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Fracture Resistance of Remaining Buccal Cusps in Maxillary Premolar Ceramic Onlay Restorations

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Clinical Relevance

Preparation designs for bondable partial coverage restorations are varied. As little as 1 mm of thickness of a remaining buccal cusp can be kept when restoring maxillary premolars with bondable partial coverage restorations.

SUMMARY

Indirect partial coverage restorations have become increasingly popular in recent years as new and improved adhesive materials have been developed. These restorations can preserve substantial amounts of tooth structure. However, there are some aspects of indirect partial coverage restorations for which no clear protocol exists. This study investigated the minimal thickness of the nonfunctional cusp that must be left in a bondable ceramic partial coverage restoration in order to resist compressive force. Ninety sound human maxillary premolar teeth were obtained and used in one of the following three ways. Ten of the sound teeth were used as a control without further preparation. Forty other sound teeth had cavities designed and were tested as "unrestored teeth." The remaining 40 sound teeth received not only cavities but also restoration and were tested as "restored teeth." Both the restored group and the unrestored group were prepared either with an overlay or with varying buccal cusp thicknesses of 1, 2, or 3 mm. In total, there were nine experimental groups with 10 in each group (n=10). The prepared teeth were digitally scanned, and the restorations were designed and fabricated from IPS e.max computer-aided design (CAD) software using a CAD/CAM machine (CEREC MC XL, Dentsply Sirona, Bensheim, Germany). The restorations were cemented with resin cement (Panavia V5). All samples underwent thermocycling and dynamic fatigue simulating approximately one year of actual use. All the teeth were then subjected to compressive load until the point of fracture, and the mode of each fracture was analyzed. Results show that the fracture resistance of the restored groups was significantly higher than the nonrestored groups ($p<0.001$) and the sound teeth ($p<0.05$). Crucially, this study determined that 1 mm of remaining buccal cusp thickness in bondable partial coverage restorations for maxillary premolars is sufficient to withstand normal use of the tooth without breakage.

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INTRODUCTION

Dental caries as well as fractures in the tooth structure or in dental restorations are common problems found routinely in clinical practice. Restorative treatment needs to be able to repair and reconstruct the integrity, morphology, and functionality of damaged tooth structure. As part of great evolutionary advances in dental materials science, bondable restorative materials have brought many benefits to the process of restorative treatment. Bondable restorative materials are able to strengthen the remaining tooth structure with only small amounts of tooth reduction, leading to increased longevity of restored teeth.[1-3]

Dental adhesive systems play a vital role in current restorative dentistry. Various restorative materials are able to bond to a natural tooth structure that has been prepared with a suitable mechanical or chemical treatment. Adhesive systems and resin-based materials can then be applied.[4,5] These bondable restorations substantially decrease the amount of tooth reduction needed during the cavity preparation process since bondable restorations do not require extensions for retention.

In cases of extensive damage, using direct dental materials for restoration requires more time and more skill than using bondable restorations, so partial coverage restoration is a preferable alternative. The benefits of the partial coverage technique are related to the increased amount of remaining tooth structure.[6] Partial coverage restoration decreases the chance of pulpal and periodontal tissue inflammation and provides more favorable stress distribution to minimize the risk of tooth fracture.[7,8] Importantly, the majority of the restoration margin is placed on enamel, which serves as an excellent bonding surface for the adhesive system. Longevity of the restoration's retention and functionality is thus increased.[9-12]

Table 1: *Experimental Groups With 10 Per Group*

Group	Experimental Design	Note
S	Sound tooth	Control
N3	Nonrestored buccal thickness 3 mm	Comparative group
N2	Nonrestored buccal thickness 2 mm	Comparative group
N1	Nonrestored buccal thickness 1 mm	Comparative group
N0	Nonrestored occlusal overlay	Comparative group
R3	Restored buccal thickness 3 mm	Test group
R2	Restored buccal thickness 2 mm	Test group
R1	Restored buccal thickness 1 mm	Test group
R0	Restored occlusal overlay	Test group

Preparation designs for partial coverage restorations will vary. The designs are related mainly to the particular features of the damaged area. There are no established guidelines for what minimum thickness of remaining cusps in bondable partial coverage restorations is sufficient to withstand normal use of the tooth without breakage. Below this thickness, reduction of the cusp and its inclusion in the restoration is required. The purpose of this study was to evaluate the influence of the remaining cusp thickness on fracture resistance in onlay restorations fabricated with IPS e.max CAD. The null hypothesis was the remaining cusp thickness has no effect on the fracture resistance of the maxillary premolar teeth when restored with ceramic onlays.

METHODS AND MATERIALS

Sample Preparation

Ninety sound human maxillary premolar teeth without cracks, restorations, or carious lesions were selected for this study. All the teeth were previously extracted for orthodontic treatment. The teeth were selected for having similar measurements on the occlusal surface: 9.5-10.5 mm bucco-lingual distance, 7.0-7.5 mm mesio-distal distance, and 8.0-8.5 mm occluso-cervical distance. The teeth had been stored in 0.1% thymol solution at room temperature before selection, and all selected teeth were used within three months of extraction. All teeth were embedded in self-cured acrylic resin 3 mm below the cemento-enamel junction (CEJ).

The teeth were then randomly divided into nine groups as shown in Table 1. The nine groups were built around three factors: whether the tooth was sound, whether the tooth was restored, and the thickness of the buccal cusp.

A high-speed hand piece with 10° taper diamond burs was used to prepare onlay mesio-occluso-distal cavities with a width and depth of 2 mm and a divergence of 10°. The occlusal cavity was continuous with the proximal cavity with an angle of departure of 120°. The gingival walls of these proximal cavities were 2 mm below the pulpal floor.

The next step in the cavity preparation was to create the varied thicknesses of the remaining buccal cusp. Those thicknesses were reduced to 3 mm, 2 mm, or 1 mm, or an occlusal overlay following the cuspal incline plane was used. The palatal cusp was reduced by 2 mm following the incline plane to obtain a butt joint margin. All the preparation depths were measured with a periodontal probe.

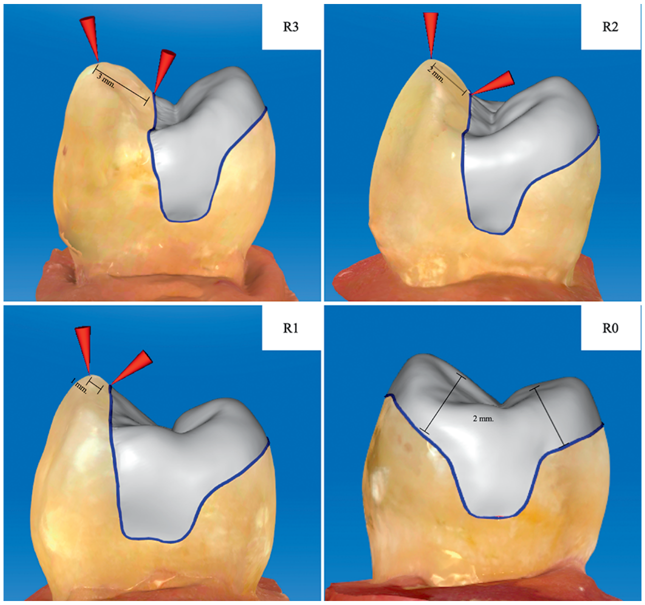

Figure 1. *Restoration designs for the four thicknesses of remaining cusp: R3, R2, R1, and R0 (3, 2, 1, and 0 mm, respectively).*

Fabrication of the Restorations

After cavity preparation, the samples were scanned with an intraoral scanner (CEREC Omnicam, Dentsply Sirona, Bensheim, Germany). The restorations were designed with computer-aided design (CAD) software (CEREC SW 4.5, Dentsply Sirona, Bensheim, Germany), re-creating the features of a natural, unprepared tooth (Figure 1). All onlay restorations were milled from lithium disilicate glass-ceramic IPS e.max CAD (Ivoclar Vivadent, Schaan, Liechtenstein) in a milling unit (CEREC MC XL, Dentsply Sirona). After the milling process, heat treatment was performed at a temperature of 840°C for 30 minutes.

Cementing the Restorations

Before cementation, all the lithium disilicate restorations were examined under a stereomicroscope (SZX-ILLD200, Olympus, Tokyo, Japan) to ensure a lack of any crack or surface flaw. The intaglio surfaces of the restorations were etched with 4.9% hydrofluoric acid (Porcelain Etch, Ultradent, USA) for 20 seconds and then thoroughly rinsed with water for 30 seconds, followed by air-drying. The etched surfaces were then treated with Clearfil Ceramic Primer Plus for five seconds (Kuraray Noritake Dental Inc, Tokyo, Japan) followed again by air-drying.

Phosphoric acid (37%) was applied to the enamel for 15 seconds using the selective etch technique. After that, the teeth were rinsed with water for 30 seconds, and excess water was removed by air-drying for 15 seconds. Tooth primer was applied and left for 20 seconds, followed by application of self-etch resin cement (Panavia V5, Kuraray Noritake Dental). The self-etch resin cement was handled as recommended by the manufacturer and applied on the intaglio surface of the restorations, which were then seated with finger pressure. The excess cement was removed after tack curing with a light-curing unit (Demi Plus LED, Kerr Corp, Orange, CA, USA) for three seconds on each surface. The restoration cement was then cured for 20 seconds on each surface. Finally, the margins of the restorations were finished and polished with a ceramic polishing kit (Luster for silicate ceramics, Meisinger, Centennial, CO, USA). After cementation, all specimens were stored in water at 37°C for seven days.

Investigation of Fracture Resistance

All specimens were thermocycled in water (SDC20 HWB332R, Yamatake Honeywell, Tokyo, Japan) between 5°C and 55°C with 15 s dwelling time for 10,000 cycles. This thermocycling represented approximately one year of *in vivo* functioning.[13] After thermal cycling, a fatigue simulation and fracture resistance test were performed in a universal testing machine (Instron Universal Tester, model 8872; Instron Inc, Canton, MA, USA). For the fatigue simulation, all specimens were subjected to dynamic loading of 127.4 N with a metal sphere of 6 mm in diameter at a frequency of 6 Hz.[14] This fatigue simulation was performed submerged in distilled water at 37°C for 240,000 cycles. In order to evaluate fracture resistance, the specimens were submitted to a shear force on the buccal inclined plane. A metal wedge shape with a blunt rounded end (not a sharp tip) was positioned blunt end down at a 20° angle to the lingual incline plane of the buccal cusp. The wedge thus made contact with both the lingual inclined plane of the buccal cusp and the buccal inclined plane of the lingual cusp (Figure 2). This wedge pressed down on each specimen submerged in distilled water with a crosshead speed of 0.5 mm/min until fracture occurred.

Investigation of the Fracture Mode

Each fractured specimen was observed under a stereomicroscope (SZX-ILLD200; Olympus) to determine the mode of fracture, which was then identified as one of the two categories described below (modified from Burke and others[15]):

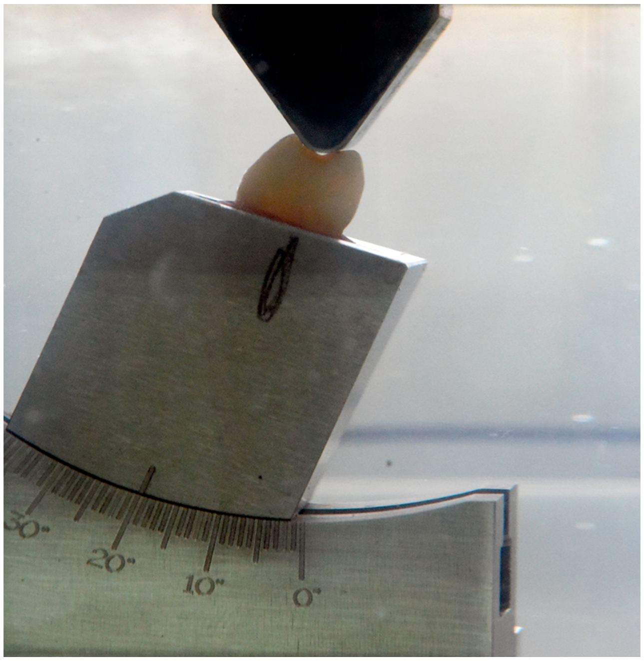

Figure 2. *A position of the metal wedge shape was used to shear the specimens at a 20° angle to the lingual incline plane of the buccal cusp.*

1. Fracture modes by involvement in restoration, dentin, or pulpal tissue
   - Type I: Fracture within the restoration
   - Type II: Fracture of the restoration and tooth structure within the dentin
   - Type III: Fracture of the restoration and tooth structure involving pulpal tissue
2. Fracture modes by location above or below the CEJ
   - Type I: Fracture above the CEJ
   - Type II: Fracture below the CEJ

Data Analysis

The means and standard deviations of the fracture resistance data were calculated and analyzed using two-way analysis of variance (ANOVA) and the Tukey honestly significant difference test in SPSS statistical software (version 23.0, SPSS Inc, Chicago, IL, USA). The significance level was set at 0.05. The fracture mode images were evaluated visually and reported descriptively.

RESULTS

Fracture Resistance of Different Cavity Designs

The eight experimental groups (excluding the control) can all be considered permutations of two factors: preparation design (buccal cusp thickness 0, 1, 2, or 3) and tooth restoration (restored or not restored). Looking at Table 2, the two-way ANOVA showed that preparation design ($p=0.034$) and tooth restoration ($p<0.001$) each had significant effects on the fracture resistance. There was also significant interaction between the preparation design and tooth restoration ($p<0.001$).

Table 2: *Effect of Preparation Design and Tooth Restoration on Fracture Resistance*

Factors	*p*-Value
Preparation design	0.034
Tooth restoration	0.000
Preparation designs_Restorations	0.000

The fracture resistance results are shown in Table 3. Within each cavity design, the restored teeth exhibited significantly higher fracture resistance than the nonrestored teeth, with the exception of the occlusal overlay group (R0 group), in which there was no significant difference in the fracture resistance between the restored and the nonrestored teeth.

Among the restored groups, the R2 group showed the highest fracture resistance (1074.80±256.91 N). This resistance was significantly higher than the sound teeth (685.67±187.40 N); however, it was not significantly different from the R1 group (998.69±279.03 N), the R3 group (986.77±303.32 N), or the occlusal overlay group (881.64±234.29 N).

In the nonrestored groups, no significant difference was found among the N1, N2, or N3 groups. The N0 group had significantly higher fracture resistance compared to those other three nonrestored groups ($p<0.05$), but it was not significantly higher than the sound teeth.

Analysis of the Fracture Mode

The fracture modes were analyzed by observing the characteristics of the fractured specimens, and the results are shown in Tables 4 and 5 and Figure 3. Looking at whether the various fractures were involved in the restoration, the dentin, or the pulpal tissue (Table 4), the sound teeth and the nonrestored groups exhibited mostly dentin-involved fractures, while the restored groups commonly had pulp tissue–involved fractures. Looking at the same fractures from the perspective of whether they are located above or below the CEJ (Table 5), fractures in the sound teeth and in the nonrestored groups were mostly above the CEJ, except in the N0 group.

Table 3: *Fracture Resistance (Mean±SD) of Different Cavity Designs in Restored and Nonrestored Teeth*[a]

Cavity Design	(Group) Fracture Resistance, N	
	Restored	Nonrestored
Buccal thickness 3 mm	(R3) 986.77 ± 303.32 ABa	(N3) 357.35 ± 105.36 Ab
Buccal thickness 2 mm	(R2) 1074.80 ± 256.91 Aa	(N2) 356.05 ± 177.12 Ab
Buccal thickness 1 mm	(R1) 998.69 ± 279.03 ABa	(N1) 432.23 ± 162.19 ADb
Occlusal overlay	(R0) 881.64 ± 234.29 ABa	(N0) 983.59 ± 220.22 BEa
Sound teeth	(S) 685.67 ± 187.40 Ba	(S) 685.67 ± 187.40 CDEa

[a] *Uppercase letters indicate significant difference within the column ($p<0.05$); lowercase letters indicate significant difference within the row ($p<0.05$).*

In contrast, fractures in the restored group were found for the most part below the CEJ.

DISCUSSION

There was no statistical difference in fracture resistance when teeth with different remaining cusp thickness (1, 2, and 3 mm) were restored with ceramic onlays. The null hypothesis was not rejected.

The popularity of partial coverage restorations has increased steadily with innovations in adhesive dentistry and in bondable restorative materials. In this study, lithium disilicate ceramics received surface treatment with hydrofluoric acid and silane,[16-18] followed by resin cement application. This process enabled these ceramics to bond to the tooth structure, forming bondable restorations.

The design of this study focused on varying thicknesses of the buccal cusp of the maxillary premolar tooth, in other words, the nonfunctional cusp. According to a previous study, the nonfunctional cusp was more prone to fracture than the functional cusps.[19] Maxillary premolar teeth were intentionally selected for the current study since they have a higher frequency of fracture than do mandibular premolar teeth.[20] Although molar teeth have an even higher fracture rate, they were not selected for this study because almost all extracted molar teeth are removed due to periodontal problems or dental caries, which would have been undesirable for this study. Extracted molar teeth have also usually been in use for a longer period of time, and they are extracted at a wider variety of ages. Thus, the dentin characteristics of different extracted molar teeth are likely to be dissimilar.[21,22]

Since maxillary premolar teeth are located at the curvature of the jaw and because they have steep cusps, they are naturally exposed to repeated oblique occlusal force.[23] To simulate this natural situation, the loading force in both the fatigue simulation and the fracture resistance tests of this study was applied at a corresponding 20° oblique angle. The resulting fracture resistance of the restored groups in this study was similar to that seen in previous studies, generally around 800-1100 N.[1,24]

Several studies have shown that cusp coverage with a bondable restoration is able to protect a weakened tooth structure.[1,25,26] In the current study, the fracture resistance of restored teeth, even those without cusp coverage, was significantly higher than that of unrestored teeth. The bondable restorations, with or without cusp coverage, were able to strengthen the remaining tooth structure. Importantly, as little as a 1 mm thickness of the

Table 4: *Fracture Modes by Involvement in Restoration, Dentin, or Pulpal Tissue*

Group	Type I, Within Restoration % (number of samples)	Type II, Within Dentin % (number of samples)	Type III, Involve Pulpal Tissue % (number of samples)
S	—	100 (10)	0
N3	—	100 (0)	0
N2	—	100 (0)	0
N1	—	100 (0)	0
N0	—	90 (9)	10 (1)
R3	0	0	100 (10)
R2	10 (1)	20 (2)	70 (7)
R1	20 (2)	30 (3)	50 (5)
R0	0	20 (2)	80 (8)

Table 5: *Fracture Modes by Location Above or Below the Cemento-Enamel Junction (CEJ)*

Group	Type I, Above CEJ % (number of samples)	Type II, Below CEJ % (number of samples)
S	100 (10)	0
N3	100 (10)	0
N2	90 (9)	10 (1)
N1	80 (8)	20 (2)
N0	40 (4)	60 (6)
R3	0	100 (10)
R2	10 (1)	90 (9)
R1	50 (5)	50 (5)
R0	0	100 (10)

remaining nonfunctional cusp of a maxillary premolar can be kept without reduction.

This study showed that differences in preparation design or buccal wall thickness had considerable influence on the fracture resistance of the maxillary premolars. The fracture resistance of the reduced-cusp restorations (overlays) was not significantly different from that of the nonreduced ones. Guess and others[1] similarly found that preparation design and ceramic thickness influenced the fracture resistance of premolar partial coverage restorations.[1] However, extending preparation from a palatal onlay to complete occlusal coverage on premolars did not increase the fracture resistance. A clinical study conducted by Van Dijken and others[27] found no statistically significant difference in performance between four preparation designs, even five years after ceramic partial coverage restorations. Similar results have been observed in other *in vitro* studies.[24,28,29]

After cementation, this study used thermal cycling and dynamic fatigue to simulate actual clinical conditions because humidity in the oral environment, along with the mechanical and thermal stress, has been shown to affect fracture resistance of restorations.[30] The mean fracture resistance of nonrestored teeth determined in the current study was lower than that found in some other studies.[31,32] The specimens in this study received dynamic fatigue and loading force underwater, while the previous studies performed the fatigue under dry conditions. Many other variables can also affect fracture resistance, such as the mode and direction of loading as well as the crosshead speed and size of the indenter.[15,29]

All of the ceramic partial coverage restorations in this study had a greater fracture resistance than the

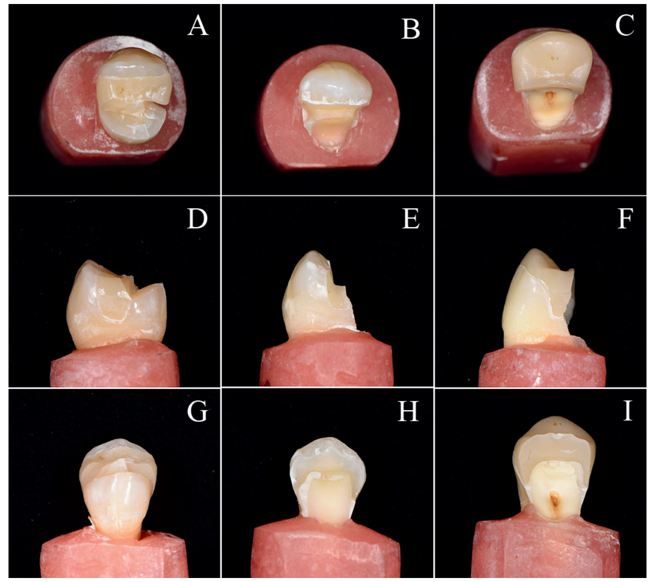

Figure 3. *These photographs show three fractured teeth (horizontally) from three perspectives (vertically). The fractures can be classified by whether they are involved in the restoration (A, D, and G), dentin (B, E, and H), or pulpal tissue (C, F, and I). They can also be classified by location above (A, D, and G) or below (B, C, E, F, H, and I) the cemento-enamel junction.*

physiological masticatory forces to which they would typically be exposed. The average occlusal forces in the first premolar area has previously been measured as 178.54 ± 77.20 N (for women) and 254.08 ± 72.20 N (for men).[33] In a 2011 study, the occlusal forces of premolars were measured as 373.8 ± 102.6 N for men and 314.7 ± 96.5 N for women.[34] Thus 400 N is a reasonable estimate of the minimum threshold of occlusal force to which a premolar tooth is normally subjected.[31]

This study assessed fracture mode from two perspectives: whether the fracture is involved in the restoration, the dentin, or the pulpal tissue or whether the fracture is located above or below the CEJ. Among the restored groups, the majority of fracture modes involved pulpal tissue and extended below the CEJ into the radicular portion. On the other hand, among the nonrestored groups, most fractures were within the dentin and above the CEJ. The restored groups had fracture resistance three times higher than the nonrestored groups. This could be explained by additional strength provided by the bondable ceramic restorations.

Resin cement has the dual benefits of esthetic appeal and bond strength, whether applied to the dental structure or to the ceramic restoration. Resin cement also enhances the flexural strength of a tooth restored with bondable stiff material, such as ceramic.[24,35] Because the force produced by actual chewing is less than the force that was applied experimentally in the laboratory, these restorations should be able to withstand normal mastication.

Some limitations of this study were associated with the mechanical testing of the extracted teeth. The single direction of force applied to the teeth is not a load typically occurring in actual mastication. The mechanical test was also not able to account for absent periodontal structure, which would provide some natural shock absorption.

CONCLUSIONS

This study succeeded in evaluating the influence of the remaining cusp thickness on fracture resistance in restorations fabricated with IPS e.max CAD onlays. Crucially, it determined that a 1 mm thickness of a remaining buccal cusp in bondable partial coverage restorations is sufficient to withstand normal use of the tooth without breakage. Other sections of this study were able to clarify outstanding questions about designing partially covered restorations conservatively, information that should be of good use during treatment.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the Naresuan University. The approval code issued for this study is 0501/61.

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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