©Operative Dentistry, 2005, **30-1**, 33-38

Effect of Restorative Procedures and Occlusal Loading on Cuspal Deflection

S González-López • F De Haro-Gasquet
MÁ Vílchez-Díaz • L Ceballos • M Bravo

Clinical Relevance

The progressive elimination of dental tissue, especially removal of marginal ridges and dentin above the pulp chamber and application of increasing occlusal loads, were related to a higher cuspal deflection.

SUMMARY

This study examined the extent of cuspal flexure caused by progressively larger cavity preparations, including endodontic access, and progressive simulated occlusal loading with 50N, 100N and 150N.

Ten intact extracted maxillary premolars were embedded in acrylic resin, and a small ball was attached to each cuspal tip as a reference point for intercuspal distance measurements. The teeth were subjected sequentially to the following procedures: conservative MO cavity preparation, extensive MO cavity preparation, endodontic access step and MOD cavity preparation. After each cavity preparation procedure, the specimens were subjected to increasing loads of 50, 100 and 150 N, and the intercuspal distance was recorded by means of a digital caliper. The extension of cavity preparation and the magnitude of occlusal load significantly influenced cuspal deflection. After 50 and 100 N loading, a similar cuspal deflection was exhibited by conservative and extensive MO preparations with or without the endodontic access step. With 150 N loading, the endodontic access step was related to a statistically larger cuspal deflection versus the deflection recorded for conservative and extensive MO preparations. The removal of both marginal ridges in MOD cavity preparation with endodontic access produced a dramatic increase in cuspal deflection for the three loads tested.

*Santiago González-López, MD, BDS, PhD, associate professor, Faculty of Dentistry, University of Granada, Granada, Spain

Francisco De Haro-Gasquet, DDS, PhD, assistant professor, Faculty of Dentistry, University of Granada, Granada, Spain

Miguel Ángel Vilchez-Díaz, MD, BDS, PhD, assistant professor, Faculty of Dentistry, University of Granada, Granada, Spain

Laura Ceballos, DDS, PhD, associate professor, Faculty of Health Sciences, Rey Juan Carlos University, Alcorcón, Madrid, Spain

Manuel Bravo, MD, DDS, PhD, associate professor, Faculty of Dentistry, University of Granada, Granada, Spain

*Reprint request: Faculty of Dentistry, Department of Pathology and Dental Therapeutics, Campus de la Cartuja, E-18071, Granada, Spain; e-mail: sglopez@ugr.es

DOI: 10.2341/04-165

INTRODUCTION

Cusps deform due to occlusal forces and lateral excursions, even though intact teeth are very stiff (Morin & others, 1988; Jantarat, Palamara & Messer, 2001a), and the stresses generated during friction between occluding surfaces are mainly absorbed in the periodontal ligament (Douglas, Sakaguchi & DeLong, 1985).

Caries, trauma and the removal of hard tissue during cavity preparation produce a significant loss of tooth strength and increase cuspal flexure under occlusal load (Mondelli & others, 1980; Larson, Douglas & Geistfeld, 1981; Morin & others, 1988; Caron & others, 1996; El-Badrawy, 1999; Pane, Palamara & Messer, 2002; Zidan & Abdel-Keriem, 2003). The association between extensive restorative procedures and high occlusal loads, combined with lateral excursive contacts, leads to a higher susceptibility to fracture (Sakaguchi & others, 1991). Accordingly, endodontically treated teeth are considered especially at risk (Reeh, Messer & Douglas, 1989; Jantarat & others, 2001a).

Several factors have been reported to affect the extent of cuspal deflection. Both the amount of tooth tissue lost and the location of the loss were found to decrease tooth stiffness (Morin & others, 1988; Reeh & others, 1989; Panitvisai & Messer, 1995). Even a small reduction in tooth structure, such as an occlusal cavity preparation, has been reported to produce a significant decrease in tooth rigidity (Hood, 1991). Reeh and others (1989) also determined that the loss of each surface resulted in an approximate 20% decrease in stiffness. Deeper cavity preparations have also been related to a higher cuspal deflection. Accordingly, Hood (1991) argued that the high fracture rate of endodontically treated teeth may be caused by cavities being deeper than in vital teeth. In contrast, Reeh and others (1989) considered that endodontic procedures had only a limited effect on the overall stiffness of the tooth, and the preservation of marginal ridge integrity was described as the greatest contributing factor to the loss of tooth strength (Mondelli & others, 1980).

It was reported that the extent of cusp flexure is also dependent on the magnitude and duration of the load (Jantarat & others, 2001a). The tooth type, direction of the loads and slope of the cuspal inclines also appear to be important in tooth fracture resistance (Panitvisai & Messer, 1995).

Therefore, the measurement of crown deformation associated with caries removal and cavity preparation procedures is important in operative dentistry to optimize cavity designs and subsequent restoration (Jantarat & others, 2001b). Mechanical loading has been considered one of the factors responsible for marginal leakage (Qvist, 1993), with independent movement of the tooth and restoration compromising the bond between them.

This study evaluated the effect on cuspal deflection of the premolars of each sequential cavity preparation procedure (including endodontic access) and the magnitude of occlusal loading, applying a non-destructive test that allowed each tooth to be used as its own baseline.

METHODS AND MATERIALS

Intact non-carious human maxillary first premolars extracted for orthodontic reasons were collected. The teeth were cleaned and stored in buffered saline with 0.5% thymol at 4°C until use. After visual and stereomicroscopic examination, ten teeth free of cracks or other defects, which had regular occlusal anatomy and were of similar crown size, were selected.

Each tooth was mounted vertically in a plastic ring with acrylic resin (Ortocryl EQ, Dentautum, Germany), leaving 2 mm of the root surface exposed to simulate the support of alveolar bone in a healthy tooth.

A small concavity was made with a diamond bur on the outer surface within the enamel at 0.5 mm below both cusp tips. A small glass ball 2-mm in diameter was bonded on each concavity. The effect of the different cavity preparations and occlusal loadings on cuspal flexure was determined by measuring the distance between the two balls to the nearest 0.001 mm using a digital caliper (Mitutoyo, Japan).

Each mounted specimen was attached to the lower platen of a universal testing machine (Electrotest 500, SAE-Ibertest, Spain) and subjected to occlusal loading by means of a steel cylinder (17 mm in length and 4.5 mm in diameter) applied perpendicular to the long axis of the tooth, contacting the cuspal inclines of the buccal and palatine cusps simultaneously (Figures 1 and 2). The teeth were sequentially subjected to 50, 100 and 150 N loads with a crosshead speed of 5 mm/minute.

The effect of increasing loading on the intercuspal distance was measured sequentially for each cavity preparation. This repeated testing of the same tooth allowed the comparison of distances relative to the baseline

Table 1: *Dimensions of the Different Cavity Preparations Evaluated*

	Conservative Preparation	Extensive Preparation	MO Preparation with Endodontic Access	MOD with Endodontic Access
Occlusal width	2 mm	2.5 mm	3 mm	3.5 mm
Occlusal depth	2.5 mm	2.5 mm	7 mm	7 mm
Proximal width	2.5 mm	3 mm	3.5 mm	4 mm
Gingival floor depth	1 mm above cemento-enamel junction	1 mm above cemento-enamel junction	Cemento-enamel junction	Cemento-enamel junction
Axial wall depth	1.5 mm	2 mm		

value. In order to simulate clinical conditions, the sequence of cavity preparations was as follows: unaltered tooth, conservative MO cavity preparation, a more extensive MO preparation, MO preparation with endodontic access and MOD preparation with endodontic access. Table 1 shows the cavity dimensions. The cavity width was one-quarter of the intercuspal distance in conservative MO preparations, with one-third or more of this distance in extensive ones. In the endodontic access step, all remaining dentin between the mesial proximal box and the pulp chamber was removed and, in the MOD cavity preparation, all remaining dentin between the distal proximal box and the pulp chamber was also removed. The cuspal enamel was supported by dentin in all cavity preparations.

Each load tested was maintained for 30 seconds before the intercuspal distance was recorded. To allow for delayed cusp recovery, there was 15-minute period of unloaded time after application of the 150 N load. After this recovery time and before preparation of a new cavity design, the intercuspal distance was again measured to ensure that it was the same as the distance recorded at the beginning of the experiment.

All measurements were performed by the same operator. Ten consecutive measurements were recorded for each specimen and experimental situation, and the mean was used for the subsequent statistical analysis.

Statistical Analysis

The effect on cuspal deflection to the extent of cavity preparation and magnitude of simulated occlusal load was analyzed by Friedman test ($p < 0.05$). After finding significant differences, multiple post-hoc comparisons were carried out using the Wilcoxon test for paired samples, corrected by the Bonferroni method for three comparisons for the influence of occlusal loading ($p \leq 0.017$) and for 10 comparisons of the effects of cavity preparation ($p \leq 0.0051$). All data were analyzed by means of SPSS 11.0 for Windows software (SPSS Inc, Chicago, IL, USA).

RESULTS

The intercuspal distances obtained for each type of cavity preparation and the occlusal load applied evaluated are shown in Table 2.

The extent of cavity preparation and magnitude of the occlusal load was detected. Under a load of 50 N, only the MOD cavity preparation with endodontic access produced a statistically significant increase in cuspal flexure. Under loads of 100 and 150 N, both conservative and more extensive MO cavity preparations were associated with a significant increase in cuspal flexure, with no differences between conservative and more extensive preparations. In the MO cavity preparation with endodontic access, a statistically significant

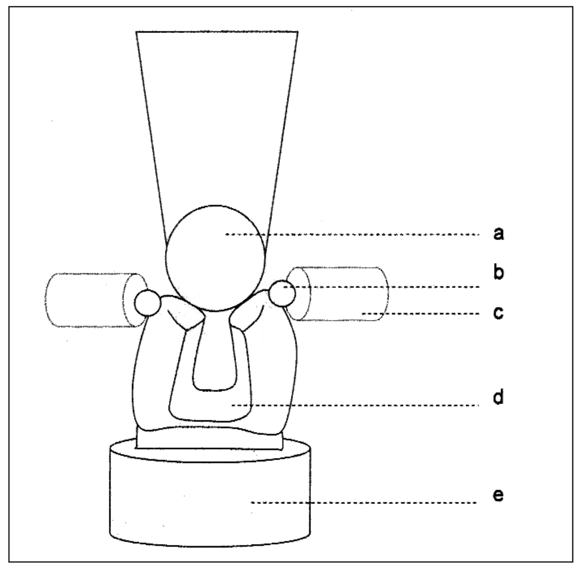

Figure 1: *a) Steel loading cylinder (4.5 mm in diameter) in contact with the cuspal inclines; b) Glass balls 1.5 mm in diameter bonded at 0.5 mm below the cusp tip; c) Mitutoyo micrometer callipers; d) Cavity preparation; e) Acrylic ring in which the tooth was vertically mounted and covered up to 2 mm from cemento-enamel junction.*

Table 2: *Mean Cuspal Displacements (a) and Standard Deviations (in µm) Associated with Each Cavity Preparation and Occlusal Load Applied*

Cavity Preparation	50 Newtons x (sd)		100 Newtons x (sd)		150 Newtons x (sd)		Global Comparison
Unaltered teeth	0.3 (1.6)	1 a	0.8 (1.6)	1. 2 a	2.6 (1.4)	2 a	p<0.01
Conservative MO	2.9 (2.8)	1 a	5.4 (2.8)	2 b	7.2 (3.6)	3 b	p<0.001
Extensive MO	3.8 (2.5)	1 a	5.8 (2.6)	2 b	8.0 (2.7)	3 b	p<0.001
MO with endodontic access	5.9 (2.3)	1 a	10.3 (3.4)	2 b	14.3 (5.4)	3 c	p<0.001
MOD with endodontic access	27.8 (8.5)	1 b	56.2 (16.4)	2 c	114.4 (53.9)	3 d	p<0.001
Global comparison		p<0.001		p<0.001		p<0.001	

In each column, the means designated by the same letter are not significantly different (no influence of cavity preparation).

In each row, the different numbers show the statistically significant influence of occlusal loading on cuspal flexure.

a: The mean cuspal distance for the unaltered teeth and no load was 9669 microns (SD=508). The figures in the table indicate the absolute increase from that distance. Some figures for unaltered teeth are below the accuracy of measurements (about 1 micron). Although they represent means, the clinical significance of those figures should be interpreted with caution.

increase in intercuspal distance was only produced when a load of 150 N was applied. In contrast, the MOD cavity preparation with endodontic access step showed significantly increased cuspal flexure under all three loads tested.

In all cavity preparations, the application of greater occlusal loads produced a statistically significant increase in intercuspal distance. In unaltered teeth, significant differences were only detected between loadings of 50 and 150 N.

DISCUSSION

In this study, incremental cusp displacement with sequential cavity preparation and increasing loading was observed. Cuspal flexure was determined by linear displacement of the cusps in a non-destructive test, allowing assessment of the relative effects of sequential cavity preparation and loading magnitude on tooth strength (Linn & Messer, 1994), because each unaltered tooth could be used as its own control (Reeh & others, 1989). This approach minimizes the effect of variations in morphology and stiffness among teeth that have been reported to increase after cavity preparation (Jantarat & others, 2001b). Accordingly, only a small sample size is required to achieve statistical significance, improving the efficiency of the experimental design and statistical analysis (Reeh & others, 1989; Linn & Messer, 1994; Panitvisai & Messer, 1995).

In order to measure the maximum cuspal displacement produced, small glass balls used as reference points were bonded as close as possible to cusp tips (Panitvisai & Messer, 1995). The use of two glass balls allowed for measurements to be taken using a digital caliper in different planes without affecting the cuspal displacement recorded. Linear displacement of the cusps has been previously reported using other devices, such as Linear Variable Differential Transformers (LVDTs) and Direct Current Differential Transformers (DCDTs) (Panitvisai & Messer, 1995) that have been reported to be highly sensitive to the vertical angle of tilt (Jantarat & others, 2001b). Another method of assessing cuspal deflection is by measuring the strain generated within the deformed cusp using strain gauges (Morin & others, 1988; Reeh & others, 1989; Sakaguchi & others, 1991; Jantarat & others, 2001b).

In this study, loads of 50, 100 and 150 N were selected to evaluate the effect of increased loading on cuspal deflection; these are within the range of loads commonly applied to maxillary premolars during normal biting (DeLong & Douglas, 1983; Tortopidis & others, 1998) and have been widely used in numerous studies with no reported damage (Reeh & others, 1989; Linn & Messer, 1994; Panitvisai & Messer, 1995). According to Jantarat and others (2001a), loads of up to 300 N can be safely applied without tooth fracture.

Figure 2: *Premolar with MOD cavity preparation, showing both the loading cylinder in contact with the cuspal inclines and the glass balls fixed at 0.5 mm from the cusp tips.*

Only the application of 150 N produced a significant effect on cuspal deflection in intact teeth, which agreed with studies conducted by Panitvisai and Messer (1995) and Jantarat and others (2001a,b), who reported that intact teeth behave very stiffly and show very little deformation under load.

When a load of 50 N was applied, the progressive removal of dental tissue was associated with an increased cuspal flexure, although a statistically significant increase was only observed in MOD preparations with endodontic access. However, when 100 and 150 N loads were applied, removal of the mesial marginal ridge was sufficient to produce a significant reduction in tooth stiffness. Mondelli and others (1980); Reeh and others (1989) and Hansen, Asmussen and Chistiansen (1990) reported this marked effect of the loss of the marginal ridge on tooth stiffness. According to their studies, the ridge should be preserved, whenever possible, to maintain tooth strength.

Conservative and more extensive MO preparations exhibited similar behavior under all three loads. Therefore, an increase in the width of the isthmus produced no effect on cuspal deflection. This factor, which made a smaller contribution to tooth weakening compared with cavity depth (Blaser & others, 1983), was previously reported, along with preservation of other strategic structures, such as the remaining dentin above the pulp chamber and the distal marginal ridge.

With the endodontic access procedure, the cavity floor serves as the floor of the pulp chamber, and this marked increase in cavity depth resulted in a doubling of cuspal flexure when a load of 150 N was applied. This major weakening effect of cavity depth was also reported by Panitvisai and Messer (1995). On the other hand, under a load of 100 N, Reeh and others (1989) found only minimal reductions in the stiffness of teeth prepared in this way.

Removal of the distal marginal ridge led to a dramatic increase in cuspal movement under all three loads tested, which agreed with observations by Linn and Messer (1994) and Jantarat and others (2001a). No fractures were observed, despite the large cusp displacements recorded. In MOD preparations with endodontic access, the two cusps were virtually isolated, since all remaining dentin between the access opening and proximal boxes was eliminated, producing a much larger cuspal deflection according to Panitvisai and Messer (1995). Jantarat and others (2001b) also observed a change in pattern of cuspal deflection from a predominantly flexural deformation to a bulk displacement due to a wedging apart of the cusps without deformation.

The overall deformation of the tooth is a function of the elastic properties of the dentin (Sakaguchi & others, 1991), which may explain why each progressive increase in 50 N loading resulted in a two-fold increase in cuspal movement (27.8 µm, 56.2 µm and 114.6 µm). These cuspal displacements are higher than those reported by Panitvisai and Messer (1995). It may be that continuous and prolonged loading, which allowed no time for delayed cusp recovery, produced an incremental cusp displacement due to the viscoelastic properties of dentin (Jantarat & others, 2001a).

Cuspal deflection associated with cavity preparation procedures should be taken into account in the selection of an appropriate restorative material, especially in patients with occlusal problems. Traditional amalgam restores tooth contour and occlusion but does not strengthen the weakened tooth, since the restoration does not bond to tooth structure and is entirely mechanically retained (Morin, DeLong & Douglas, 1984; Mondelli & others, 1980; Reeh & others, 1989; Hood, 1991; Panitvisai & Messer, 1995). The application of bonding techniques to amalgam restorations has been reported to produce a partial recovery of lost rigidity (Zidan & Abdel-Keriem, 2003). Nevertheless, contradictory results have been obtained for more extensive cavity preparations (Bonilla & White, 1996; Oliveira, Cochran & Moore, 1996; Lindemuth, Hagge & Broome, 2000). Most of these studies demonstrated that adhesively bonded composite restorations significantly reinforce cuspal strength in conservative cavity preparations (Blaser & others, 1983; Morin & others, 1984; Reeh & others, 1989; Medige & others, 1995; Ausiello & others, 1997; Zidan & Abdel-Keriem, 2003). However, the cuspal rigidity of unaltered teeth is never fully recovered (Molinaro, Diefenderfer & Strother, 2002). Moreover, polymerization shrinkage of composite restorations produces an inward cuspal movement that is larger, with greater cavity size, and may act as a preloading, facilitating tooth fracture under occlusal loads (Meredith & Setchell, 1997; Ausiello & others, 2001).

In the case of posterior pulpless teeth, *in vitro* (Linn & Messer, 1994) and *in vivo* studies (Sorensen & Martinoff, 1985) have shown the importance of complete cuspal covering restorations to decrease failure rates.

CONCLUSIONS

The progressive removal of dental tissue and the application of higher loads significantly increased cuspal deflection.

The effects of tooth rigidity on the elimination of strategic dental structures such as marginal ridges and dentin above the pulp chamber were especially marked under higher loads. Elimination of the distal marginal ridge in MOD cavity preparations with endodontic access led to a dramatic increase in cuspal movement under all three loads tested.

(Received 14 September 2004)

References

Ausiello P, de Gee AJ, Rengo S & Davidson CL (1997) Fracture resistance of endodontically treated premolars adhesively restored *American Journal of Dentistry* **10** 237-241.

Ausiello P, Apicella A, Davidson CL & Rengo S (2001) 3D-finite element analyses of cusp movements in human upper premolar, restored with adhesive resin-based composites *Journal of Biomechanics* **34** 1269-1277.

Blaser PK, Lund MR, Cochran MA & Potter RH (1983) Effects of designs of Class II preparations on resistance to fracture *Operative Dentistry* **8(1)** 6-10.

Bonilla E & White SN (1996) Fatigue of resin-bonded amalgam restorations *Operative Dentistry* **21(2)** 122-126.

Caron GA, Murchison DF, Cohen RB & Broome JC (1996) Resistance to fracture of teeth with various preparations for amalgam *Journal of Dentistry* **24** 407-410.

DeLong R & Douglas WH (1983) Development of an artificial oral environment for the testing of dental restoratives. Bi-axial force and movement control *Journal of Dental Research* **62** 32-36.

Douglas WH, Sakaguchi RL & DeLong R (1985) Frictional effects between natural teeth in an artificial mouth *Dental Materials* **1** 115-119.

El-Badrawy WA (1999) Cuspal deflection of maxillary premolars restored with bonded amalgam *Operative Dentistry* **24(4)** 337-343.

Hansen EK, Asmussen E & Chistiansen N (1990) *In vivo* fractures of endodontically treated posterior teeth restored with amalgam *Endodontics & Dental Traumatology* **6** 49-55.

Hood JAA (1991) Biomechanics of the intact, prepared and restored tooth: Some clinical implications *International Dental Journal* **41** 25-32.

Jantarat J, Palamara J & Messer H (2001a) An investigation of cuspal deformation and delayed recovery after occlusal loading *Journal of Dentistry* **29** 363-370.

Jantarat J, Panitvisai P, Palamara JEA & Messer HH (2001b) Comparison of methods for measuring cuspal deformation in teeth *Journal of Dentistry* **29** 75-82.

Larson T, Douglas W & Geistfeld R (1981) Effect of prepared cavities on the strength of teeth *Operative Dentistry* **6(1)** 2-5.

Lindemuth JS, Hagge MS & Broome JS (2000) Effect of restoration size on fracture resistance of bonded amalgam restorations *Operative Dentistry* **25(3)** 177-181.

Linn J & Messer HH (1994) Effect of restorative procedures on the strength of endodontically treated molars *Journal of Endodontics* **20** 479-85.

Medige J, Deng Y, Xinyi Y, Davis EL & Joynt RB (1995) Effect of restorative materials on cuspal flexure *Quintessence International* **26** 571-576.

Meredith N & Setchell DJ (1997) *In vitro* measurement of cuspal strain and displacement in composite restored teeth *Journal of Dentistry* **25** 331-337.

Molinaro JD, Diefenderfer KE & Strother JM (2002) The influence of a packable resin composite, conventional resin composite and amalgam on molar cuspal stiffness *Operative Dentistry* **27(4)** 516-524.

Mondelli J, Steagall L, Ishikiriama A, De Lima Navarro MF & Soares F (1980) Fracture strength of human teeth with cavity preparations *Journal of Prosthetic Dentistry* **43** 419-422.

Morin DL, DeLong R & Douglas WH (1984) Cusp reinforcement by the acid-etch technique *Journal of Dental Research* **63** 1075-1078.

Morin DL, Douglas WH, Cross M & DeLong R (1988) Biophysical stress analysis of restored teeth: Experimental strain measurement *Dental Materials* **4** 41-48.

Oliveira JP, Cochran MA & Moore BK (1996) Influence of bonded amalgam restorations on the fracture strength of teeth *Operative Dentistry* **21(2)** 110-115.

Pane ES, Palamara JEA & Messer HH (2002) Stainless steel bands in endodontics: Effects on cuspal flexure and fracture resistance *International Endodontic Journal* **35** 467-471.

Panitvisai P & Messer HH (1995) Cuspal deflection in molars in relation to endodontic and restorative procedures *Journal of Endodontics* **21** 57-61.

Qvist V (1993) Resin restorations: Leakage, bacteria, pulp *Endodontics & Dental Traumatology* **9** 127-152.

Reeh ES, Messer HH & Douglas WH (1989) Reduction in tooth stiffness as a result of endodontic and restorative procedures *Journal of Endodontics* **15** 512-516.

Sakaguchi RL, Brusr EW, Cross M, DeLong R & Douglas WH (1991) Independent movement of cusps during occlusal loading *Dental Materials* **7** 186-190.

Sorensen JA & Martinoff JT (1985) Endodontically treated teeth as abutments *Journal of Prosthetic Dentistry* **53** 631-636.

Tortopidis D, Lyons MF, Baxendale RH & Gilmour WH (1998) The variability of bite force measurements between sessions, in different positions within the dental arch *Journal of Oral Rehabilitation* **25** 681-686.

Zidan O & Abdel-Keriem U (2003) The effect of amalgam bonding on the stiffness of teeth weakened by cavity preparation *Dental Materials* **19** 680-685.