**ABSTRACT**

**Aim:** This study aimed to evaluate the marginal microleakage and maximum occlusal fracture loads and fracture modes of two novel class II preparation designs, “infinity edge” and the 2.5 mm cuspid reduction preparations as compared to a traditional class II preparation without cuspal involvement.

**Materials and methods:** Thirty extracted human mandibular molars were prepared for moderate-sized class II restorations with extensions into all occlusal grooves. Of these, ten class II preparations served as control. Ten were modified for a 2.5 mm even reduction of the cusps adjacent to the interproximal box. An additional 10 preparations were modified with an “infinity edge” bevel on the interproximal and occlusal portions. All teeth were restored utilizing a flowable bulk-fill composite in the apical portion of the interproximal box and 2–4 mm of heated bulk-fill composite in one increment for the remainder. All groups were cyclic loaded and thermocycled, then imaged with microcomputed tomography (µCT) before and after infiltration with a silver nitrate solution. Images were subtracted to obtain volumetric measurements of microleakage and reported as a percentage of the total volume from the apical extent of the proximal box. All groups were loaded to failure and fracture load and mode were recorded.

**Results:** No significant differences were found in microleakage volume as a percentage of total tooth volume; however, the “infinity edge” group had significantly greater microleakage in the proximal box compared to the traditional class II group. No significant differences were found in fracture load or mode between the groups.

**Conclusion:** Traditional class II, 2.5 mm cuspid reduction, and “infinity edge” preparation designs have similar fracture loads as well as volumes of microleakage; however, an “infinity edge” preparation has a higher ratio of microleakage in the proximal box.

**Clinical significance:** Clinicians should carefully consider the use of “infinity edge” margins, particularly on dentin in the apical extent of the proximal box.

**Keywords:** Composite restorations, Fracture resistance, Infinity edge, Microleakage.

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**INTRODUCTION**

The traditional class II cavity preparation originated over a century ago and was designed for amalgam restorations. However, when composite resin was first introduced in the 1960s, dentists continued using traditional preparation designs despite the differences in mechanical and physical properties. Posterior composite restorations are susceptible to multiple clinical defects including sensitivity, fracture, staining, poor interproximal and occlusal contacts, recurrent caries, and overhanging margins; therefore, they potentially have less longevity than amalgam restorations. When restoring posterior restorations, clinicians are faced with a decision on whether to preserve, reduce, or replace the remaining cuspal structure. Clinical judgments are often clouded by the lack of evidence-based guidelines in preparation design, and no clear answers are available on which restorative material is the most suitable. Additionally, the advent of new technologies and techniques further complicates decision-making.

Recently, composite has been shown short-term effectiveness in replacing fractured cusps. Additionally, bulk-fill composites have shown promise in this application due to their relative ease of placement and clinical performance. However, long-term clinical studies are limited and there is a lack of evidence-based guidelines on tooth preparation for large posterior composite restorations.
restorations. In vitro studies have indicated that composite with a 2.5 mm thickness over a replaced cusp has considerably increased fracture resistance.\(^4\)

The introduction of a bevel onto a composite preparation has not been shown to increase retention rates or decrease marginal discoloration of cervical composites.\(^5\) Studies have shown an occlusal bevel does not decrease marginal quality.\(^10\) However, researchers, clinicians, and manufacturers have claimed that increasing enamel bonding surface increases retention, decreases marginal microleakage, and may also improve shear bond strength.\(^11\) Examples of beveling techniques include “saucer” style preparations, inclusion of air particle abrasion of the enamel margin to remove biofilm, or creation of a more obtuse cavosurface angle (e.g., a bevel) of varying widths and angulations at the cavosurface margins of composite preparations.\(^12\)–\(^16\) One such design even extends this concept onto the occlusal for an “infinity edge” preparation of cavosurface margins. This theory of preparation design involves rounded internal line angles to reduce stress concentration and maximize enamel bonding surface area with a wide “feather edge” bevel of all enamel cavosurface margins.\(^17\)

Historically, bevels have not been recommended on the occlusal of class I and class II composite preparations because the conventional preparation design creates orthogonally oriented, “end-on” enamel rods to the tooth surface. Furthermore, thin composite margins in the areas of occlusion might cause concern for increased marginal wear or fracture.\(^18\) Although previously described in the literature by David Clark,\(^19\) a PubMed search with the terms “infinity edge,” “infinity margin,” “feather edge,” or “feather margin” revealed neither published laboratory studies of this design nor any clinical literature that supports bevels on the occlusal aspects of class I or class II composite restorations. One study found no clinical differences in nonbeveled vs beveled occlusal margins, but the nonbeveled margins did display an increase in marginal staining after one year.\(^13\)

Based on this literature review, two preparation designs for a buccolingually wide class II composite were considered in this study. One involved the preparation of two cusps adjacent to the interproximal lesion, allowing for approximately 2.5 mm of composite. The other involved the “infinity edge” extension of the preparation onto the occlusal with rounded internal and external line angles. For both designs, a flowable bulk-fill composite was used to fill the depth of the proximal box, where one increment of a heated bulk-fill composite was inserted to minimize defects.\(^20\)

The aim of this in vitro study was to compare the micro- and macromechanical effects of two novel preparations, the “infinity edge” class II preparation and a class II preparation with a 2.5 mm cusp reduction, to a traditional class II preparation. The null hypotheses were that there would be no differences in microleakage volume, fracture load, or failure mode based on preparation design.

**Materials and Methods**

This original in vitro research study was conducted at the United States Air Force Postgraduate Dental School at Joint Base San Antonio (JBSA), Lackland, Texas, USA from July 2021 to May 2023. The Institutional Review Board at Wilford Hall Ambulatory Surgical Center, JBSA, Lackland, TX, USA approved the protocol #FWH20220017N. Thirty extracted, mandibular human third molars of similar size were used in this study. The sample size of 10 per group provides 80% power to detect a moderate effect size of 0.6 or approximately 1.2 standard deviation (SD) difference among means when testing with a one-way analysis of variance (ANOVA) at \(\alpha = 0.05\) (number cruncher statistical systems (NCSS Pass 2020, version 20.03)). Extracted human teeth were utilized to create composite restorations to examine microleakage and fracture strength. All teeth were completely formed with no visual defects and free from caries and pathology. Each tooth was embedded in a cylindrical block of self-cured bis-acryl resin (Integrity, Dentsply Sirona, Charlotte, North Carolina, USA) to 3.0 mm below the cementoenamel junction (CEJ) in a custom cylindrical block.

**Preparation of Teeth**

All 30 teeth were prepared with a standard mesio-occlusal composite preparation with an interproximal box extending 1 mm apical to the CEJ, pulpal floor depth of 2.5 mm, and an interproximal box width of three-fourths of the intercuspal distance (Fig. 1). The preparation was extended into occlusal grooves and all line angles were rounded.

One-third of these teeth (n = 10) served as the control (group I). In 10 of these teeth (group II), the preparation was modified to add an even cuspal reduction of the mesiobuccal and mesiolingual cusps to allow for 2.5 mm of composite thickness (Fig. 2). In the remaining 10 teeth (group III), an “infinity edge” margin was extended onto the occlusal surface and proximal walls (not including the gingival margin), ensuring rounded internal line angles and an “infinity edge” margin (Fig. 3). One operator prepared all the teeth. An independent operator verified consistency of preparations, returning preparations to the original operator for modifications as necessary.
Microleakage and Fracture Resistance of Infinity Edge Restorations

Restoration of Teeth

All groups of teeth were restored according to the following protocol. A 40% phosphoric acid etch (Dentin and Enamel Etching Gel, Henry Schein, Inc., Melville, New York, USA) was applied to enamel margins of the preparation as well as any deep pits and fissures. After 20 seconds, teeth were rinsed and dried leaving a slightly wet dentinal surface prior to bonding. Care was taken to remove the smear layer to ensure a smear-free pulpal floor and internal and external walls. Due to lack of proximal surface, a matrix band (Toefflemire, WaterPik, Ft. Collins, Colorado, USA) was utilized to ease the ability of marginal adaptation, ensuring the coronal extent of the matrix band was at the level of the approximate marginal ridge height.

A universal bonding agent (Scotchbond Universal, 3M ESPE, St. Paul, MN, USA) was applied to the preparation surface as well as any deep buccal pits or fissures and rubbed in with a microbrush for 20 seconds. Then, it was air dried for 5 seconds and cured with a light emitting diode (LED) light curing unit (VALO Grand, Ultradent Products, South Jordan, Utah, USA), outputting a 1000 mW/cm² irradiance for 20 seconds. The irradiance of the light curing unit was removed via flash, 3M ESPE).

Next, a flowable composite (Filtek One Flowable, shade A1, 3M ESPE) in capsules, which was pre-heated to 155°F with a composite heater (Bioclear HeatSync, Bioclear Matrix Systems, Tacoma, Washington, USA). The composite was shaped and festooned with good anatomical contours and simple occlusal anatomy—avoiding deep pits, fissures, and grooves—by a single operator. Then, it was light cured for 20 seconds. After removal of the matrix band, the interproximal portion was directly cured from the side of the tooth for another 20 seconds. Flash was removed with a No. 12 stainless-steel surgical blade (Miltex, Integra Life Sciences, Princeton, New Jersey, USA) and polished (Sof-Lex XT pop-on, 3M ESPE).

Following restoration, all teeth were stored in distilled water solution at 37°C for 24 hours in an incubator (Model 20 GC, Quincy Labs, Chicago, Illinois, USA). After storage, specimens were thermocycled for 2000 cycles between 5°C and 55°C distilled water baths with a dwell time of 30 seconds at each temperature (Sabri Dental Enterprises, Downers Grove, Illinois, USA).

All teeth were then mechanically loaded in a chewing simulator (Sabri Dental Enterprises). The machine subjected the mounted teeth, still submerged in distilled water, to a cyclic force of 10–150 N at a rate of 1 cycle per second (1 Hz) for 100,000 cycles. The force was applied perpendicular to the occlusal surface via a 12.7 mm diameter and flat-ended cylindrical piston resting on the cusp tips. Each group (consisting of 10 teeth) was loaded separately from the other groups. The load was verified with a digital force meter (Infinity CS, Cooper Instruments, Warrenton, Virginia, USA) before each load sequence.

Microleakage Assessment

A microcomputed tomography unit (SkyScan 1172, Bruker microCT, Billerica, Massachusetts, USA) was used to nondestructively collect the baseline images of all specimens (set I). Each specimen was scanned 180° with a 0.14° rotational increment per frame at a resolution of 9.40 μm using a source voltage and current of 90 kV and 110 A, respectively. A standard 1 mm aluminum filter was applied for scanning. At each rotational degree, five scans were captured and averaged to give one projected frame.

After obtaining the μCT baseline images, the specimens were immersed into 5 mL of 50% ammonium silver nitrate (AgNO₃, pH = 9). Each batch of ammonium silver nitrate solution was prepared by dissolving 50 gm of silver nitrate crystals (CAS 7761-88-8, Fischer Chemical, Zurich Switzerland) in 40 mL of distilled water for 10–15 minutes, then adding 50 mL of ammonium hydroxide (CAS 1335-14-3, Fischer Chemical) with a dropper until the solution became clear. Distilled water was added with a dropper to achieve 100 mL. Each batch was freshly prepared for each sample group. Specimens were then immersed in the solution for 12 hours in the absence of light. Then, silver nitrate excess was removed via running water and wet cotton rolls and specimens were then immersed in 5 mL of film developer solution (T-Max Developer, Kodak, Rochester, New York, USA) in the presence of light for 8 hours. Excess precipitated silver was removed via running water and wet cotton rolls, and new μCT scans of all specimens (set II) were performed with the same parameters used for the set I scans. An orientation jig was utilized to ensure alignment of sets I and II scans. The projected scans per specimen from all sets I and II were then reconstructed into a three-dimensional (3D) volume with a voxel size of 8 μm and 2000 × 1048 pixels per slice, using a customized Feldkamp algorithm (NRecon v-1.7.4.6, Bruker, Billerica, Massachusetts, USA). All μCT scan files were saved as BMP (Bit-Mapped Pixels) image format. Image processing, segmentation, analysis, and comparison was
performed using a proprietary software (CTAn v-1.18.9.0+, Bruker) to the same region of interest (ROI) for each pair of scans (before and after silver nitrate).

A mean and SD was determined per group for microleakage volume as a percentage of the total tooth volume, as well as the percentage of total leakage in apical 1 mm of the proximal box. Microleakage volume data was analyzed with an ANOVA and Tukey’s post hoc tests to evaluate the effects of preparation design ($\alpha = 0.05$). All data were analyzed with a Shapiro-Wilk test to determine normality and a Levene test to examine the equality of variances ($\alpha = 0.05$). All statistical analyses were completed using statistical software (SPSS, version 25, IBM, Chicago, Illinois, USA).

**Fracture Loading**

Following microleakage evaluation, teeth were stored in water until static occlusal fracture loading was completed. The teeth were removed from the water and oriented so that a 6 mm diameter and round-ended probe was applied to the center, long axis of the molars, while the edges of the probe rested on the occlusal inclines of the buccal and lingual cusps. Loading was performed in a universal testing machine (Model 5543, Instron, Norwood, Massachusetts, USA) at a crosshead speed of 1 mm/min until the first fracture occurred. The fracture force was recorded in newtons, and a mean and SD was determined for each group. Fracture load data were analyzed with an ANOVA test and Tukey’s post hoc test to evaluate the effects of preparation design ($\alpha = 0.05$).

The fracture mode of each specimen was analyzed visually and ordinally categorized according to the following criteria: Type I, isolated fracture of the restoration; type II, isolated fracture of a small portion of the tooth; type III, restoration fracture involving 1 cusp; type IV, fracture involving more than half of the total coronal tooth volume, without periodontal involvement; and type V, fracture with periodontal involvement. The teeth were additionally categorized as restorable or nonrestorable. Fracture mode data were compiled and analyzed with Kruskal–Wallis and Mann–Whitney U tests to determine the effect of preparation design ($\alpha = 0.05$).

**Results**

There were no significant differences (group I = group II = group III) between any of the groups in percent total leakage volume/tooth volume microleakage ($p = 0.615$). Group I had the lowest percent total leakage volume/tooth volume (0.043 ± 0.029%), with group III performing more moderately (0.050 ± 0.028%). Group II had the greatest percent total leakage volume/tooth volume (0.056 ± 0.034%) (Fig. 4).

There were significant differences (group I ≤ group II ≤ group III) between groups in percent microleakage in the apical 1 mm of the proximal box. Group I had the lowest percent leakage in the proximal box, but it was not significantly different ($p = 0.692$) from group II. Group III had the highest percent leakage (82.9 ± 12.1%), which was significantly greater than group I (60.7 ± 18.5%, $p = 0.023$), but not significantly different than group II (67.1 ± 19.3%, $p = 0.125$) (Fig. 5).

There was no significant difference (group I = group II = group III) between any of the groups ($p = 0.241$) in fracture load. Group II had the greatest fracture load (4561.3 ± 741.4 N) and group I had the lowest fracture load (3828.1 ± 1257.3 N), with group III performing more moderately (4028.6 ± 903.4 N) (Fig. 6). Group III had the greatest number of unrestorable fractures with periodontal involvement (type V), but there were no significant differences.
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between any of the groups based on mode of fracture (group I = group II = group III) (Fig. 7).

**Discussion**

No laboratory or clinical research has been published evaluating the performance of composite restorations utilizing “infinity edge” or 2.5 mm cusp reduction preparation designs to traditional class II preparations. This study evaluated the micro- and macromechanical effects of these preparation designs in a laboratory setting.

For microleakage volume, the null hypothesis was accepted, as there was no difference in microleakage as a percentage of total tooth volume between the groups. However, it should be noted that the microleakage in the apical 1 mm of the proximal box was significantly higher in the “infinity edge” group. The “infinity edge” group had minimal microleakage in the above-box portion but a greater total volume in the apical 1 mm of the proximal box vs the traditional class II and 2.5 mm cuspal reduction groups (Fig. 8). This is an interesting observation as all groups had the same proximal box shape, however the “infinity edge” group had an infinity margin bevel on the facial and lingual aspects of the proximal box and the traditional class II and 2.5 mm cuspal reduction groups did not. All groups had an identical gingival margin of the proximal box. The increase in microleakage of the “infinity edge” group could be attributable to the apical extent of the facial and lingual margins of the proximal box being apical to the CEJ, resulting in an increased extent of restorative margin on dentin. The fact that the remainder of the “infinity edge” group margins had less microleakage than the traditional class II and 2.5 mm cuspal reduction groups indicates that infinity margin bevels can be effective in limiting microleakage on enamel but not on dentin.

It has been claimed that μCT is less accurate than traditional dye-infiltration techniques at measuring microleakage and that μCT, by nature of limitations in voxel size, has lower resolution than dye-penetration tests and could lead to underestimation. However, silver ions penetrate dentin as much, if not more than dye, which would suggest that dye penetration could underestimate microleakage. Additionally, use of developer solution causes silver to aggregate, increasing the amount of microleakage detected, even at 10 μm resolution. Use of higher resolution is unlikely to be clinically relevant and scanning at higher resolutions becomes increasingly impractical due to exceedingly long scan times. Furthermore, a majority of studies show strong correlation of μCT-based analysis with 2D dye penetration with resolutions ranging from 7.8 to 20 μm and μCT was recently shown to have better discrimination overall than dye penetration tests. It should also be noted that dye-penetration methods are not without variability due to nonstandardization of factors such as dye used, immersion time, characteristics of the immersion solution (such as pH, concentration, and diffusion coefficient), and size, number, direction, and location of sections. Additionally, slicing the adhesive interface can create artificial gaps which can affect reliability of results. Use of μCT also allows three-dimensional assessment of microleakage, providing a complete picture of distribution of microleakage which is not possible in cross-sections. In fact, use of cross-sections only could lead to a poor representation of microleakage of a sample. Rizzante et al. demonstrated that with a 3D μCT analysis, it is possible to select 2D slices which misrepresent microleakage, leading to low correlation between 3D volume predicted based on 2D samples. In other words, it is impossible to know if the slice selected for a cross-section over or underestimates total microleakage. Infiltration with ammonium

![Fracture modes](image)

**Fig. 7:** Figure demonstrating fracture modes. (Fx, fracture)

![Representative images of microleakage distribution per each group](image)

**Figs 8A to C:** Representative images of microleakage distribution per each group. (A) Group I, traditional class II; (B) Group II, cuspal reduction; (C) Group III, infinity edge
silver nitrate and μCT, although technique sensitive and requiring extensive postprocessing, is an excellent method assessing volume and distribution of microleakage.26 This method has the added benefit of preventing sample destruction in cross-sectioning, allowing additional studies of the samples after infiltration.

For fracture load, the null hypothesis was accepted as there were no statistically significant difference in the fracture load between the preparation design groups. Additionally, all fracture loads were above normal masticatory forces of 956 N.20 This was an interesting observation, as prior laboratory studies have shown that there is a correlation between composite thickness and fracture load, indicating that 2.5 mm increments of composite are ideal.21 However, the “infinity edge” group composite thickness on the occlusal margins of the preparation was significantly less than 2.5 mm, particularly at the infinity margin. Although no fracturing of occlusal margins was noted, a volumetric assessment of marginal wear was not completed.

For fracture mode, the null hypothesis was accepted as there was no statistically significant difference in fracture mode or restorability between the preparation design groups. Although sample size was small, this contradicts manufacturer claims that the “infinity edge” preparation design leads to less catastrophic failure modes. However, fracture loading was only completed on a longitudinal axis and had limited standardization due to differences in occlusal anatomy between natural teeth and restorations. Attempts were made to ensure even distribution of the piston on all cusps; however, this was not always achievable. Differences between the piston vs opposing dentin and lack of off-axis forces limit the clinical relevance of this portion of the study. Additional limitations of this study include a smaller sample size and inability to completely standardize tooth preparations due to use of natural teeth. However, based on the results of this study, clinicians should carefully consider use of “infinity edge” margins, particularly on dentin in the apical extent of the proximal box. Increased research into use of occlusal bevels and infinity margins as well as preparation design in vivo is needed.

**Conclusion**

Within the limitations of this study, there was no statistically significant differences in total microleakage volume, fracture load, or fracture mode between the three preparation design groups. However, there was a statistically significant difference in microleakage volume in the proximal box, with significantly more microleakage noted in group III, the “infinity edge” design group.

**References**


