Evaluation of the carbon dioxide laser on vital human primary pulp tissue

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Abstract

Purpose: The purpose of this study was to evaluate the response of the human primary pulp to the carbon dioxide laser and formocresol for vital pulp therapy.

Methods: Fifteen healthy children with intact, caries-and restoration-free, contralateral primary cuspids with at least two-thirds of the roots remaining who were scheduled for orthodontic extraction were randomly assigned to pulpotomy treatment with a carbon dioxide laser or formocresol. The treated teeth were clinically and radiographically evaluated at 28 and 90 days post-treatment prior to extraction. The extracted teeth were evaluated histologically for pulpal response.

Results: All teeth were asymptomatic and clinically normal at both observation periods. Internal root resorption was observed in one formocresol and two laser treated teeth. There was a significant inverse correlation between the laser energy applied to the pulp and the degree of inflammation at 28 days (P=.01) but not at 90 days (P=.27).

Conclusion: Carbon dioxide laser treatment compared favorably to formocresol for pulpotomy in primary teeth.(Pediatr Dent 21:327-331, 1999)

The optimum technique for treating the exposed vital primary dental pulp continues to be elusive.[1-11] Formocresol is a widely accepted medicament for pulpotomy in primary teeth judged to have inflammation limited to the coronal pulp.[12,13] However, the use of formocresol became a concern following reports of wide tissue distribution of the medicament beyond the apices of the tooth following its use and the demonstration of an immune response to formocresol-fixed autologous tissue.[14-19]

Several medicaments,[20-24] electrosurgery,[25-27] and lasers[28-29] have been investigated in an attempt to identify a more tissue-compatible alternative to formocresol. The carbon dioxide laser has found wide application in oral and general surgery procedures involving soft tissue.[30-32] The laser emits an infrared beam at a wavelength of 10.6 m, has an affinity for water, and is capable of producing well-localized cautery to soft tissue. Tissue is removed by ablation through conversion of the laser beam to heat. Based on these characteristics and on previous studies,[28,33-35] the carbon dioxide laser appears to have promise as an alternative for pulpotomy therapy.

The purposes of this study were to clinically and histologically evaluate the response of the human primary pulp to the carbon dioxide laser and to compare the effects of the carbon dioxide laser to formocresol for direct vital pulp therapy.

Methods and Materials

Children between 6 and 10 years of age and in good health having two or four contralateral caries-and restoration-free primary cuspids that exhibited two-thirds or more root remaining, and required extraction as part of the patient's orthodontic treatment were selected for the study. The research protocol and associated consent/assent forms were reviewed and approved by the University of North Carolina (UNC) School of Dentistry Committee on Investigations Involving Human Subjects.

The intraoral soft tissues and teeth were examined and a periapical radiograph was taken of each primary cuspid to confirm that it met the inclusion criteria. A coin toss was performed to assign the first cuspid in an arch to either the test group (laser treated) or control group (formocresol). Randomization resulted in eight patients in the 28-day protocol and seven patients in the 90-day protocol. A total of 30 teeth were included in the study. The mean age of the patients in the 28-day group was 8 years, 4 months (range: 7 years 3 months—9 years 11 months) and the mean age of the 90-day group was 9 years 4 months (range: 7 years 5 months—10 years 3 months).

All of the teeth in the study were anesthetized, by block injection when possible, using 2% lidocaine with 1:100,000 epinephrine. The teeth were then isolated with a rubber dam, swabbed with povidine iodine 10% solution (Clinidine Solution —The Clinidine Corporation, Guilford, CT) followed by 70% isopropyl alcohol, and dried with a sterile gauze pad. No instruments used previously were reintroduced to the surgical field. The access cavity on the lingual surface of the each tooth was partially completed with a high-speed dental handpiece using a new, sterile #245 bur under water spray. The pulp was exposed with a slow-speed round bur without air or water spray. Pulp amputation was completed with a new, sterile #4 slow-speed round bur and spoon excavator followed by copious irritation with sterile saline. A cotton pellet dampened with sterile saline was placed over the amputated pulp stump for five minutes prior to pulp therapy with either the carbon dioxide laser or formocresol.

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Table 1. Inflammation Intensity Score

Grade 1	Occasional inflammatory cells seen throughout the pulp without a specific pattern. The odontoblastic layer was intact along the radicular pulp walls.
Grade 2	One focus of inflammatory cells was present which occupied less than one fourth of the pulp. A small section of odontoblasts was disrupted.
Grade 3	Inflammatory cell infiltrates were present in over one-half of the pulp and edema was prominent. Extensive areas were missing in the odontoblastic layer.
Grade 4	Heavy collections of acute inflammatory cells and areas of necrosis occupying the pulp chamber were noted. Odontoblasts could not be identified.
Grade 5	Ischemic (gangrenous) non-vital pulp

In the control group teeth, a cotton pellet dampened with formocresol[36] was placed in contact with the pulp for five minutes followed by placement of a zinc oxide and eugenol base. Varnish (Copalite- Teledyne Getz, Elk Grove Village, IL) was applied to the cavity margins and a dental amalgam (Sybraloy Capsules – Kerr Manufacturing Company, Orange, CA) restoration placed. All operative procedures for the test group (laser) were the same as described for the control group except for pulp treatment. Following amputation of the pulp and control of bleeding, the amputated pulp stump was lased at the canal orifice using the carbon dioxide laser (LX-20 Dental, ESC Medical Systems, Bothell, WA) set at 6 watts, 0.1 second, single impulse (mode 9). The laser energy was delivered through a 1.0 m (length) hollow wave guide attached to a right angle handpiece with a hollow 0.8 mm(diameter) ceramic tip. The distance between the end of the ceramic tip and the canal orifice was approximately 1-1.5 mm. Multiple firings were administered until a char layer was present over the amputated pulp tissue and there was no evidence of recurrent bleeding. The mean amount of energy applied to each tooth was 12.6±4.2 (7.2-21.0) joules. An increase in applied energy equates to increased heat exposure to the pulp stumps.

The teeth were extracted at either 28 days or 90 days after treatment. Each tooth and surrounding soft tissue was evaluated and a periapical radiograph was obtained prior to extraction. The extracted tooth was placed in a code-labeled bottle containing 10% formalin solution. The teeth were decalcified in 5% formic acid, embedded in paraffin, sectioned parallel to the long axis of the teeth at 5-6 μm thickness, and stained with hematoxylin and eosin. An oral pathologist, blinded to the mode and time of treatment, examined each specimen at 40x and 100x. An inflammation score was assigned to each section using a numerical scale.[37] (Table 1) The presence and intensity of inflammatory cells were graded for four fields. The score assigned to the tooth was the mean value of the four examined sections.

Two clinicians, blind to the mode and time of treatment examined the pre-extraction radiographs. Evidence of internal resorption, pulpal calcification, dentinal bridging, or pathologic root resorption was recorded as either present or absent. The pre-treatment radiograph served as a base line for the post-treatment radiographic evaluation. The Mantel Haenszel row mean score test was used for inflammation and

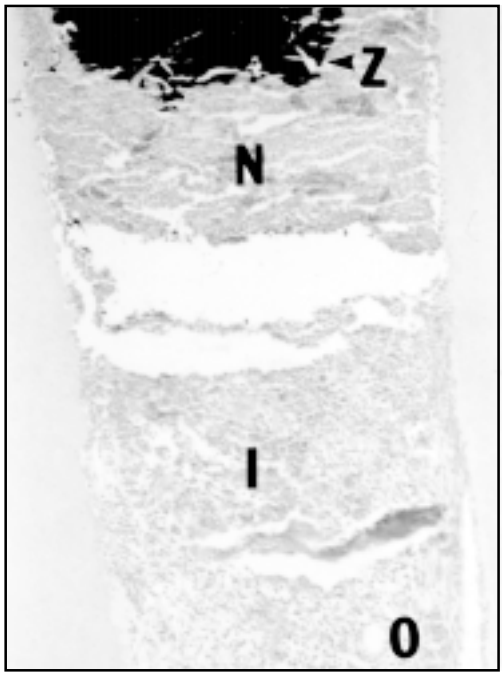

Fig 1. Formocresol 28-day protocol group. Section shows a zone of necrosis (N) adjacent to the zinc oxide and eugenol base material (Z), inflammatory cells (I) and intact odontoblasts (O). (Mag. 40X)

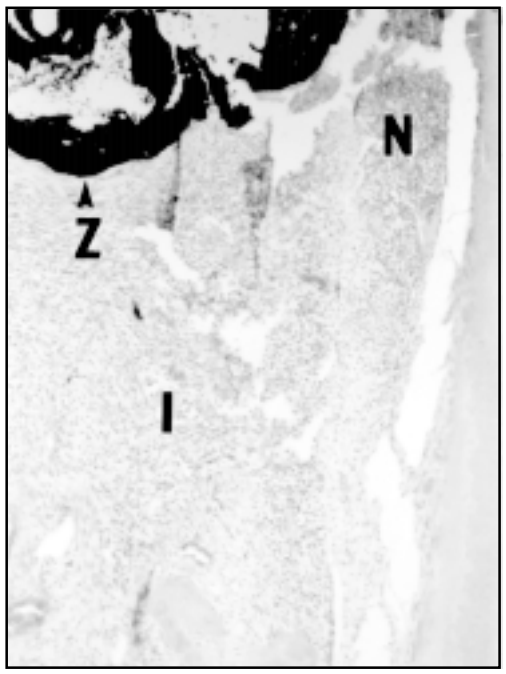

Fig 2. Formocresol 90-day protocol. Section exhibits a zone of necrosis (N) adjacent to the zinc oxide and eugenol base material (Z) and inflammatory cells (I) throughout the pulp. (Mag. 40X)

Table 2. Summary of Pre-extraction Clinical Evaluation

Criteria	Formocresol 28-day (N=8)	Formocresol 90-day (N=7)	Laser 28-day (N=8)	Laser 90-day (N=7)
Excess mobility	0	0	0	0
History of pain	0	0	0	0
Fistula/Abscess present	0	0	0	0
Soft tissues appear normal	8	7	8	7

a general association test was used for other outcomes. A Breslow Day test of homogeneity for 2x2 tables was used to compare 28-and 90-day subjects controlling for group (formocresol or laser). McNemar's test was used to compare responses to laser and formocresol treatment (P=.05).

Results

Clinical and Radiographic Results

No teeth were found to exhibit clinical signs of pathologic mobility, history of pain, presence of fistula/abscess, or abnormal supporting soft tissues. No pathologic external root resorption or abscess formation was observed. One formocresol group cuspid (28-day protocol) and two laser group cuspids (one 28-day protocol and one 90-day protocol) exhibited evidence of internal root resorption. (Tables 2 and 3)

Histological Results

Formocresol (28-day)

The formocresol treated pulps received inflammation scores ranging from 2 to 5 (Table 1); the most common score was a 4. A typical pulp showed inflammatory cell infiltrate in the coronal portion which varied from moderate to severe. A thick zone of necrosis and heavy infiltration with acute inflammatory cells was present adjacent to the zinc oxide and eugenol base. Below this zone, the pulp was edematous and heavily infiltrated with acute and chronic inflammatory cells. Occasional inflammatory cells were present and a small number of multi-nucleated giant cells were seen within the lacunae of the dentin near the apex. The odontoblasts were somewhat flattened in the middle third of the pulp. (Fig 1)

Formocresol (90-day)

The formocresol treated pulps received inflammation scores ranging from 2 to 4; the most common score was a 3. A typical pulp exhibited a variable thickness zone of necrosis adjacent to the zinc oxide and eugenol base. The most severe change showed coronal pulp necrosis and heavy infiltrates of both chronic and acute inflammatory cells throughout the length of the specimen. (Fig 2)

Laser (28-day)

Inflammation scores ranging from 1 to 4 were recorded; the most common score was a 3. A typical pulp exhibited a zone of edema and infiltrates of chronic and acute inflammatory cells below a zone of fixation and necrosis. There was a mild chronic inflammatory cell infiltrate throughout the length of the pulp. Flattened but intact odontoblasts were present along much of the length of the pulp. (Figure 3)

Laser (90-day)

Inflammation scores ranging from 1 to 3 were recorded; the most common score was a 2. A typical pulp exhibited moderate but less concentrated acute and chronic inflammatory cell infiltrate beneath the zinc oxide and eugenol base. Columnar odontoblasts were prominent along the dentin wall. (Figure 4)

Statistical Results

There was a statistically significant difference (P=.0001) between 28 and 90 days in the percentage of subjects demonstrating reparative dentin in the pulp. The difference in the presence of reparative dentin between 28 and 90 days was similar for both laser and formocresol. In comparing the laser and formocresol for inflammatory response, all—subjects regardless of protocol time—were included in the analysis. There were no statistically significant differences observed (Table 4). There was no statistically significant difference between formocresol and laser in stimulating an odontoblastic layer or dentin formation (Table 5).

In the laser group, the association between inflammation and amount of energy applied is moderately strong when 28-and 90-day data are combined (r_s=-.49; P=.06). At 28 days (r_s=-.83, P=.01) the relationship was much stronger than at 90 days (r_s=-.48, P=.27).

Discussion

In this study, there were no significant differences between the formocresol and laser groups with respect to symptomatic, clinical, or radiographic findings. The observed presence of isolated areas of internal resorption in one of the formocresol treated teeth and two of the laser treated teeth was puzzling. An ex-

Table 3. Summary of Pre-extraction Radiographic Evaluation

Criteria	Formocresol 28-day (N=8)	Formocresol 90-day (N=7)	Laser 28-day (N=8)	Laser 90-day (N=7)
External root resorption	0	0	0	0
Abscess formation	0	0	0	0
Internal root resorption	1	0	1	1

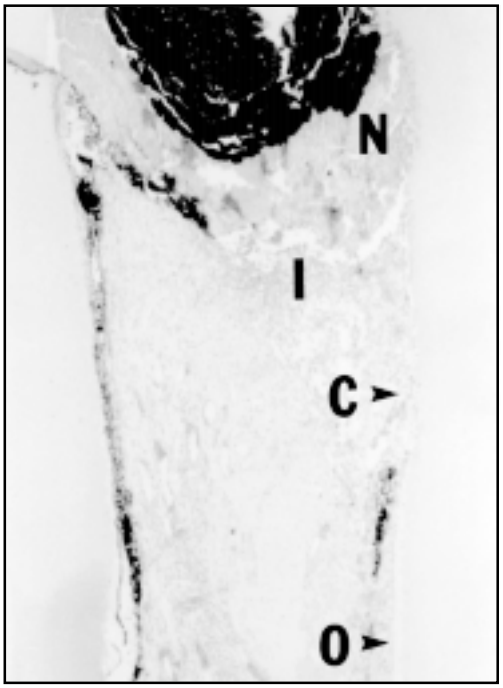

Fig 3. Laser 28-day protocol group. Section shows a zone of edema and inflammatory cells (I) below a zone of fixation and necrosis (N), intact odontoblasts (O) and occasional clastic cells (C). (Mag. 40X)

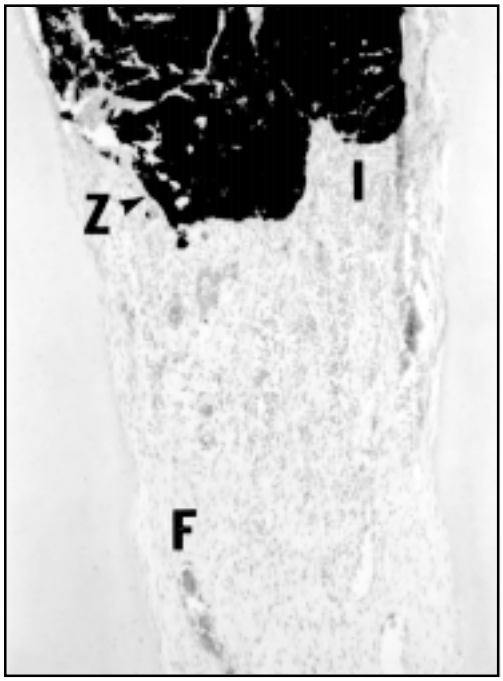

Fig 4. Laser 90-day protocol group. Section demonstrates inflammatory cells (I) with mild fibrosis (F) of the pulp beneath the zinc oxide and eugenol base material (Z). (Mag. 40X)

Table 4. Inflammatory Response

Formocresol inflammatory intensity score	28-day CO_2 Laser Inflammatory intensity score					90-day CO_2 Laser Inflammatory intensity score				
	1	2	3	4	5	1	2	3	4	5
1	0	0	0	0	0	0	0	0	0	0
2	0	0	1	0	0	0	0	1	0	0
3	0	1	1	0	0	1	4	0	0	0
4	1	0	2	1	0	0	0	1	0	0
5	0	1	0	0	0	0	0	0	0	0

(McNemar Test)=No statistical difference P=.08 (combined 28- and 90-day groups)
(Mantel-Haenszel)=No statistical difference in recovery from inflammation between 28 and 90 days in the laser group than was observed in the formocresol group P=.06
Note: Number of subjects (patients) are given.

Table 5. Odontoblastic Layer

Formocresol odontoblastic layer present	28-day CO_2 Laser Odontoblastic layer present		90-day CO_2 Laser Odontoblastic layer present	
	Yes	No	Yes	No
Yes	4	0	3	2
No	2	2	0	2

(McNemar Test)=No statistical difference, P=.08 (combined 28 and 90-day groups).

tended period of observation would be helpful to determine if this was transient and would arrest and potentially repair.

The histologic observations in this study revealed three interesting effects which were consistent with previous observations.[34,35] First, the laser treatment was at least as effective in minimizing post-treatment inflammation as the formocresol treatment. Second, there was no statistically significant recovery from inflammation between the 28- and 90-day observation period in either the laser or formocresol group. Third, there was a strong and statistically significant inverse correlation between the energy used during the respective laser pulpotomies and the degree of inflammation observed at 28 days.

The data imply that there is an energy threshold necessary to create some condition required to minimize an initial inflammatory response. We speculate that the higher energy created a thicker char layer over the remaining pulp which in some way had a favorable effect. This energy threshold appears to be less important over time.[33-34] Miserendino et al.[35] reported that the pulp can predictably heal itself when the temperature does not rise more than 5.5° C above physiological baseline. In this study, the total energy applied did not exceed 21 joules; thus it would be reasonable to assume that we were well within the safety threshold dose level for carbon dioxide laser pulpotomy.

Conclusions

1. On the basis of symptomatic, clinical, radiographic, and histologic findings, the carbon dioxide laser for pulpotomy appears to compare favorably to formocresol treatment.
2. The application of enough laser energy to create a dense char layer results in less initial inflammatory response in the residual pulp.
3. Additional studies should be conducted to establish the ideal applied laser energy to maximize optimum residual pulp response, and to explore the effects of laser treatment to pulps exposed previously by caries.

References

1. Sweet CA: Procedure for treatment of exposed and pulpless deciduous teeth. J Am Dent Assoc 17:1150-53, 1930.
2. Glass RL, Zander H: Pulp healing. J Dent Res 28:97-107, 1949.
3. Berk H, Cohen MM: Histological evaluation of pulpotomy. J Dent Res 33:647, 1954.
4. Berk H, Stanley HR Jr: Pulp healing following capping in human sound and carious teeth. J Dent Res 37:66, 1958.
5. Berman DS, Massler M: Experimental pulpotomies in rat molars. J Dent Res 37:229-42, 1958.
6. Massler MJ, Berman DS, James VE: Pulp capping and pulp amputation. Dent Clin North Am , November 1957, pp 789-804.
7. Fuks AB, Bimstein E: Clinical evaluation of diluted formocresol pulpotomies in primary teeth of school children. Pediatr Dent 3:321-24, 1981.
8. Ranly D: Assessment of the systemic distribution and toxicity of formaldehyde following pulpotomy treatment: part one. J Dent Child 52:431-4, 1985.
9. Ranly D, Horn D: Assessment of the systemic distribution and toxicity of formaldehyde following pulpotomy treatment: part two. J Dent Child 54:40-44, 1987.
10. Fei AL, Udin RD, Johnson R: A clinical study of ferric sulfate as a pulpotomy agent in primary teeth. Pediatr Dent 13:327-332, 1991.
11. Seow WK, Thong YH: Evaluation of the novel anti-inflammatory agent tetrandrine as a pulpotomy medicament in a canine model. Pediatr Dent 15:260-6, 1993.
12. Doyle WA, McDonald RE, Mitchell DF: Formocresol versus calcium hydroxide in pulpotomy. J Dent Child 29:86-96, 1962.
13. van Amerongen WE, Mulder GR, Vingerling PA: Consequences of endodontic treatment in primary teeth. Part I: A clinical and radiographic study of the influence of formocresol pulpotomy on the life-span of primary molars. J Dent Child 53:364-70, 1986.
14. Block RM, Lewis RD, Sheats JB, Fawley J: Cell-mediated immune response to dog pulp tissue altered by formocresol within the root canal. J Endod 3:424-30, 1977.
15. Thoden Van Velzen SK, Feltkemp-Vroom TM: Immunologic consequences of formaldehyde fixation of autologous tissue implants. J Endod 3:179-85, 1977.
16. Dilley GJ, Courts FJ: Immunological response to four pulpal medicaments. Pediatr Dent 3:179-83, 1981.
17. Fulton R, Ranly DM: An autoradiographic study of formocresol pulpotomies in rat molars using ^{3}H-formaldehyde. J Endod 5:71-78, 1979.
18. Myers DR, Shoaf HK, Dirksen TR, Pashley DH, Whitford GM, Reynolds KE: Distribution of ^{14}C-formaldehyde after pulpotomy with formocresol. J Am Dent Assoc 96:805-13, 1978.
19. Myers DR, Pashley DH, Whitford GM, McKinney RV: Tissue changes induced by the absorption of formocresol from pulpotomy sites in dogs. Pediatr Dent 5:6-8, 1983.
20. Feigal RJ, Messer HH: A critical look at glutaraldehyde. Pediatr Dent 12:69-71, 1990.
21. Ranly DM, Horn D, Hubbard GB.: Assessment of the systemic distribution and toxicity of glutaraldehyde as a pulpotomy agent. Pediatr Dent 11:8-13, 1989.
22. Seow K, Thong YH: Evaluation of the novel anti-inflammatory agent tetrandine as a pulpotomy medicament in a canine model. Pediatr Dent 15:260-6, 1993.
23. Landau MJ, Johnsen DC: Pulpal responses to ferric sulfate in monkeys. J Dent Res 67:215, 1988.
24. Fuks AB, Eidelman E, Cleaton-Jones P, Michaeli Y: Pulp response to ferric sulfate, diluted formocresol and IRM in pulpotomized primary baboon teeth. J Dent Child 64:254-9, 1997.
25. Anderman I.: Indications for use of electrosurgery in pedodontics, Symposium on Electrosurgery. Dent Clin N Am, 26:711-28, 1982.
26. Mack RB, Dean JA: Electrosurgical pulpotomy: A retrospective human study. J Dent Child 60:107-14, 1993.
27. Sheller B, Morton TH: Electrosurgical pulpotomy: a pilot study in humans. J Endod 13:69-76, 1987.
28. Liu J-F, Chen L-R, Chao S-Y: Laser pulpotomy of primary teeth. Pediatr Dent 21:128-29, 1999.
29. Jukic' IA, Anic' I, Liba K, Najzar-Fleger D, Matsumoto K: The effect of pulpotomy using CO_2 and Nd:YAG lasers on dental pulp tissue. Int Endod J 30:175-80, 1997.
30. Miller M, Truhe T: Lasers in dentistry: an overview. J Am Dent Assoc 124:32-35, 1993.
31. Partovi F, Izatt JA, Cothren RM, Kittrell C, Thomas JE, Strikwerda S, Kramer JR, Feld MS: A model for thermal ablation of biological tissue using laser radiation. Lasers Surg Med 7:141-54, 1987.
32. Lobe TE: The applications of laparoscopy and lasers in pediatric surgery. Surg Annu 25:175-91, 1993.
33. Arrastia AMA, Wilder-Smith P, Berns MW: Thermal effects of CO_2 laser on the pulp chamber and enamel of human primary teeth: an invitro investigation. Laser Surg Med 16:343-50, 1995.
34. Shoji S, Nakamura M, Horiuchi H: Histopathological changes in dental pulp irradiated by CO2 laser: a preliminary report on laser pulpotomy. J Endod 11:379-84, 1985.
35. Miserendino LJ, Neiburgerr EJ, Walia H, Luebke N, Brantley W: Thermal effects on continuous wave CO_2 laser exposure on human teeth: an in vitro study. J Endod 15:302-5, 1989.
36. Morawa AP, Straffon LH, Han SS, Corpron RE: Clinical evaluation of pulpotomies using dilute formocresol. J Dent Child 42:360-3, 1975.
37. Stanley HR, Swerdlow H: Reaction of the human pulp to cavity preparation results produced by eight different grinding techniques. J Am Dent Assoc 58:49-59, 1959.