Analysis of Primary Tooth Dentin After Indirect Pulp Capping

Juliana J. Marchi, DDS, MS   Andrea M. Froner, DDS
Hugo L.R. Alves, DDS, MS   Carlos P. Bergmann, DDS, MS, PhD
Fernando B. Araújo, DDS, MS, PhD

ABSTRACT

Purpose: The purpose of this study was to evaluate the characteristics of primary molar dentin after indirect pulp capping (ICP) by of color, consistency and microhardness analyses.
Methods: The study design consisted of 3 groups: a test group of 13 primary molars that had been submitted to ICP with either calcium hydroxide or resin-modified glass ionomer cement; a positive control group of 15 sound molars; and a negative control group of 15 molars with deep acute carious lesions. The test group teeth had their restorations and pulp-capping materials removed and their cavity depth measured (mean depth=3-4 mm). In the positive control group, 3- to 4-mm-deep cavities were prepared. In the negative control group, the infected dentin was removed following the same parameters used for dentin excavation in a previous study by the authors. In all groups, the remaining dentin was analyzed according to descriptive standards (consistency and color). Microhardness was performed by a calibrated examiner blinded to the groups. Data were analyzed statistically by 1-way analysis of variance and Tukey's test ($P<.01$).
Results: The dentin of all teeth in the test group became hard. Nine teeth had yellow-clear dentin, and 4 teeth had dark-brown dentin. Microhardness means (±SD) were: test group=40.81 (±16.28) KHN (Knoop hardness number); positive control group=62.73 (±11.24) KHN; and negative control group=19.15 (±6.99) KHN. Microhardness assessment showed no statistically significant differences ($P<.01$) among the groups.
Conclusion: This study's results suggest a mineral gain by the affected dentin after IPC, regardless of the protective base material.
(J Dent Child 2008;75:295-300)

Received April 16, 2007; Last Revision September 28, 2007; Revision Accepted December 10, 2007.

KEYWORDS: INDIRECT PULP CAPPING, DENTIN CARIOUS LESIONS, GLASS IONOMER CEMENT, REMINERALIZATION, MICROHARDNESS

Indirect pulp capping technique (**IPC**) is well-documented as a conservative treatment of the dentino-pulpar complex. IPC may be a definitive treatment for the primary dentition, as primary teeth have a defined biological cycle in the oral cavity. Studies[1,2] conducted to improve the understanding of the histopathology of dentin carious lesions have shown evidences that IPC can be completed in a single clinical session. The satisfactory clinical and radiographic findings of previous studies with primary teeth support the choice for a one session treatment, which means no need to reopen the capped tooth within nearly 3 months.[2-10]

The findings of previous investigations have shown that calcium hydroxide does not have different clinical, radiographic, microbiological, or ultrastructural outcomes

Drs. Marchi and Froner are postgraduate students, and Dr. Araújo is associate professor , all in the Department of Pediatric Dentistry and Orthodontics, School of Dentistry. Dr. Alves is a postgraduate student, and Dr. Bergmann is associate professor, both in the Department of Materials, School of Engineering, all at Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Rio Grande do Sul, Brazil.
Correspond with Dr. Araújo at fernando.araujo@ufrgs.br

from those of inert materials, such as gutta-percha and wax. This implies that the success of the IPC does not seem to be dependent on the material placed in contact with the demineralized remaining dentin.[1,9]

Particularly in pediatric dentistry, resin-modified glass ionomer cements (**RMGICs**) may act simultaneously as base and restorative materials because of their ease of handling, advantageous mechanical characteristics compared to conventional glass ionomer cements (**GICs**), and high success rates when used as IPC materials.[10,11]

In addition to data relative to the increase of consistency suggestive of remineralization of the remaining dentin,[4,9,12-14] studies have described dentin remineralization after partial removal of carious tissue based on the increase of calcium[2] and phosphorus[1] content. Nevertheless, this information is restricted to these 2 elements evaluated within a short time interval after the procedure (approximately 3 months), and little is known about the actual mineral gain. This study's purpose was to evaluate the characteristics (color, consistency, and microhardness) of the dentin of primary molars submitted to IPC with either calcium hydroxide or RMGIC after an average time of 3 years, 8 months.

METHODS

SPECIMENS

This study comprised 3 groups. The test group was taken from a previous study of our research team[10] that included 27 primary maxillary and mandibular molars of 17 children submitted to IPC. Of these, 12 were capped with calcium hydroxide-based cement (Dycal, Dentsply/Caulk, Milford, Del) and restored with composite resin (Z250, 3M/ESPE, St. Paul, Minn), and 15 were capped and restored with RMGIC (Vitremer, 3M/ESPE). From the 22 teeth in which clinical and radiographic success was observed by Marchi et al,[10] only 13 teeth were included in the present study because 3 teeth exfoliated without being collected by the patient, 5 teeth have not exfoliated at the present time, and 1 tooth was lost due to the patient's family moving away from the contact address. These teeth were in the final phase of physiological root resorption. They underwent either natural exfoliation (each patient received a receptacle containing 5 mL sterile saline to keep the tooth, which was stored for up to 6 months) or extraction due to advanced physiological root resorption or orthodontic purposes based on a clinical-radiographic diagnosis. These 13 teeth, which had had clinical and radiographic success after an average follow-up period of 3 years, 8 months in the study by Marchi et al,[10] were selected as the test group. The positive control group consisted of 15 sound primary maxillary and mandibular molars, and the negative control group consisted of 15 primary molars with deep acute carious lesions diagnosed clinically and radiographically (these teeth were selected with the identical parameters used for the test group by Marchi et al[10]). The teeth in the positive and negative control groups were obtained after natural exfoliation or extraction for orthodontic reasons.

All children involved in this study were enrolled in a dental care program that includes routine professional monitoring of their oral health status and their oral health is maintained until the present time. The patients' parents/caregivers were instructed about the purposes of the study and read and signed an informed consent form authorizing the donation of the primary teeth. The study protocol was approved by the Ethics in Research Committee of the Federal University of Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, Brazil.

TOOTH PREPARATION

In the test group, the restorations were removed from the teeth using spherical diamond burs (KG Sorensen, São Paulo, São Paulo, Brazil) at high-speed under continuous air/water spray cooling up to close to the cavity floor. For the teeth that had been capped with calcium hydroxide-based cement, the capping material was carefully removed with a periodontal probe with no pressure on the remaining dentin. For the teeth in which RMGIC had been used, most of the material was removed with the air/water-cooled high-speed spherical diamond burs. Close to the pulpal wall floor, a magnifying lens was used and the remaining material was removed using spherical carbide burs (KG Sorensen) at low-speed, always comparing the moistness difference between dentin surface and the capping material. A calibrated examiner evaluated the color and consistency of the dentin on the cavity floor according to the criteria defined by Miller and Massler[15] and measured the depth of the cavities using sterile size 20 K-type files (Dentsply/Maillefer, Ballaigues, Switzerland).

In the positive control group, cavities were prepared in dentin with spherical diamond burs at high-speed under continuous air/water spray cooling up to a depth of 3 to 4 mm, which was the average cavity depth observed in the test group teeth after removal of the restorations. In the negative control group, the carious tissue was removed according to the same IPC parameters followed in the test group.[10] The same investigator that examined the test group's cavities prepared the positive control group's cavities and excavated the negative control group's teeth.

The investigator was previously calibrated to warrant a reliable evaluation of the color and consistency of the remaining dentin on the cavity floor, according to Miller and Massler's criteria.[15] For such purposes, the investigator examined in vitro 20 primary maxillary and mandibular molars with active and inactive deep dentin carious lesions that were stored in saline and were not included in the study. Intraexaminer reproducibility was assessed by double diagnosis after 7 days and calculated using kappa statistics. Kappa values for color and consistency were 0.83 and 0.84, respectively.

SPECIMEN PREPARATION FOR MICROHARDNESS ASSESSMENT

All group specimens were embedded in autopolymerizing acrylic resin (Clássico Dental Products, São Paulo, São Paulo, Brazil) and were sectioned longitudinally in a mesiodistal direction using a sectioning machine (Isomet 2000, Buehler, Lake Bluff, Ill) with a water-cooled 0.30-mm-thick diamond saw at low speed (3,500 rpm) and with a 250 g load.

The sections were included in acrylic resin again and polished with water-cooled, 1,200-grit silicon carbide paper for 5 minutes in a polishing machine (Strues, Copenhagen, Denmark) with a load of 100 N and speed of 150 rpm. Final polishing was done with a felt disc and a 0.5-µm diamond paste for 10 minutes. The specimens were washed in running tap water, labeled, and properly stored in closed receptacles with moist gauze.

A microhardness tester (Micromet 2001, Buehler) with a Knoop diamond indenter was used with a 10-g load for 15 seconds. Knoop hardness number (KHN) values were measured in 5 linear points. The first indentation was undertaken close to the pulp chamber at a distance of 50 µm below the occlusal cavity floor. The other indentations were undertaken towards the dentinoenamel junction, keeping a distance of 25 µm between each point. The dentin in the center of the occlusal cavity or occlusoproximal cavity was examined. For each specimen, an average value was obtained from the 5 indentations, and the KHN for each group was calculated. A single examiner (nondentist), blinded to which group each specimen belonged, performed all measurements. To warrant microhardness assessment reliability, the examiner was calibrated by performing 30 indentations in 6 primary molars (3 sound and 3 carious, not belonging to the sample) within a 1-week interval, following the same criteria as those established for the present study. The reproducibility of the examiner was assessed by student's t test, and no significant difference was found between the evaluations.

Dentin color and consistency were evaluated according to descriptive criteria using a periodontal probe as light-yellow/dark brown and soft/hard because none of the teeth showed consistency between hard and soft (leathery).[15] Dentin microhardness, according to the material used in the group test (calcium hydroxide or RMGIC), was analyzed statistically by student's t test at a 5% significance level. KHN values from the 3 groups were assessed by comparing the results of the test group to those of the positive and negative controls and analyzed statistically by 1-way analysis of variance and Tukey's post-hoc test at a 5% significance level.

RESULTS

DENTIN COLOR AND CONSISTENCY

Nine teeth in the test group presented light-yellow remaining dentin (8 teeth capped with RMGIC and 1 tooth capped with calcium hydroxide). In the other 4 teeth, dentin had a dark-brown color (1 tooth capped with RMGIC and 3 teeth capped with calcium hydroxide-based cement).

Table 1. Frequency Distribution of Color and Consistence in the Test Group (N=13) According to the Capping Material

Indirect capping material	Color		Consistency	
	Light yellow	Dark brown	Soft	Hard
Resin-modified glass ionomer cement (N=9)	8	1	0	9
Calcium hydroxide (N=14)	1	3	0	4
Total	**9**	**4**	**0**	**13**

Regarding consistency, in all 13 test group teeth, the dentin became hard (Table 1). Five teeth had 3-mm-deep cavities (all capped with RMGIC), and 8 teeth had 4-mm-deep cavities (4 capped RMGIC and 4 capped with calcium hydroxide-based cement).

MICROHARDNESS ANALYSIS

KNH values (found in Table 2) were 40.81 (±16.28), 62.73 (±11.24), and 19.15 (±6.99), respectively, for the test group, positive control group, and negative control group. Statistical analysis showed that all groups differed significantly from each other (P<.01).

Table 2. Knoop Hardness Number (KHN) Values for Test and Control Groups *

Variable	N	Means±(SD)	*P*-value
Test group	13	40.81±16.28a	
Positive control	15	62.73±11.24b	.01
Negative control	15	19.15±6.99c	

** Different letters indicate a statiscally significant difference at 5%.*

DISCUSSION

The high clinical and radiographic success rates reported in the literature, regardless of the capping material,[2,3,5,7,9,10] point to the IPC technique as a viable and definitive treatment option for active deep dentin carious lesions in primary molars.

Studies investigating the use of GICs as restorative materials have shown satisfactory results in the primary dentition in both occlusal and occlusoproximal cavities after up to 3 years of clinical and radiographic follow-up.[16-18] Few studies, however, have evaluated the use of GICs as a capping material placed in contact with the carious dentin associated with its use as a restorative material. Studies in which partial removal of carious tissue was done showed good results based on clinical-radiographic,[10] ultrastructural, and microbiological outcomes.[11] These findings suggest that the possibility of using RMGICs as base/restorative materials might make them the most indicated materials for routine pediatric dentistry practice, especially in infant patients with active deep dentin carious lesions. RMGIC has the same desirable biological and adhesive properties as, and advantages over, conventional GIC.[19] It may be considered a definitive material in the primary dentition because of the predictability of the physiological exfoliation of primary teeth.

In the present study, microhardness assessment showed no significant difference between the 2 materials (calcium hydroxide and RMGIC) used in IPC (test group), which justifies why the materials were allocated in a single group. Removal of the infected carious dentin provided favorable conditions for remineralization of the affected dentin that was intentionally preserved. Dentin remineralization was not dependent on the indirect capping agent used because both were biocompatible materials. The technique of IPC prevents possible pulpal exposures that might occur during excavation of deep carious lesions in primary teeth. This technique also presents more satisfactory clinical and radiographic outcomes compared to more invasive procedures, such as direct pulp capping or pulpotomy.[6,20,21]

Several studies in primary[2-4,9] and permanent teeth[12-14,22] have demonstrated a change of consistency of necrotic carious dentin into a more hardened tissue with a smaller number of micro-organisms after partial removal of carious tissue and IPC, which is suggestive of remineralization. This study's results agree with those of the aforementioned authors and are consistent with those of Massara et al.[2] These authors concluded that dentin consistency is a reliable clinical parameter both to limit carious dentin removal in conservative operative techniques, such as IPC, and to assess technique success in cases of two sessions treatment. These findings corroborate those of studies that used teeth with inactive carious lesions[15,23,24] or performed partial removal of carious tissue and IPC.[2,4,9,14]

Kidd[25] reported that studies using conservative techniques for removal of carious dentin present: high clinical success rates; prevention of pulpal exposures (in contrast with pulpal exposure when complete removal of carious tissue is done); changes in the remaining dentin on cavity reopening (darkened and hardened dentin); and a significant reduction of the microbiota after treatment. The author also discussed the need for reopening the cavity because the progression of carious processes occurs due to biofilm activity. This is interrupted when the cavity is adequately sealed, thus allowing remineralization of the remaining dentin by tubular sclerosis and production of tertiary dentin. This study's major contributions to clinical pediatric dentistry is the confirmation that IPC can be completed in a single session, thereby optimizing the restorative technique and minimizing the clinical chairtime, which is extremely important when dealing with pediatric patients. Our findings indicate that is not necessary to re-open the sealed cavity sometime after the restorative procedure to confirm treatment success by checking the consistency of the remaining dentin tissue.

Measurement of dentin hardness has been traditionally indicated to assess tissue mineralization and is, therefore, an important tool to evaluate the mechanical properties of calcified tissues and their caries-related alterations.[26,27] There are few studies investigating the microhardness of sound and carious primary tooth dentin. Furthermore, as far as could be ascertained, there is no study referring to the assessment of microhardness of the remaining carious dentin in primary and/or permanent teeth submitted to IPC. KHN values recorded in this study's control groups (sound dentin and active carious dentin) are similar to those reported in previous primary teeth investigations.[26,28]

Hosoya et al[26] compared the microhardness of carious and sound dentin of primary teeth and observed that, regardless of the depth (one third outer, middle, and inner regions), KHN values of carious dentin were significantly lower than those of sound dentin. The authors did not mention the characteristics of the carious lesions, however, such as activity and depth of dentin involvement. The ultrastructural analysis of the carious dentin confirmed the demineralization, which justifies the significant difference in microhardness observed between carious and sound dentin. In a recent study, Angker et al[29] reported that dentin's mechanical properties are dependent on its mineral content and, hence, the decrease in dentin microhardness is directly related to a reduction in its mineral content. During carious process progression, there is a considerable dentin mineral loss,[30] which would explain the low microhardness values observed in the negative control group. Removal of the infected dentin led to a mineral gain, as observed with the increase of microhardness in the test group, which differed significantly from the negative control group. The origin of the mineral gain is from the dentin and pulp and not from the material or saliva.[2]

Pulpal diagnosis, cavity sealing, and control of caries activity are of paramount importance for a successful treatment. A combination of a detailed clinical interview, clinical examination, and radiographic assessment is essential for correct case selection. Child enrolment in a preventive program under periodical professional supervision is also necessary for maintenance of good oral health over time.

The pediatric dentist may benefit from the remineralization process of the dentinopulpar complex in cases of increased risk of pulp exposure during caries excavation. Dentin consistency is a reliable clinical parameter to limit the removal of irreversibly denatured, infected, nonremineralizable outer carious dentin. IPC is a conservative operative technique which, if adequately indicated and performed, is a definitive one-session treatment for primary teeth with no need of scheduling the child for a second visit just for assessment of technique success. This study's outcomes suggest a mineral gain by the affected dentin after IPC, regardless of the material used as a protective base. Further longitudinal studies with longer follow-up periods should be conducted to corroborate these findings.

CONCLUSIONS

Based on these findings, the following conclusions can be made:

1. There is no need to reopen the capped tooth within nearly 3 months after indirect pulp capping.
2. Dentin consistency is a reliable clinical parameter to limit carious dentin removal in conservative operative techniques.
3. There was a mineral gain after indirect pulp capping (IPC), regardless of the material used.
4. If adequately performed and indicated, IPC may be a definitive single-session treatment for primary teeth.

REFERENCES

1. Eidelman E, Finn S, Koulourides T. Remineralization of carious dentin treated with calcium hydroxide. J Dent Res 1965;32:218-25.
2. Massara MLA, Alves JB, Brandão PRG. Atraumatic restorative treatment: Clinical, ultrastructural, and chemical analysis. Caries Res 2002;36:430-6.
3. King JB, Crawford JJ, Lindahl RL. Indirect pulp capping: A bacteriologic study of deep carious dentin in human teeth. Oral Surg Oral Med Oral Pathol 1965;20:663-71.
4. Aponte AJ, Hartsook JT, Crowley MC. Indirect pulp capping success verified. J Dent Child 1966;33:164-6.
5. Ribeiro CC, Baratieri LN, Perdigao J, Baratieri NM, Ritter AV. A clinical, radiographic, and scanning electron microscopic evaluation of adhesive restorations on carious dentin in primary teeth. Quintessence Int 1999;30:591-9.
6. Farooq NS, Coll JA, Kuwabara A, Shelton P. Sucess rates of formocresol pulpotomy and indirect pulp therapy in the treatment of deep dentinal caries in primary teeth. Pediatr Dent 2000;22:278-86.
7. Falster CA, Araujo FB, Straffon LH, Nor JE. Indirect pulp treatment: In vivo outcomes of an adhesive resin system vs calcium hydroxide for protection of the dentin-pulp complex. Pediatr Dent 2002;24:241-8.
8. Al-Zayer MA, Straffon LH, Feigal RJ, Welch KB. Indirect pulp treatment of primary posterior teeth: A retrospective study. Pediatr Dent 2003;25:29-36.
9. Pinto AS , Araujo FB, Franzon R, Figueiredo MC, Hendz S, Garcia-Godoy F, Maltz M. Clinical and microbiological effect of calcium hydroxide protection in indirect pulp capping in primary teeth. Am J Dent 2006;19:382-6.
10. Marchi JJ, Araujo FB, Fröner AM, Straffon LH, Nör JE. Indirect pulp capping in the primary dentition: A 4-year follow-up study. J Clin Pediatr Dent 2006;31:68-71.
11. Wambier DS, Guedes-Pinto AC, Simionato MRL. Ultrastructural and microbiological analysis of the dentin layers affected by caries lesions in primary molars treated by minimum intervention. Pediatr Dent 2007;29:228-34.
12. Bjørndal L, Larsen T, Thylstrup A. A clinical and microbiological study of deep carious lesions during stepwise excavation using long treatment intervals. Caries Res 1997;31:411-7.
13. Bjørndal L, Thylstrup A. A practice-based study on stepwise excavation of deep carious lesions in permanent teeth: A 1-year follow-up study. Community Dent Oral Epidemiol 1998;26:122-8.
14. Maltz M, de Oliveira EF, Fontanella V, Bianchi R. A clinical, microbiologic, and radiographic study of deep caries lesions after incomplete caries removal. Quintessence Int 2002;33:151-9.
15. Miller W, Massler M. Permeability and staining of active and arrested lesions in dentine. Br Dent J 1962;112:187-97.
16. Donly KJ, Segura A, Kanellis M, Erickson RL. Clinical performance and caries inhibition of resin-modified glass ionomer cement and amalgam restorations. J Am Dent Assoc 1999;130:1459-66.
17. Fuks AB, Araujo FB, Osorio LB, Hadani PE, Pinto AS. Clinical and radiographic assessment of Class II esthetic restorations in primary molars. Pediatr Dent 2000;22:479-85.
18. Croll TP, Bar-Zion Y, Segura A, Donly KJ. Clinical performance of resin-modified glass ionomer cement restorations in primary teeth. A retrospective evaluation. J Am Dent Assoc 2001;132:1110-6.
19. Francci C, Deaton TG, Arnold RR, Swift EJ Jr, Perdigao J, Bawden JW. Fluoride release from restorative materials and its effects on dentin demineralization. J Dent Res 1999;78:1647-54.
20. Fitzgerald M, Heys RJ. A clinical and histological evaluation of conservative pulpal therapy in human teeth. Oper Dent 1991;16:101-12.
21. Vij R, Coll JA, Shelton P, Farooq NS. Caries control and other variables associated with success of primary molar vital pulp therapy. Pediatr Dent 2004;26:214-20.
22. Bjørndal L, Larsen T. Changes in the cultivable flora in deep carious lesions following a stepwise excavation procedure. Caries Res 2000;34:502-8.
23. Sarnat H, Massler M. Microstructure of active and arrested dentinal caries. J Dent Res 1965;44:1389-401.

24. Ricketts DN, Kidd EA, Beighton D. Operative and microbiological validation of visual, radiographic, and electronic diagnosis of occlusal caries in noncavitated teeth judged to be in need of operative care. Br Dent J 1995;179:214-20.
25. Kidd EAM. How "clean" must a cavity be before restoration? Caries Res 2004;38:305-13.
26. Hosoya Y, Marshall SJ, Watanabe LG, Marshall GW. Microhardness of carious deciduous dentin. Oper Dent 2000;25:81-9.
27. Zheng L, Hilton JF, Habelitz S, Marshall SJ, Marschall GW. Dentin caries activity status related to hardness and elasticity. Eur J Oral Sci 2003;111:243-52.
28. Johnsen DC. Oral development and histology. In: *Oral Development and Histology.* Avery JA, ed. 2nd ed. New York, NY: Thieme Medical; 1994:282-96.
29. Angker L, Swain MV, Kilpatrick N. Micromechanical characterization of the properties of primary tooth dentine: J Dent 2003;31:261-7.
30. Little MF, Dirksen TR, Schlueter G. The Ca, P, Na, and Ash content at different depths in caries. J Dent Res 1965;44:362-5.