Grade 2 horizontal fracture of a Dentsply denture tooth.

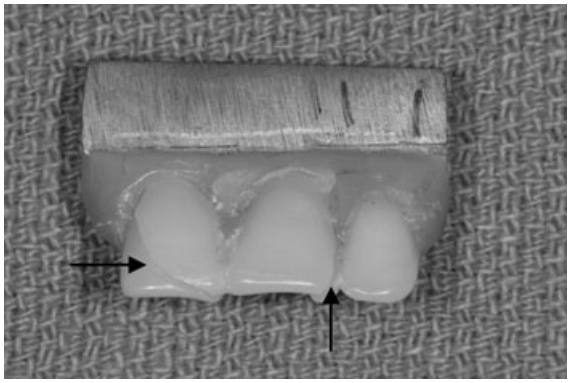

Figure 7 Grade 3 vertical fracture of an Ivoclar denture tooth.

Table 1 Compressive load force values (N)

Vident tooth, compression-molded	1106.97 ± 223.20
Vident tooth, injection-molded	1168.18 ± 322.52
Dentsply tooth, compression-molded	1098.08 ± 286.32
Dentsply tooth, injection-molded	1023.80 ± 282.45
Ivoclar tooth, compression-molded	1616.98 ± 204.87
Ivoclar tooth, injection-molded	1373.54 ± 282.58

Mean ± standard error.

Dentsply denture teeth had the most fractures occurring at the facial/interproximal surfaces, and the Vident teeth had the fewest.

In addition to the way the denture teeth fractured, the direction of these fractures was noted. This occurred either vertically, from incisal to gingival, or horizontally, from mesial to distal. Figures 10 and 11 detail these results. All Vident denture teeth (Fig 5) except one fractured horizontally, and all the Dentsply denture teeth (Fig 6) fractured horizontally. With the Ivoclar denture teeth (Fig 7), more fractured vertically, 16 out of 20, or 80%, than horizontally.

In further describing the horizontal and vertical fractures, the denture teeth would either splinter or shatter. When a denture tooth would splinter (Fig 5) the fractured denture tooth would stay intact and would not detach from the specimen. The shattered denture tooth (Fig 6) would completely detach from the denture tooth.

The Dentsply CM and the Vident CM groups had the most shattered teeth, four in each, of the groups (Fig 11). The Ivoclar

Table 2 Maximum/Minimum values (N)

	Minimum	Maximum
Vident tooth, compression-molded	764.8	1339.4
Vident tooth, injection-molded	723.2	1672.0
Dentsply tooth, compression-molded	818.0	1690.0
Dentsply tooth, injection-molded	615.2	1469.2
Ivoclar tooth, compression-molded	1203.2	1949.1
Ivoclar tooth, injection-molded	991.0	1822.3
Total	852.6	1657.0

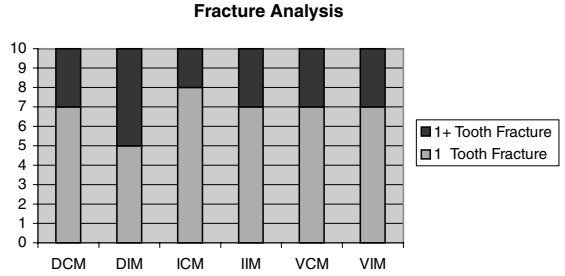

Figure 8 Fracture analysis of one tooth fracture and one plus tooth fracture. DCM = Dentsply tooth, compression-molded; DIM = Dentsply tooth, injection-molded; ICM = Ivoclar tooth, compression-molded; IIM = Ivoclar tooth, injection-molded; VCM = Vident tooth, compression-molded; VIM = Vident tooth, injection-molded.

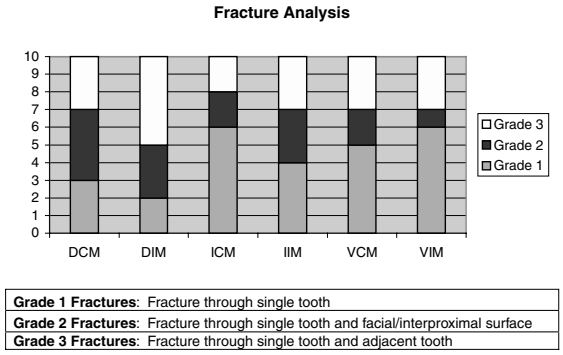

Figure 9 Fracture analysis of grade 1, grade 2, and grade 3 fractures. See Figure 8 for legend.

CM group had the most denture teeth splinter (7) and the fewest (0) that shattered. The Vident CM group had the fewest (0) that splintered.

Discussion

A resin-retained fixed implant prosthesis is a superior treatment option for the edentulous patient. With the lack of proprioception, patients may invariably fracture a denture tooth from the prosthesis. The resultant fracture of a tooth from these prostheses can be discouraging and frustrating. In vivo fractures in this manner are shown in Figure 1 and the in vitro fractures in this experiment are shown in Figures 5-7. Repair of the fractured tooth consumes clinic time and is not cost-effective. In this study, the primary failure was found in the teeth and not the bond between the tooth and acrylic resin, as in a clinical setting. Other studies have shown failure to be found in the teeth and also the bond between the teeth and the acrylic resin.[9,10]

Since there was a strong main effect of the type of tooth used, this experiment showed a trend in average compressive load force values (N). The Ivoclar teeth had the highest force values, and the Dentsply teeth had the lowest force values. The IM technique with the SR-Ivocap system has reported advantages, including less polymerization shrinkage, which results in decreased tooth movement and decreased need for clinical remount.[19-21] The injection-molding technique for denture construction has less polymerization shrinkage and produces a more accurate denture compared to that produced by the compression-molding method.[21] There was not any difference in fracture resistance found in this study. The way the teeth were processed, either by compression or injection, was not significant.

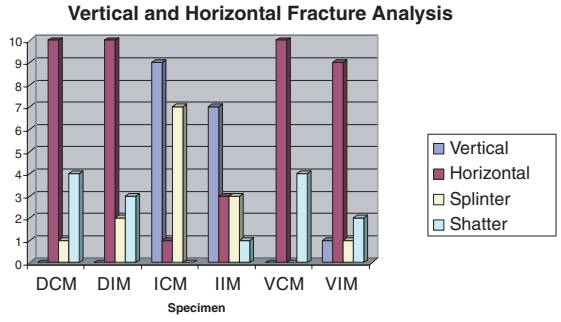

Figure 10 Vertical and horizontal fracture analysis. See Figure 8 for legend.

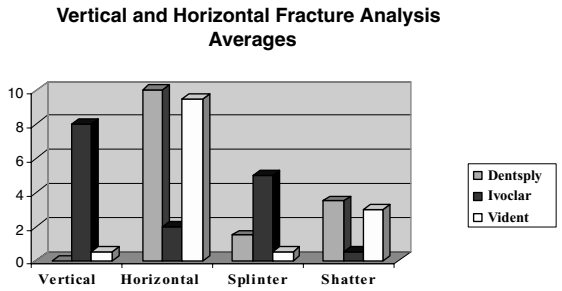

Figure 11 Vertical and Horizontal fracture analysis averages.

Fracture analysis for the experiment is shown in Figures 8-11. The grade 3 fractures, which fracture through a single tooth and an adjacent tooth, are catastrophic in nature and may be difficult to easily restore (Fig 7).

Fracture tests to determine failure load with three commercially available denture teeth with different processing materials were tested in this experiment. Gibbs et al demonstrated that the maximum occlusal force with natural dentition on average was 721 N, and the normal chewing stroke produced an average force of 261.1 N.[22,23] In the present study, all specimens were able to withstand 30° off-axis loading with the exception of one specimen (Dentsply IM at 614.71 N). In another study, subjects with natural teeth in the maxilla had a higher maximal force than those with a maxillary implant-supported fixed partial denture (FPD), and there was no significant correlation between age and occlusal force. These patients with implant-supported FPDs have masticatory function equal to or approaching that of patients with natural teeth or FPDs supported by natural teeth.[24] For the anterior region, occlusal forces were reported in the range of 90 to 370 N[25] and 150 to 235 N.[24]

In this study, the teeth were processed to a metal framework, which permits little movement. This differs greatly from in vivo conditions, because bone and its cortication and trabeculation are involved. The cast metal framework used in this study, Techniq, was readily available and not advocated for the oral cavity. Also, loading the specimen at a 30° angle reproduces only one of many possible mechanical conditions in the oral cavity and does not replicate the mastication system. The type of testing used in this study does assist in assessing maximum failure. The load surface point and anatomy of lingual surface of each denture tooth group was different, which may have led to varied fracture loads.

The study had additional limitations of not using thermocycling and cyclic loading. Thermocycling is a treatment that theoretically allows repeated expansion and contraction of the tooth and denture base resin components, thereby stressing the bond and simulating the oral condition. The secondary benefit

of thermocycling is the hydration of the specimen, which would further simulate the clinical condition;[26] however, previous studies have shown the bond strengths of hydrated and unhydrated specimens produced similar results both with acrylic resins and composite resins.[2] Cyclic loading is fatigue failure where a structure eventually fails after being repeatedly subjected to lesser loads over a time period replicating clinical tooth contacts. Future studies should be directed to include cyclic loading.

It is well accepted that in vivo performance does indeed differ from an in vitro setting. Future longitudinal studies are also needed to record the type of debonding in resin-retained fixed implant prostheses. Reproducing the natural dentition stress pattern was impossible. With the study as designed, the vertical chewing pattern rather than a horizontal chewing pattern, was mostly reproduced. Fabricating identical specimens was difficult with the multitude of laboratory procedures in fabricating a fixed-detachable prosthesis.

Within the limitations of this study, possible recommendations could be made for tooth selection considerations with a fixed-detachable prosthesis. The Ivoclar teeth as a group demonstrated the most fracture resistance and the fractures produced were more favorable in the vertical axis and with greater splintering than shattering. This can possibly relate to a greater ease of clinical repair of fractured teeth. The laboratory procedures for the fixed-detachable prosthesis require a specific protocol to be followed for consistent results. This relates to proper tooth surface preparation for bonding; adequate space for teeth, resin, and framework; attachment/bonding of the tooth-resin-framework interfaces; and processing with minimal errors. Though no significant differences were noted in this study as to compression- versus injection-molding techniques, the ease, time, and accuracy tends to give the advantage to the injection-molding technique if available.

Conclusion

1. The Ivoclar tooth, CM method, had the statistically significant highest fracture load.
2. On average, the teeth within the groups fractured at a higher compression force than the average maximum occlusal force in natural dentition.
3. Dentsply and Vident denture teeth fractured more horizontally, and the Ivoclar denture teeth fractured more vertically within the groups.
4. There was no significant difference among the groups between the IM and CM processing methods.

Acknowledgment

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