ACP
AMERICAN COLLEGE OF PROSTHODONTISTS

Effect of Auxiliary Grooves on Molar Crown Preparations Lacking Resistance Form: A Laboratory Study

Po-Ching Lu, BDSc(Hons), GradDipClinDent, DClinDent,[1] & Peter Wilson, BDS, FDSRCS, MS, DRDRCS, PhD[2]

[1] Prosthodontist, Private Practice, Sydney, Australia
[2] Associate Professor in Restorative Dentistry, School of Dental Science, The University of Melbourne, Melbourne, Australia

Keywords
Grooves; resistance form; compromised preparations; large pulp.

Correspondence
Peter Wilson, School of Dental Science, The University of Melbourne, 720 Swanston St., Carlton, Melbourne 3053, Australia. E-mail: prwilson@unimelb.edu.au

Previously presented at the biennial meeting of the Academy of Australian and New Zealand Prosthodontists, Sydney, 31 July 2004.

Support provided by The University of Melbourne.

Accepted 3 October 2006

doi: 10.1111/j.1532-849X.2007.00263.x

Abstract

Purpose: To investigate the effect of auxiliary grooves on resistance to dislodgment of crowns on compromised molar preparations lacking resistance form.
Materials and Methods: Thirty human molar teeth were randomly assigned to three groups of ten, and prepared to a height-to-width ratio of 0.3 with a total convergence of 50°, and 1-mm shoulder margin. Base metal alloy copings were constructed with a 45° loading platform and cemented with zinc phosphate cement under a 50 N load. Initially, resistance testing was conducted using a Universal Testing Machine (Instron) at 1 mm/min for all 30 specimens. Following crown dislodgment, Group 1 copings were recemented and retested, Group 2 had one axial groove added, and Group 3 had two axial grooves added. New copings for Groups 2 and 3 were made, cemented, and again tested for resistance. Standardized radiographs were taken prior to initial cementation and scanned into digital images. The percentage of area occupied by the pulpal chamber above the acrylic mounting (PS), and the closest distance to pulp from the preparation surface (CD) were measured.
Results: Recementation or the addition of one groove did not affect the dislodgment values ($p > 0.05$), but addition of two grooves caused a highly significant increase in resistance ($p < 0.001$). Regression analysis showed an inverse relationship between initial resistance values and pulpal space area. Lower resistance values were observed when the pulpal space area was large ($p = 0.004$).
Conclusions: Crowns can be recemented without affecting resistance to dislodgment. Two grooves should be incorporated into compromised molar crown preparations to increase resistance form. Teeth with large pulps and therefore less coronal dentine have poorer resistance form, and therefore would benefit from placement of auxiliary grooves.

Retention and resistance forms are features of crown preparations that prevent dislodgment of crowns. Historically, retention has been the main focus of interest in crown dislodgment; however, resistance form is perhaps more crucial because occlusal forces are directed in a lateral or an apical direction. Resistance form is defined as "the features of a tooth preparation that enhance the stability of a restoration and resist dislodgment along an axis other than the path of placement."[1]

Many factors, such as height, width, and convergence angle,[2-5] influence resistance form of a crown preparation; however, it is the combination of all these factors that determines whether a preparation has resistance form. Lewis and Owen[6] devised a mathematical method that considered the division between the resistive and nonresistive areas on a preparation wall. The axial inclination of the preparation wall and the width of the preparation determine this boundary.

Weed and Baez[3] proposed a different method of assessing resistance form using a circle centered on the margin of the opposing side. Their concept was that if the preparation wall falls inside this arc, then it lacks resistance form. Parker et al[7] argued that the Weed and Baez method[3] of evaluating resistance was erroneous, and suggested that the resistance form at each point on the axial wall could be evaluated by drawing an arc of the circle centered on the opposite margin. The point on the preparation has resistance form if the direction of the arc is into the preparation. Zuckerman[8] offered a different theoretical analysis of resistance form, which was using a boundary arc centered at the base of the preparation. Both the Parker et al

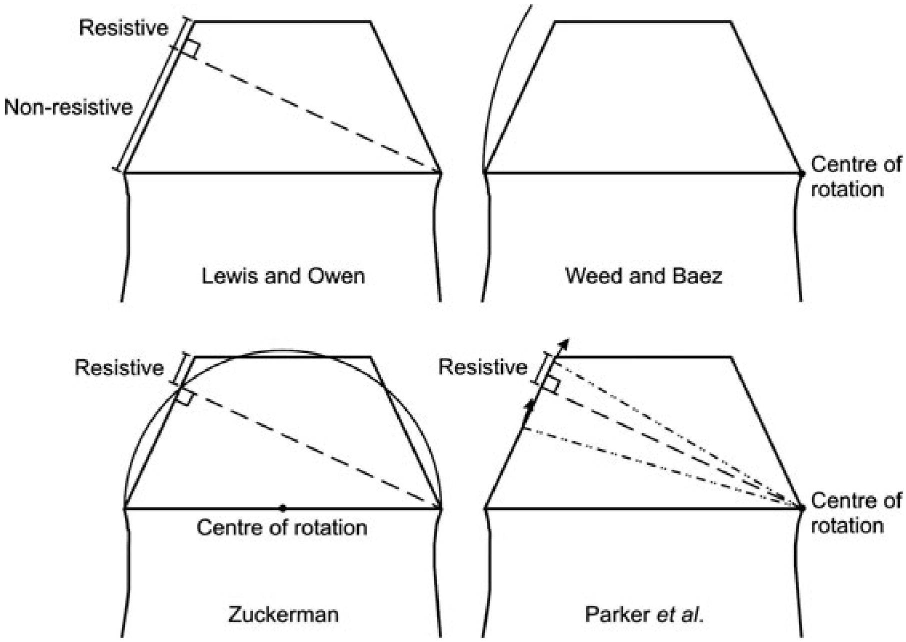

Figure 1 Theoretical methods for determining resistance form.

and Zuckerman methods supported the mathematical derivation of Lewis and Owen (Fig 1). More recently, Wiskott et al[9] urged a revision using an axis of rotation located at the crown margin. Using a 3D finite element model, they found a rotational axis passing through the center of the core, and the location of the axis was dependent on the stiffness of the core and the cement.

Molar crown preparations usually possess the greatest convergence angles when compared to premolars and anterior teeth.[10-14] This, along with the molar's shorter clinical crown and wide diameter, adds to a frequent lack of resistance form in molar preparations. Parker et al[12] investigated the resistance form of 107 clinical molar preparations by applying a tipping force digitally on crowns on their dies in a dental laboratory. They found only 46% of molars had resistance form, and only 7% had grooves.

The controversy of the nature of resistance form and the lack of clinical guidelines make judgment difficult, especially when the preparation is not ideal. Goodacre et al[15] recommended that the total convergence should be within 10–20°, and occlusocervical/faciolingual ratio to be 0.4 or higher. Molar preparations would likely not satisfy these recommendations, and auxiliary features such as boxes and grooves would be required to improve the resistance form.[11,15]

Grooves are said to reduce the rotational radius.[16] By incorporating a groove, the rotational radius is divided in half. Numerous studies have shown an increase in resistance to crown dislodgment when grooves are placed.[17-19] Woolsey and Matich[19] showed that grooves on the proximal surfaces provided resistance to buccolingual movement, but buccal/lingual grooves only provided partial resistance to the same movement. In a recent study,[20] grooves, boxes, occlusal isthmus, and modified inclined occlusal planes were all found ineffective in enhancing resistance form when the tooth preparations had inadequate resistance.

Most of the studies on resistance form have used metal dies due to the ease of standardization; however, metals have different properties than natural teeth, and the response of the core to the nonaxial force applied is important in resistance testing and may influence the results. The purpose of this study was to evaluate the effect of auxiliary grooves on crown preparations lacking resistance form using human teeth.

Materials and methods

Thirty extracted human molar teeth were collected and stored in 1% chloramine T solution until use. All teeth were intact and free of caries. These were aligned vertically using a dental surveyor in relation to the crown form and mounted within 20-mm PVC tubes in autopolymerizing acrylic resin (Vertex, Dentimex, Zeist, The Netherlands). They were then randomly assigned to three groups of ten. The three preparation groups were (1) standard preparation with no grooves, (2) standard preparation with one axial groove, and (3) standard preparation with two axial grooves.

Cores were prepared with one type of flat-ended diamond-shaped diamond bur (FG038047, Horico, Hopf Ringleb & Co. GmBH & CIE, Berlin, Germany). Preparations were standardized with a high-speed handpiece mounted in a fixed position on the arm of a modified dental surveyor (Krupp Dentograph, Fried-Krupp GmBH, Essen, Germany). The geometry of the bur created standardized preparations, with total convergence angle of 50°. The teeth were prepared to a level of 2.5 mm above the tube with a 1-mm shoulder margin. The width of

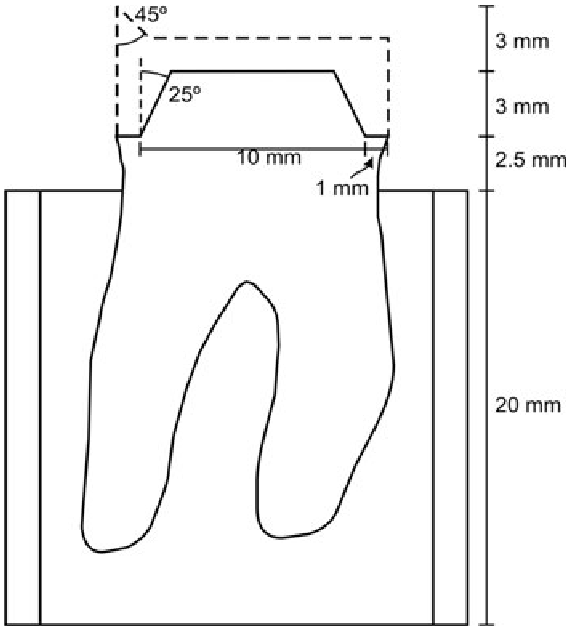

Figure 2 Standard preparation with H/B ratio of 0.3 and 45° loading platform coping.

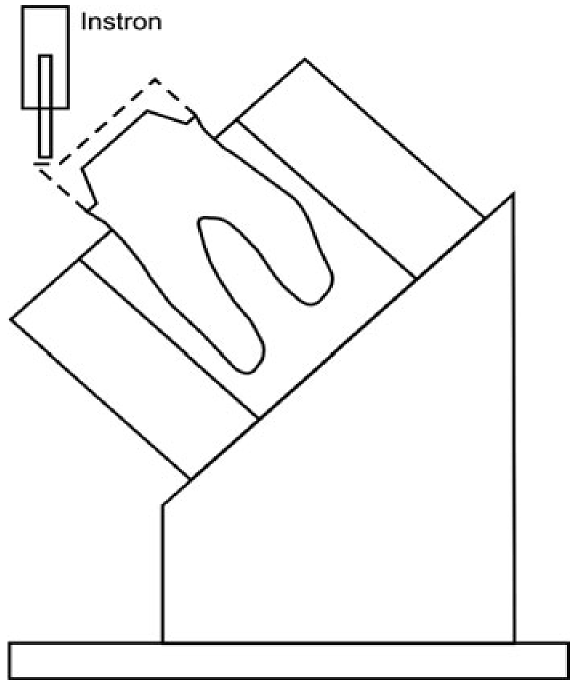

Figure 3 Mounting of specimen on the apparatus attached to the Instron.

the core was measured with a caliper (CD-8″CS, Mitutoyo, Tokyo, Japan), and the height of the core was reduced until height-to-base ratio reached 0.3. Due to the variation in forms of natural teeth, the midpoint width of the core was chosen for ratio calculation. A standard preparation is shown in Figure 2.

Following core preparation, a standardized radiograph was taken for each tooth, perpendicular to the dislodgment axis. Radiographs were scanned into digital images, and by using software program Image J (http://www.ncbi.nlm.nih.gov), two variables of each tooth were measured. These included the percentage of space occupied by the pulpal chamber above the acrylic mounting (PS), and the closest distance to pulp of the preparation (CD).

Initially, no grooves were placed in any of the preparations. A wax pattern was formed directly on each individual preparation, with four layers of die-spacer (Tru-Fit, Geo Taub Products, Jersey City, NJ) applied within 1 mm of the margin. A 45° platform was incorporated into each wax pattern at a level 3 mm above the preparation. The wax copings were invested according to the manufacturer's instructions (Fujivest, GC, Tokyo, Japan), and cast with Ni–Cr base metal alloy (Remanium CS, Dentarum, Pforzheim, Germany). Die-spacer was peeled off from the tooth surfaces with ease, and copings were cleaned and adjusted internally under 10× magnification to ensure good seating and fit.

Following adjustments, the internal fitting surface was sandblasted with aluminum oxide and cleaned with an air steamer. The tooth surfaces were cleaned with flour of pumice prior to cementation. Copings were cemented with an encapsulated form of zinc phosphate cement (PhosphaCEM IC, Ivoclar Vivadent AG, Schaan, Liechtenstein) with 50 N load for 10 minutes. A silicone putty (Lab-Putty, Coltene/Whaledent AG, Altstaetten, Switzerland) key of the 45° loading platforms was formed for each of the specimens in Groups 2 and 3. The cemented specimens were stored in distilled water for at least 24 hours before testing. All specimens were tested within 48 hours of cementation.

The specimens were placed 45° to the axis of load application in an apparatus, which is mounted to the Universal Testing Machine (Model 5544, Instron, Canton MA), and positioned beneath a 2-mm diameter brass rod (Fig 3). A loading speed of 1 mm/min was used, and values were recorded when failure of the cement seal or core fracture occurred, which was seen as a sudden drop in load.

Following dislodgment, Group 1 copings were recemented under the same conditions following sandblasting and cleansing. For Group 2, one axial groove was placed in the middle of the axial wall, which is perpendicular to the axis of dislodgment. For Group 3, two grooves were cut with one groove placed in both axial walls perpendicular to the axis of dislodgment. These grooves were cut to the full depth of the bur (H23L010, Komet, Lemgo, Germany) parallel to the axial wall. This created grooves of 1 mm in diameter, at a level 0.5 mm above the margin as shown in Figure 4. The same die-spacing procedure was applied to the new wax patterns for preparations in Groups 2 and 3 using the silicone putty key to replicate the exact position of the 45° loading platform. Similar to the initial protocol, these new copings were invested, cast, and cemented. All 29 specimens were remounted, and resistance testing was performed. Maximum resistance was recorded when failure of the cement seal or fracture of the core occurred.

One-way analysis of variance (ANOVA) was conducted to ensure homogenous samples between the groups, and paired *t*-test was used to examine the treatment effect within each

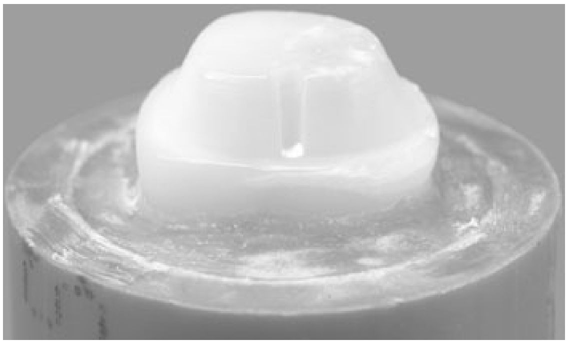

Figure 4 Example of groove placement parallel to the axial wall of the preparation.

group. Differences between the different treatment effects were tested using pairwise comparisons. Analysis of covariance (ANCOVA) was used to test the effects of variables of the dentine core on resistance.

Results

Dislodgment loads are given in Table 1 for each of the three groups. Tooth 15 was eliminated from the study due to rocking of fitting observed prior to recementation. A large variation of initial dislodgement forces was seen within each group, ranging from 23 to 173 N. One-way ANOVA was conducted to examine the forces for initial load between groups, and the samples were not statistically different between the groups ($p = 0.527$). Boxplots in Figure 5 show the distribution of the initial resistance values and resistance values after treatment for each group.

Group 1 copings were recemented, and slightly lower loads were required to dislodge the copings in eight out of nine specimens; however, paired *t*-tests showed that the effect was not statistically significant ($p = 0.08$). Only six samples in Group 2 showed an increase in load following groove placement, and the treatment effect was not statistically significant ($p = 0.22$). All crowns exhibited a large increase in dislodgment forces following two groove placements, and the effect was shown to be highly significant ($p < 0.001$). Pairwise comparisons demonstrated that the treatment effect of one groove was no different to when no groove was placed ($p = 0.07$), and two grooves had a treatment effect that was highly statistically different from both the no groove and one groove groups ($p < 0.001$).

Following the initial dislodgment, none of the dentine cores fractured. Cement failures were seen at the crown–cement and tooth–cement interfaces, and no cohesive failure was observed. Examination under magnification of the cores after the second dislodgment revealed only three cores in Group 2 had fractures of dentine adjacent to the groove, but all of the cores in Group 3 had dentine fractures, with six cores exhibiting catastrophic fracture, as shown in Figure 6.

Measurements for the percentage of space occupied by the pulpal chamber above the acrylic mounting (PS), and the closest distance to pulp of the preparation (CD) are presented in Table 2. ANCOVA showed that PS was highly significant ($p = 0.004$) in affecting the dislodgment load, and CD was also significant ($p < 0.05$). Teeth with enamel remaining following core preparation generally exhibited large initial dislodgment loads, with most of these forces greater than 100 N.

Table 1 Initial and second (after treatment effect) dislodgment forces for each specimen in the three test groups

Tooth number	Initial dislodgment load (N)	Second dislodgment load (N)
Group 1		
10	94.23	73.51
11	23.05	10.55
12	92.86	73.76
13	32.32	21.21
14	141.67	105.32
16	148.00	138.98
17	113.88	75.44
18	95.37	81.32
19	172.56	207.46
Group 2		
20	39.67	70.20
21	37.28	55.14
22	83.62	53.33
23	35.63	33.34
24	56.83	99.76
25	124.76	147
26	104.31	210.73
27	71.82	93.47
28	146.15	114.12
29	96.66	86.73
Group 3		
30	51.09	240.88
31	136.27	331.19
32	147.34	201.66
33	93.10	323.03
34	41.67	308.23
35	115.75	217.56
36	41.56	141.16
37	106.58	184.35
38	63.61	276.15
39	59.85	320.99

Discussion

The excessive convergence angle and height-to-base ratio was chosen to simulate a severely compromised clinical situation. Goodacre et al[15] suggested a ratio of 0.4 or more to ensure proper resistance to dislodgment. According to theoretical concepts of resistance form previously discussed and Goodacre's recommendation, our standard preparation did not have resistance form (Fig 7). Nonresistive preparations allowed the investigation of the effects of axial grooves on resistance form when it is most needed.

Absence of core fracture following initial dislodgment allowed individual teeth to act as a control for treatment effects. This was important, because in this laboratory study, the circumferential morphology of the preparations could not be standardized due to the varying form of the teeth used, and a

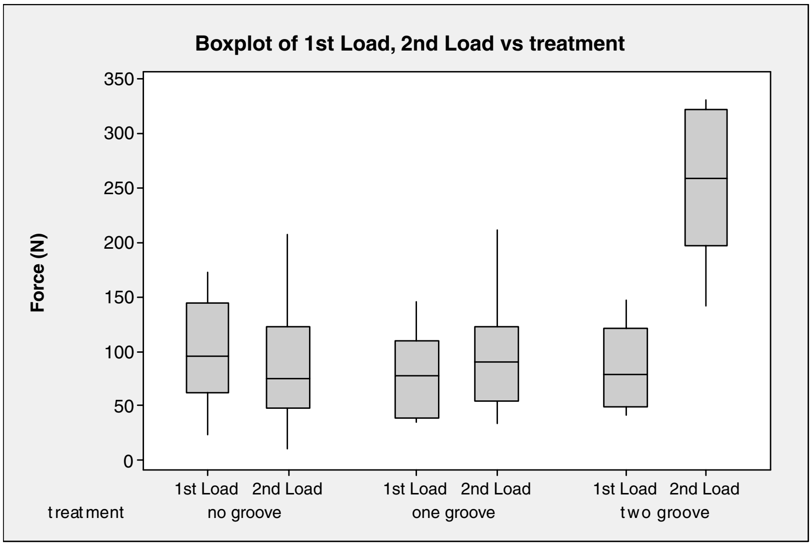

Figure 5 Distribution of sample population.

difference in dislodgment loads was expected due to the use of natural teeth.

Zinc phosphate cement was chosen for this study owing to its nonadhesive nature. Proussaefs[21] evaluated the effect of different cements on resistance to dislodgement of crowns on metal dies. His results suggested zinc phosphate cement was superior in providing resistance to nonaxial forces in nonresistive preparations; however, no account was made for the chemical adhesion that normally occurs between tooth structure and adhesive cements, such as resin composite and resin-modified glass ionomer cements. In this study, substitution of zinc phosphate cement with adhesive cements may have resulted in increased resistance values or caused core fracture.

Group 1 copings were recemented without alterations to the core structure following initial dislodgment. Kaufman et al[2] and Ayad et al[22] found recemetation with zinc phosphate cement produced reduced retention. Their hypothesis for this effect was that minute undercuts of the internal surface of castings were burnished following recementation, and resulted in loss of retention with zinc phosphate cement. Our study was on crown resistance instead of retention, and it is perhaps logical that our results showed recementation with zinc phosphate cement had no effect on crown resistance because resistance is more reliant on geometric configuration.

It was surprising to find the lack of significant enhancement of resistance with the addition of one groove. Dentine cores have a relatively low modulus of elasticity[23] (18 GPa), and flexure of the core during force application may have resulted in groove disengagment and consequently dislodgment of the crowns; however, when two grooves were placed, the flexure of dentine did not allow disengagement, and thus more than half of Group 3 had catastrophic core fractures. Figure 6 shows that the improvement of resistance achieved with two grooves is independent of the initial dislodgement force.

Proussaefs et al[20] found grooves to be ineffective at increasing resistance form for a short tooth preparation with 20° total convergence. They attributed this to the axial inclination of the grooves, which were parallel to the axial walls. This study used metal as the core structure, and average forces (1240 N in the control group) required to dislodge the crowns were high. In this range of forces, even the compressive strength of zinc phosphate cement is probably exceeded. Therefore, the addition of auxiliary features probably would not increase resistance much further; however, using dentine cores, we were able to show significant enhancement of resistance form by the addition of two grooves.

In our study, the magnitude of forces required to dislodge copings without grooves were all less than 200 N. This is far less than the loads (410–5690 N) reported in the Proussaef study, which used metal dies. Using finite element analysis, Wiskott et al[9] concluded that restorations rotate around an axis perpendicular to and intersecting the axis of symmetry of the

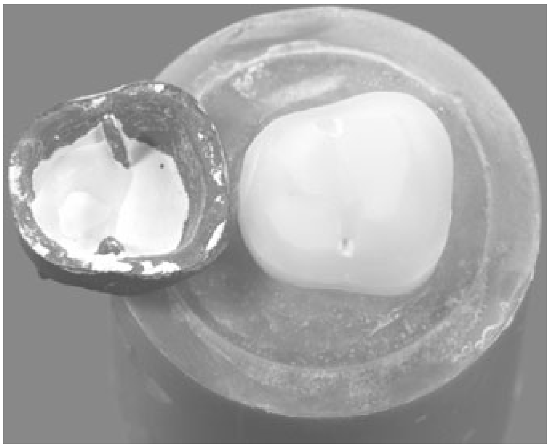

Figure 6 Example of catastrophic dentine core fracture in the two grooves group.

Table 2 Dentine core variables and initial dislodgment forces for each specimen of the three test groups

Tooth number	Initial dislodgment load (N)	PS (%)	CD (mm)
Group 1			
10	94.23	21.84	1.86
11	23.05	36.89	0.2
12	92.86	24.95	1.45
13	32.32	31.37	0.56
14	141.67	14.02	2.03
16	148.00	10.82	2.50
17	113.88	25.97	0.66
18	95.37	31.07	1.12
19	172.56	16.55	2.06
Group 2			
20	39.67	33.29	0.25
21	37.28	30.46	0.36
22	83.62	39.85	1.19
23	35.63	38.21	0.66
24	56.83	20.86	0.05
25	124.76	26.81	1.12
26	104.31	16.27	0.57
27	71.82	13.69	0.42
28	146.15	29.40	1.90
29	96.66	35.29	0.26
Group 3			
30	51.09	32.16	0.50
31	136.27	27.92	1.53
32	147.34	16.27	1.56
33	93.10	32.05	1.55
34	41.67	30.14	0.54
35	115.75	15.06	2.02
36	41.56	35.39	0.36
37	106.58	22.57	1.16
38	63.61	41.69	0.10
39	59.85	36.97	1.34

core, and the level of this axis was largely dependent on the modulus of elasticity of the cement and the abutment. High elastic modulus results in less tension and shear forces. As cements are weak in tension and shear, this suggests that core stiffness is important for resistance. Our results showed that when a tooth has a small pulpal area, the proportion of dentine remaining following crown preparation is greater, which results in a stiffer core structure and higher resistance to dislodgment.

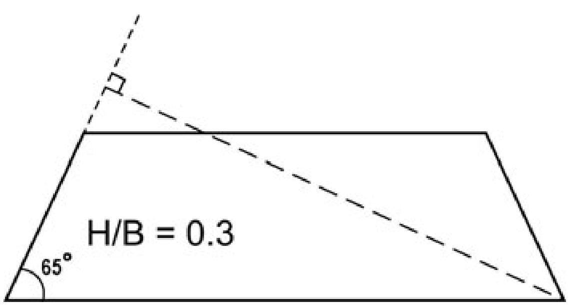

Figure 7 Lack of resistance form when H/B ratio is 0.3 with 50° of convergence.

The relationship between closest distance (CD) and resistance is probably related to the size of the pulp chamber. Larger pulps would naturally be closer to the edge of the axial surfaces. Radiographs are only 2D images of 3D objects. Measurements conducted in this study on digital images of radiographs are a very crude method of measuring area and distance. Overlapping and blurred contrast of these images were often encountered. Further investigations with more accurate measurements are required to confirm the findings of this study.

Conclusion

From our results, it can be concluded that the dislodged crowns can be recemented without affecting resistance. In a compromised molar crown preparation, two grooves should be incorporated instead of one to enhance the resistance form. Sufficient enhancement of resistance form achieved with these auxiliary grooves can save the tooth from elective endodontic treatment. Teeth with large pulps and therefore less coronal dentine have more flexible cores, and thus poorer resistance form. Therefore, they would benefit from placement of auxiliary grooves.

Acknowledgment

The authors would like to thank Mr. Karl Rahaus and Mr. Chris Owen for their technical assistance, and Ms. Te-Chieh Hung for her expertise in statistical analysis.

References

1. The glossary of prosthodontic terms. J Prosthet Dent 1999;81:39-110
2. Kaufman E, Coelho D, Colin L: Factors influencing the retention of cemented gold castings. J Prosthet Dent 1961;11:487-502
3. Weed RM, Baez RJ: A method for determining adequate resistance form of complete cast crown preparations. J Prosthet Dent 1984;52:330-334
4. Wiskott HW, Nicholls JI, Belser UC: The relationship between abutment taper and resistance of cemented crowns to dynamic loading. Int J Prosthodont 1996;9:117-139
5. Wiskott HW, Nicholls JI, Belser UC: The effect of tooth preparation height and diameter on the resistance of complete crowns to fatigue loading. Int J Prosthodont 1997;10:207-215
6. Lewis R, Owen M: A mathematical solution of a problem in full crown construction. J Am Dent Assoc 1959;59:943-947
7. Parker MH, Gunderson RB, Gardner FM, et al: Quantitative determination of taper adequate to provide resistance form: concept of limiting taper. J Prosthet Dent 1988;59:281-288
8. Zuckerman GR: Resistance form for the complete veneer crown: principles of design and analysis. Int J Prosthodont 1988;1:302-307
9. Wiskott HW, Krebs C, Scherrer SS, et al: Compressive and tensile zones in the cement interface of full crowns: a technical note on the concept of resistance. J Prosthodont 1999;8:80-91
10. Leempoel PJ, Lemmens PL, Snoek PA, et al: The convergence angle of tooth preparations for complete crowns. J Prosthet Dent 1987;58:414-416

11. Nordlander J, Weir D, Stoffer W, et al: The taper of clinical preparations for fixed prosthodontics. J Prosthet Dent 1988;60:148-151
12. Parker MH, Malone KH 3rd, Trier AC, et al: Evaluation of resistance form for prepared teeth. J Prosthet Dent 1991;66:730-733
13. Annerstedt A, Engstrom U, Hansson A, et al: Axial wall convergence of full veneer crown preparations. Documented for dental students and general practitioners. Acta Odontol Scand 1996;54:109-112
14. Al-Omari WM, Al-Wahadni AM: Convergence angle, occlusal reduction, and finish line depth of full-crown preparations made by dental students. Quintessence Int 2004;35:287-293
15. Goodacre CJ, Campagni WV, Aquilino SA: Tooth preparations for complete crowns: an art form based on scientific principles. J Prosthet Dent 2001;85:363-376
16. Panno FV: Preparation and management of full coverage restorations for combination fixed removable prostheses. Dent Clin North Am 1987;31:505-528
17. Kishimoto M, Shillingburg HT Jr., Duncanson MG, Jr.: Influence of preparation features on retention and resistance. Part II: three-quarter crowns. J Prosthet Dent 1983;49:188-192
18. Potts RG, Shillingburg HT Jr., Duncanson MG Jr.: Retention and resistance of preparations for cast restorations. J Prosthet Dent 1980;43:303-308
19. Woolsey GD, Matich JA: The effect of axial grooves on the resistance form of cast restorations. J Am Dent Assoc 1978;97:978-980
20. Proussaefs P, Campagni W, Bernal G, et al: The effectiveness of auxiliary features on a tooth preparation with inadequate resistance form. J Prosthet Dent 2004;91:33-41
21. Proussaefs P: Crowns cemented on crown preparations lacking geometric resistance form. Part II: effect of cement. J Prosthodont 2004;13:36-41
22. Ayad MF, Rosenstiel SF, Woelfel JB: The effect of recementation on crown retention. Int J Prosthodont 1998;11:177-182
23. Craig RG: Restorative Dental Materials, (ed 9). St Louis, MO, Mosby, 1993, pp. 64