Load-induced Stresses in Photoelastic Primary Canines with Facial Restorations

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ABSTRACT

Purpose: The purpose of this study was to photoelastically compare the stresses generated by loads on primary canines with facial restorations of different stiffness.
Methods: Composite photoelastic models of a typical maxillary primary canine were fabricated using individual simulant materials for enamel, dentin, periodontal ligament, and alveolar bone. Models were made with identical facial preparations included either near the cementoenamel junction or at 2 mm incisally. The model teeth were restored using the following materials of disparate elastic moduli: (1) high modulus, hybrid composite (Herculite XRV); and (2) lower modulus compomer (Dyract). Three replications of each type of restored tooth were fabricated. Simulated masticatory forces were applied on the cusp tip and the cingulum of each tooth model. The resulting stress patterns were observed and recorded photographically in the field of a circular polariscope.
Results: Prior to load application, similar low-level, polymerization-induced shrinkage stresses were localized at the preparation margins of all models. Under both incisal and cingular loading, the higher modulus hybrid composite tended to concentrate stress along the gingival and proximal margins more than did the lower modulus compomer. This effect was more pronounced with cingular than with incisal loading. For both preparations and restoratives, higher stresses were produced by the cingulum loading. No significant differences were observed within each group of replicated restored models.
Conclusion: These results suggest that, regardless of preparation height, lower modulus compomer restoration of facial lesions in primary maxillary canines may reduce stress production by occlusal forces. (J Dent Child 2006;73:170-174)

KEYWORDS: PHOTOELASTIC EVALUATION, FACIAL RESTORATION, COMPOSITE, COMPOMER, PRIMARY CANINE

The pediatric dentist is continually challenged with the restoration of cervical lesions in primary anterior teeth and should be aware of the potential effects of abfractive forces in such instances. Abfractive forces can have negative effects on restorations of cervical lesions.[1] Abfraction is dependent on the magnitude, duration, direction, frequency, and location of the forces. Abfraction causes flexure and ultimate material fatigue of susceptible teeth at locations away from the point of loading.[1,2] A complication with the primary dentition is that abfractive forces encountered are constantly changing due to normal resorption and resultant changes in crown-root ratio.

Occlusal loading is the initiating factor in the development of abfraction lesions. Although masticatory forces are a major contributing factor, they are unlikely to be entirely responsible. Intraoral chemical influences and toothbrush abrasion, combined with the dynamics of chewing, swallowing, and parafunction, lead to stress corrosion and may also contribute to abfraction lesions.[3]

The practitioner has a variety of restorative materials available for the restoration of Class V lesions in primary canines. Restorative choices have been: (1) amalgam; (2) composite; (3) compomer; or (4) glass ionomer. These materials have different characteristics, and the stiffness of the material may play a role in the longevity of the restoration.

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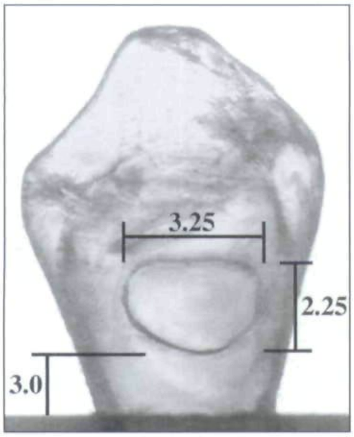

Figure 1. Two identical Class V preparations at different heights from the cementoenamel junction. Left: low preparation; right: high preparation.

A survey was conducted in Europe to see which dental materials were being used to restore the primary anterior dentition. Composite resins were the material of choice in Nice, France, whereas in Amsterdam, The Netherlands, compomers (ionomer modified composites) were preferred.[4] Compomers are good materials for Class V restorations, since they provide excellent esthetics and bond well to tooth structure when the currently available adhesives are used.[5] Oberholzer, Grobler, and Rossouw found that Dyract Flow exhibited significantly more polymerization shrinkage when compared to 3 different composites with a higher modulus.[6] An increase in the amount of fillers in the composition of the material leads to a decrease in polymerization shrinkage, while an increase in the monomer concentration gives rise to more shrinkage. The authors suggest that:

1. The stress that builds up during the polymerization process is reduced by stress relaxation of the material.
2. The shrinkage of the flowables is, therefore, counteracted by their reduced stiffness.[6]

The aforementioned studies lend credence to the clinical utilization of low modulus restoratives for the restoration of Class V lesions in primary teeth. The rationale for the utilization of a low modulus restorative material, however, has not been studied biomechanically.

The purpose of this study was to photoelastically compare the stresses generated by loads on primary canines with Class V restorations of different stiffness.

METHODS

MODEL PREPARATION

A typical primary maxillary canine was chosen for study. This tooth was selected because it is among the last primary teeth to exfoliate and, therefore, represents the greatest restorative challenge. Life-size master models were fabricated from an anatomically correct primary maxillary canine replica (Precision Growth and Development, 3M Unitek, Monrovia, Calif). From these models, 2 identical Class V preparations at different heights from the cervical-enamel junction (CEJ) were cut using a no. 330 bur in a high-speed handpiece. The facial dimensions of the preparations are shown in Figure 1. The depths of the preparations were 1.25 mm. The varied heights of the preparations were utilized to represent early to late exfoliative changes.

The coronal portions of the prepared tooth models were reduced by 1 mm to represent the enamel thickness. Models were made separately for enamel and dentin portions, from which individual molds for enamel portion and entire tooth were fabricated. Using sequential modeling techniques, composite 3-dimensional models of the typical primary maxillary canine were fabricated for quasi-3-dimensional photoelastic stress analysis utilizing the techniques described by Kuroe et al.[1,7] Individual materials were used to simulate: (1) enamel (PLM-1, Photolastic Division, Measurements Group, Inc, Raleigh, NC); (2) dentin (PL-2, Photolastic Division, Measurements Group, Inc); (3) periodontal ligament (Solithane, Uniroyal Chemical Co, Inc, Middlebury, Conn); and (4) alveolar bone (PL-2; Table 1).

Table 1. Photoelastic Modeling Materials

Tissue	Simulant	Modulus of E (MPa)	Poisson's ratio, v
Dentin	PL-2*	207	0.42
Enamel	PLM-1*	2931	0.36
Alveolar bone	PL-2*	207	0.42
PDL	Solithane†	7	0.45

*Photoelastic Division, Measurements Group, Inc, Raleigh, NC.
†Uniroyal Corp, Middlebury, Conn.*

Table 2. Restorative Materials

Composite type	Manufacturer	Modulus (psi x 106)	GPa
Hybrid composite resin (Herculite XRV)	Kerr, Sybron Dental Specialties, Inc, Orange, Calif	1.38	9.5
Flowable compomer (Dyract Flow)	Dentsply Caulk Milford, Del	0.87	6.0

First, PLM-1 was poured into the mold for the enamel portion. The cured enamel crown portion was placed into the mold of the entire tooth, and PL-2 was then poured into this mold. The completed tooth model was embedded into a socket made in a supporting bone model.

For this study, normal alveolar bone support was defined as the alveolar crest located 2 mm below the facial CEJ. The alveolar bone model was a block with cross section dimensions of 20 x 20 mm and 25 mm in height (PL-2). The alveolar socket was located within the center of the bone model and was 12 mm deep. The socket was formed larger than the root to provide space for a 0.3-mm thick periodontal ligament (PDL)simulant.

COMPOSITE PLACEMENT

Micromechanical retention of the Class V preparations was attained by a 10-second air abrasion treatment. The preparations were gently cleansed with alcohol to clear away debris. A resin bonding system was placed onto the preparations following the manufacturer's instructions (Single Bond, 3M ESPE, St. Paul, MN). Specimens were restored with a hybrid

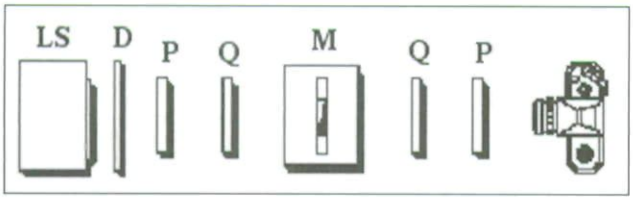

Figure 2. Circular polariscope arrangement for visualization of isochromatic fringes. LS=light source; D=diffuser; P=polarizer; Q=quarter-wave plate; M=model.

composite resin (Herculite XRV, Shade A1, Sybron-Kerr, Inc, Orange, Calif) or a flowable compomer resin with a lower modulus (Dyract Flow, Dentsply Caulk, Milford, Del; Table 2). The photoelastic models were restored utilizing a bulk fill technique.[8-10] Composite was cured to manufacturer's recommendations (40 seconds) using a traditional halogen light on both the buccal and lingual surfaces (Optilux 400, Dementron Research Corp, Danbury, Conn).

After polymerization, the margins were finished carefully using finishing burs and fine abrasive. All filling techniques and finishing procedures were done under a stereo microscope at X15 magnification.

LOADING OF MODELS

Loads of 10 lbs were applied to the cusp tip and cingulum parallel to the tooth's long axis as bounding conditions of masticatory contacts. This load level was selected because it:

1. is a realistic functional load level[11-13]; and
2. provided a satisfactory optical response without leaving any permanent deformation within the models.

Loads were applied in a straining frame by means of a calibrated load cell mounted on the movable head of a loading frame. Loads were monitored by a digital readout after signal treatment using a strain gauge conditioner (model nos. 2130 and 2120A, Instruments Division, Measurements Group).

The models were immersed in a tank of mineral oil to minimize surface refraction and, thereby, facilitate photoelastic observation. Under load, the stress within the model caused the light to be refracted, producing a pattern of colored lines called stress fringes.[14] The interpretation of photoelastic patterns is based upon the number and proximity of these stress fringes adjacent to the composite. The more stress fringes present, the higher the stress generated. When the fringes in the photoelastic model are closer, the stresses are more concentrated.[8] The resulting stresses within the tooth model were monitored and recorded photographically in the field of a circular polariscope arrangement (Figure 2).

RESULTS

RESTORATIVE POLYMERIZATION STRESS

The photoelastic models with restorations were evaluated in the circular polariscope before loads were applied in order to evaluate for preload stress. Polymerization-induced shrinkage stress fringes were localized at the preparation margins of models with both restoratives. Models with the high modulus composite (Herculite XRV) exhibited higher level stress

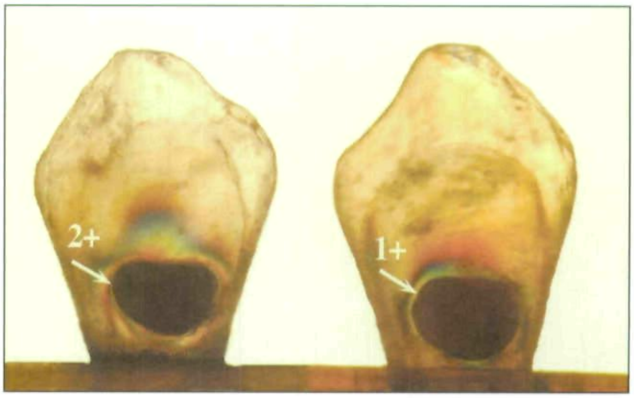

Figure 3. Polymerization shrinkage stresses. Left: high modulus restorative; right: low modulus restorative.

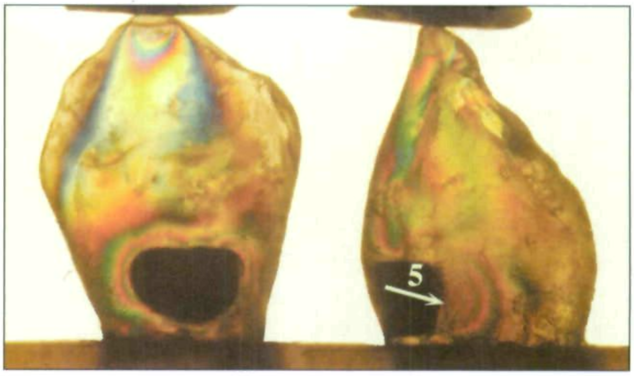

Figure 4. Low preparation with high modulus restorative under a cuspal load of 10 lbs.

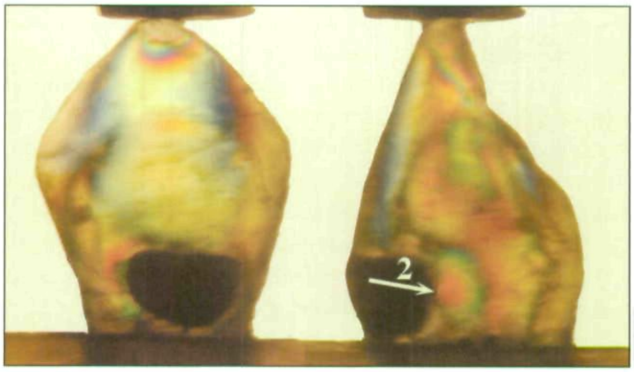

Figure 5. Low preparation with low modulus restorative under a cuspal load of 10 lbs.

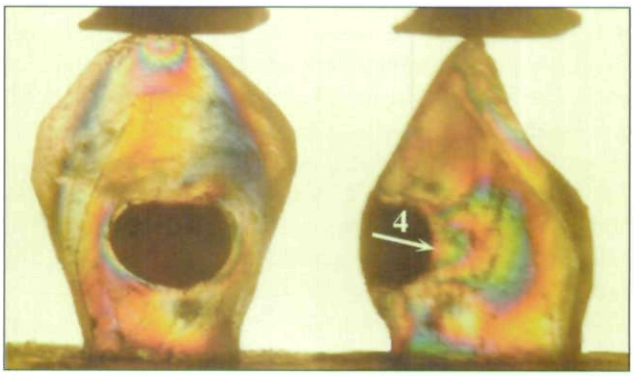

Figure 6. High preparation with high modulus restorative under a cuspal load of 10 lbs.

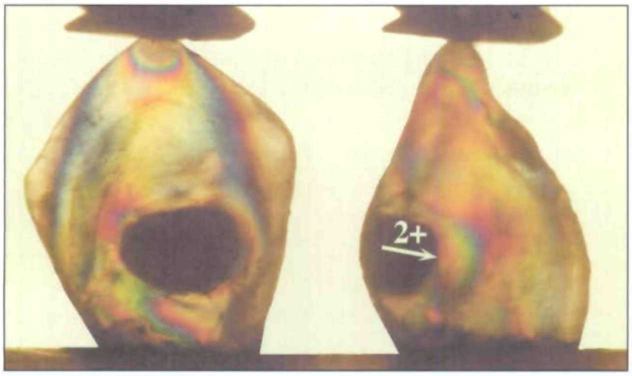

Figure 7. High preparation with low modulus restorative under a cuspal load of 10 lbs.

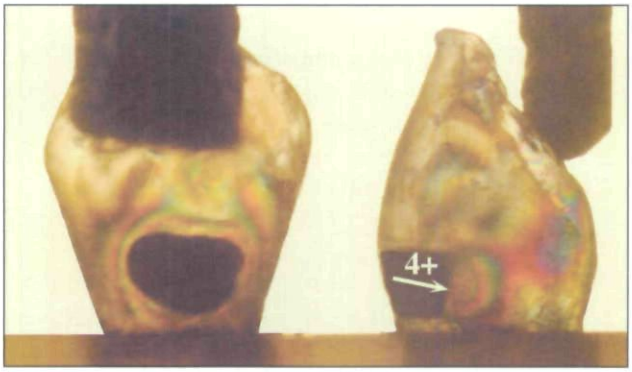

Figure 8. Low preparation with high modulus restorative under a cingulum load of 10 lbs.

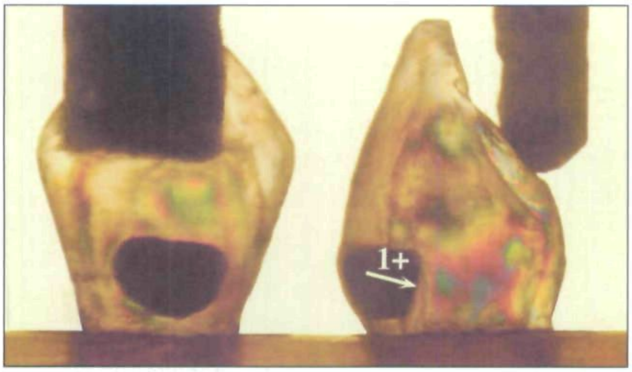

Figure 9. Low preparation with low modulus restorative under a cingulum load of 10 lbs.

(Figure 3L) than models with the low modulus compomer (Dyract Flow; Figure 4r).

CUSPAL LOADING

The effects of cuspal loading on the low preparation models are shown in Figures 4 and 5. With the high modulus composite, stresses were concentrated at the margins (2 to 3 fringes). Very high stress (5 fringes) developed along the internal axial wall. With the low modulus compomer, a similar stress response was observed, but at much lower intensity: 1+ fringe at the margin; 2 fringes internally.

For the high preparation, lower stresses were seen for both restoratives than with the low preparation (Figures 6 and 7). The stresses again tended to localize at the margins (2 fringes for high modulus, 1+ for low modulus) and at the internal axial wall. (4 fringes for high modulus, 2+ for low modulus).

CINGULUM LOADING

The effects of cingular loading on the low preparation models are shown in Figures 8 and 9. A greater amount of concentrated stress was noted along the margins of the higher modulus composite (2 to 3 fringes) than on the lower modulus compomer (1+ fringe). Stresses were noted along the internal axial wall with both restoratives. The high modulus material exhibited a much higher level of stress fringes (4+ fringes) compared to 1+ fringe for the compomer.

The high preparation exhibited lower stresses (Figures 10 and 11) with both restoratives than the low preparation. The stresses tended to localize at the margins and the internal wall.

DISCUSSION

The primary maxillary canine was chosen for study since it is generally the last primary tooth to be exfoliated. Consequently, restoration of these teeth presents a challenge since the restorations must remain sound for long periods. There are a wide variety of tooth-colored materials available in clinical practice for the restoration of Class V lesions in primary teeth. Herculite and Dyract Flow were chosen for this study as they fulfilled the following criteria—the material could be:

1. light cured;
2. clinically utilized in a moisture-controlled environment; and

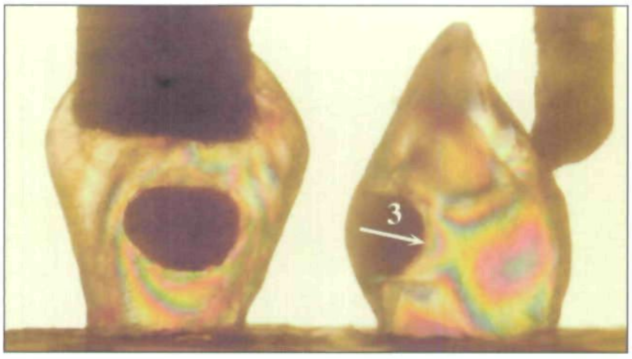

Figure 10. High preparation with high modulus restorative under a cingulum load of 10 lbs.

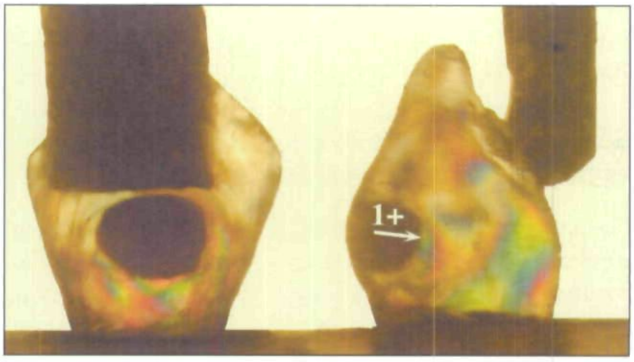

Figure 11. High preparation with low modulus restorative under a cingulum load of 10 lbs.

3. clinically representative high and low modulus materials could be utilized in this study.

The stress fringes were qualitatively evaluated rather than quantitatively assessed. As part of the qualitative nature of this analysis, descriptive techniques involving the stress fringes provided a means of systematically determining the nature of the load placed through direct observation. If a quantitative approach was to be applied, tools and techniques involving measurement (used to determine characteristics of the stress fringes with respect to the load) would have been employed. For the purposes of evaluation in this study, the qualitative assessments were sufficient because the stress fringes were able to be deciphered by visual examination.

The elastic moduli of the photoelastic materials used did not coincide with the dental tissues being replicated. PLM–1 and PL–2 do not have the same modulus of elasticity as enamel and dentin, respectively, but actually have a modulus lower than that of the replicated tissues. Mahoney, Holt, Swain, and Kilpatrick found that:

1. primary enamel had a mean modulus of 4.88±0.35 GPa; and
2. the modulus of dentin was 0.92.±0.11 GPa.[15]

The elastic modulus for enamel and dentin was 80.35±7.71 GPa and 19.89±1.92 GPa, respectively. Although there is a difference between the material being used to simulate the anatomical structure, the difference between the simulated material (PLM-1 and PL–2) with respect to the difference between the anatomical structures (enamel and dentin) is comparable. These materials utilized in the simulated tooth allowed the authors to fairly accurately duplicate the tooth's anatomic layers.

Abfractive forces are known to have deleterious effects on restoration longevity. This study was designed to photoelastically evaluate the restorative, which allows the least stresses within the tooth structure adjacent to the preparation. The authors have demonstrated that the lower modulus restorative produces less stress in adjacent tooth structure when compared to the higher modulus material. The clinical implications of less stress concentration with the lower modulus material are: (1) better resistance to abfractive forces; and (2) a potentially longer-lived restoration.

The photoelastic modeling technique utilized in this study—as with all modeling systems—inclusive of finite element analysis, mathematic models, or strain gauge studies, have limitations when predicting the response of biologic systems to applied loads. All of these systems can indicate, under carefully controlled conditions, however, where potential stress-related differences may arise. The results of the photoelastic information obtained in the present investigation may suggest relative guidelines for restoring Class V preparations in primary canines with materials of different stiffness.

CONCLUSIONS

Load-induced stresses by identical Class V preparations on maxillary primary canine models of varying distance from the CEJ restored with materials of different moduli were compared photoelastically. This study's results indicate the following:

1. The effect of restorative material stiffness depended on the location of the cavity preparation in relation to the cementoenamel junction (CEJ). The further the preparation from the CEJ, the less relevance that varying moduli had on stress concentrations.
2. Regardless of the incisal-gingival position of Class V facial, lower modulus restorative materials reduced stress production originating from simulated masticatory abfractive forces.

Putatively, clinical utilization of low modulus restoratives for the restoration of primary anterior teeth as well as canines should allow longer restoration longevity as a result of reduced stress production from abfractive masticatory forces.

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