Scientific Article

A Retrospective Study of a Modified 1-minute Formocresol Pulpotomy Technique Part 1: Clinical and Radiographic Findings

Zahra A. Kurji, BSc, DMD, MSc, FRCD (C)[1] • Michael J. Sigal, DDS, MSc, Dip Paed, FRCD (C)[2] • Paul Andrews, BSc, DDS, Dip Paed, MSc, FRCD (C)[3] • Keith Titley, BDS, LDS, Dip Paed, MScD, FRCD (C)[4]

Abstract: ***Purpose:*** *The purpose of this study was to assess the clinical and radiographic outcomes of a 1-minute application of full-strength Buckley's formocresol with concurrent hemostasis using the medicated cotton pledget in human primary teeth.* ***Methods:*** *Using a retrospective chart review, clinical and radiographic data were available for 557 primary molars in 320 patients. Descriptive statistics and survival analysis were used to assess outcomes.* ***Results:*** *Overall clinical success, radiographic success, and cumulative 5-year survival rates were approximately 99%, 90%, and 87%, respectively. Internal root resorption (~5%) and pulp canal obliteration (~2%) were the most frequently observed radiographic failures. Thirty-nine teeth were extracted due to clinical and or radiographic failure. Mandibular molars were 6 times more prone to radiographic failure than maxillary molars.* ***Conclusions:*** *Success rates for the modified technique are comparable to techniques that use the 5-minute diluted or full-strength solutions reported in the literature. This 1-minute full-strength formocresol technique is an acceptable alternative to published traditional techniques. (Pediatr Dent 2011; 33:131-8) Received November 14, 2009 / Last Revision April 4, 2010 / Accepted June 20, 2010*

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Carious involvement or traumatic exposure of pulps that remain vital in primary teeth can be treated by a technique called vital pulpotomy. The treatment involves removal of the coronal pulp, application of medicaments, and restoring the tooth to maintain function and arch length until its exfoliation and the eruption of its successor.

Since the introduction of vital pulpotomy, various medicaments have been used[1-5] and various alterations to the technique itself have been advocated.[6-8] The most common pulpotomy technique involves amputation of the coronal pulp followed by the application of full-strength formocresol to the radicular pulp stumps for a 5-minute period.[9,10] Histologic, radiographic, and clinical success and failure rates have been reported for this technique and its modifications. The use of formocresol has been associated with high clinical and radiographic success rates that are due to the potent germicidal and tissue fixative qualities of formaldehyde. Over the years, modifications of the 5-minute formocresol technique have included varying concentration levels,[11,12] application times,[6,13,14] incorporation of formocresol into the sub-base,[15,16] and hemostasis with the formocresol-dampened cotton pellet.[8] Despite the high success rates reported with the use of a 5-minute application of formocresol, it has been postulated that it may be applied for a lesser amount of time and still achieve equivalent results.

The purpose of this retrospective study was to examine the outcomes of a 1-minute pulpotomy using full-strength Buckley's formocresol and concurrent hemostasis with the medicated cotton pledget.

Methods

Ethics approval was obtained from the Health Sciences Research Ethics Board, University of Toronto, Toronto, Ontario, Canada. The subjects selected for this investigation were treated at a pediatric private practice in Mississauga, Ontario, Canada between 1997 and 2008. Informed consent was obtained from their guardians prior to treatment. Healthy children who received at least 1 vital molar pulpotomy with a minimum 6-month follow-up period were included in the study. Teeth with less than a 6-month follow-up were excluded from the investigation. The clinical indications for the vital pulpotomy and inclusion into the study were as follows: (1) pulp was cariously or mechanically exposed during the

[1]*Dr. Kurji is a pediatric dentist in private practice, Edmonton, Alberta;* [2]*Dr. Sigal is professor and head, Department of Pediatric Dentistry, Faculty of Dentistry, University of Toronto, Toronto, Ontario, is dentist-in-chief and co-director, Hospital Dental Residency Program and director, Dental Program for Persons with Disabilities, Mount Sinai Hospital, Toronto, Ontario, is staff dentist, Holland Bloorview Kids, Rehabilitation Hospital, Toronto, Ontario, and is consultant staff, The Hospital for Sick Children, Toronto, Ontario;* [3]*Dr. Andrews is assistant professor and graduate clinic director, Department of Pediatric Dentistry, Faculty of Dentistry, University of Toronto, Toronto, Ontario, is a pediatric dentist in private practice, Mississauga, Ontario, and is consultant staff, The Hospital for Sick Children, Toronto, Ontario; and* [4]*Dr. Titley is Professor Emeritus, Department of Pediatric Dentistry, Faculty of Dentistry, University of Toronto, Toronto, Ontario, all in Canada.*

Correspond with Dr. Kurji at kurjiz@gmail.com

operative procedure; (2) no history of spontaneous or severe pain; (3) possible history of thermal sensitivity to hot or cold; (4) no evidence of draining fistula; (5) tooth was restorable; (6) tooth was not mobile; and (7) hemostasis of the amputated pulp was obtainable following placement of a dried formocresol pellet after 1 minute.

The radiographic indications for the vital pulpotomy and inclusion into the study were: (1) absence of furcal or periapical radiolucencies; (2) no internal or pathologic external root resorption; (3) no more than one third physiologic root resorption; and (4) no pathology of the succedaneous follicle. Radiographic assessments were made by examining bitewing and or periapical radiographs. A standardized bisecting angle technique was performed using bitewing tabs and a Rinn XCP holder for periapical films.

Inferior alveolar nerve block or infiltration of local anesthetic using 2% lidocaine 1:100,000 epinephrine was administered. The tooth was then isolated with rubber dam and all coronal caries was removed leaving the last carious dentin overlying the pulp. This ensured a clean operating field. Sterilized and disinfected instruments and burs were used for pulp removal. The pulp chamber roof was outlined and removed using a no. 558 straight crosscut fissure bur. The exposed coronal pulp was subsequently amputated with a no. 6 slow-speed round bur, and debris was removed with copious amounts of water.

A no. 4 pledget of cotton wool dampened with full-strength Buckley's formocresol was dried by squeezing onto a cotton gauze and then placed in contact with the pulp stumps for 1 minute. The pledget of cotton wool was removed and, if no excessive bleeding was noted, a putty-like paste consisting of 1 drop eugenol and pure zinc oxide powder was placed in contact with the pulp stumps to a thickness of approximately 2 mm. The preparation for the stainless steel crown was completed. A stainless steel crown was fitted, checked for occlusion, and cemented in place using glass ionomer cement. The contact points and margins were checked for proper adaptation, excess cement was removed, and appropriate occlusion was verified.

Each patient was designated a numerical code for purposes of maintaining anonymity. Data collected for each numerical entry included: date of birth (age); gender; tooth treated; treatment date; follow-up time in months; and clinical notes regarding the treated tooth at follow-up or recall intervals.

At recall dates of at least 6 months, clinical and radiographic observations were noted as per the criteria outlined for success and failure. Radiographs of treated teeth were taken every 6 months. The therapy was considered successful when the: (1) clinical findings specified below were fulfilled; (2) radiographic findings were normal; and (c) tooth exfoliated naturally.

Teeth were scored as clinical success if they had: (1) no symptoms of pain; and (2) no swelling, fistula, or pathologic tooth mobility. Teeth were scored as a radiographic success if they had: (1) absence of pathologic internal or external resorption; (2) absence of inter-radicular or periapical radiolucency; (3) absence of pulp canal obliteration (narrowing of canals); and (4) crypt of the surrounding succedaneous tooth was intact.

These observations were noted until the treated and contralateral teeth exfoliated or were extracted. The dates of extraction and indications for extractions were noted. When the precise date of the 2 events (extraction or exfoliation) were unavailable, the first recall date that indicated absence of the teeth was noted as the endpoint of the treated and contralateral teeth.

All data were entered into a spreadsheet program (Microsoft Excel 2007, Microsoft Corp, Redmond, Wash) and SAS 8.0 software (SAS Institute, Cary, NC) for statistical analysis. Data for continuous variables such as patient age and recall interval were presented as means and standard deviations. Categorical data such as clinical and radiographic observations were summarized as percentages.

Survival analysis was used to more accurately estimate the probability of success by taking into account the varying observation time for each tooth. The survival probability was calculated as the number of teeth surviving divided by the number of teeth at risk. The teeth that "failed" due to radiographic or clinical failure or because they "dropped out" or exfoliated were not counted as "at risk." Lost teeth were considered "censored" and not counted in the denominator. Probability of surviving to any point was estimated from cumulative probability of surviving each of the preceding time intervals. This was done using the SAS procedure Proc Lifereg (SAS 8.0 SAS Institute).

To test the relationship of the failures of the modified technique to different variables such as age, gender, first vs second molars, maxillary vs mandibular molars, a regression analysis (Cox proportional hazards model) was performed. A likelihood ratio chi-square test from the Cox proportional hazards model is reported. The analysis was carried out using SPSS 8.0.

Clinical and radiographic assessments were made by the principal investigator. Clinical assessments were made by reviewing chart entries pertaining to each tooth up to the period that the treated tooth exfoliated or until the last date that an entry was made. Radiographic assessments were made by reviewing radiographs pertaining to the treated tooth.

The principal investigator examined all the radiographs of 557 teeth. To evaluate the principal investigator's observations, intra-rater reliability of the principal investigator and inter-rater reliability against 2 experienced pediatric dentists were performed by independently reading radiographs of 30 randomly selected patients. Inter-rater agreement was measured using the Kappa statistic against 2 experienced pediatric dentists. The observations of the principal investigator were further evaluated to determine the degree of intra-rater reliability. All radiographs were read using a standard view box illuminator. Measures of inter-rater and intra-rater reliability were categorized as poor, slight, fair, moderate, substantial, and almost perfect.[17]

The data were entered into Microsoft Excel by the principal investigator. The sample size required to achieve

Table 1. RADIOGRAPHIC SUCCESS RATES FOR PRIMARY MOLARS OVER TIME BY MOLAR AND ARCH TYPE

Time	0-12 mos N=34	12-24 mos N=90	24-36 mos N=86	36-48 mos N=118	48-60 mos N=71	>60 mos N=158	Total
Molar type							
First molars N (%)	20/24 (83)	55/65 (85)	51/62 (82)	69/74 (93)	49/51 (96)	100/102 (98)	344/378 (91)
Second molars N (%)	10/10 (100)	19/25 (76)	19/24 (79)	36/44 (82)	19/20 (95)	53/56 (95)	156/179 (87)
P-value	.30	.40	.80	.70	1.00	.30	.20
Maxillary molars N (%)	20/22 (91)	40/41 (98)	40/42 (95)	60/61 (98)	26/26 (100)	70/70 (100)	256/262 (98)
Mandibular molars N (%)	10/12 (83)	34/49 (69)	30/44 (68)	45/57 (80)	42/45 (93)	83/88 (94)	244/295 (83)
P-value	.60	.05	.05	.05	.30	.10	.05
All molars N (%)	88	82	81	89	96	97	90

90% power and a 0.05 alpha level using Fisher's exact test was determined to be 124 teeth.

Results

A total of 1,039 teeth underwent pulpotomies, and 557 teeth were selected based on the previously stated inclusion criteria.

The mean age of the 323 patients (males=186, females=137) included in the study was 73.2±21.8 months, with a range of 24.7 to 172.6 months. These patients comprised 557 teeth treated (primary first molars=378, primary second molars=179, maxillary molars=262, mandibular molars=295). The mean follow-up period was 44.9±23.2 months, with a range of 6.0 to 118.3 months.

Four of 557 teeth failed, accounting for an overall clinical success rate of approximately 99%. All the teeth that demonstrated clinical failures also showed radiographic failures. At 1 year, the clinical success rate was approximately 99%. The reason for a declining number of teeth with increased follow-up is primarily a result of exfoliation. A total of 229 teeth were available for evaluation at 5 years, and the clinical success rate at the 5-year follow-up was approximately 99% (1/229).

All available radiographs were assessed according to radiographic assessment criteria. Inter-rater reliability was 0.62 (Kappa statistic, considered substantial) with 70% agreement, and intra-rater reliability was 0.70 (Kappa statistic, considered substantial) with 86% agreement.

The radiographic success rates for primary molars over time by molar and arch type are shown in Table 1. The radiographic success rate in the 12- to 24-month period was 98% for maxillary molars and 69% for mandibular molars ($P<.05$). Once a tooth was classified as a failure, it was tabulated as being unavailable for evaluation in the next time period. In the 24- to 36-month observation period, the radiographic success rates were 95% and 68%, respectively ($P<.05$). The radiographic success rates for maxillary and mandibular molars in the 36- to 48-month observation period was 98% and 80%, respectively ($P<.05$).

As illustrated in Table 2, the probability of a 1-year survival was 0.99. The probability of a 5-year survival was 0.87. Figure 1 shows the distribution of radiographic failures over time, with the highest incidence of radiographic failures occurring in the second and third years, post-treatment.

The types of radiographic failures (N=57) that occurred through the follow-up periods are shown in Figure 2. The most frequently observed pulpal responses were internal root resorption (N=27) and pulp canal obliteration (N=11).

As illustrated in Table 3, there is a statistically significant difference in radiographic success rates between the mandibular first and second molars. This effect is primarily due to radiographic failures occurring in the mandibular second molars at the 36- to 48-month interval.

The Cox proportional-hazards regression analysis was used to determine the association between age at treatment, gender, mandibular vs maxillary teeth, first vs second molars,

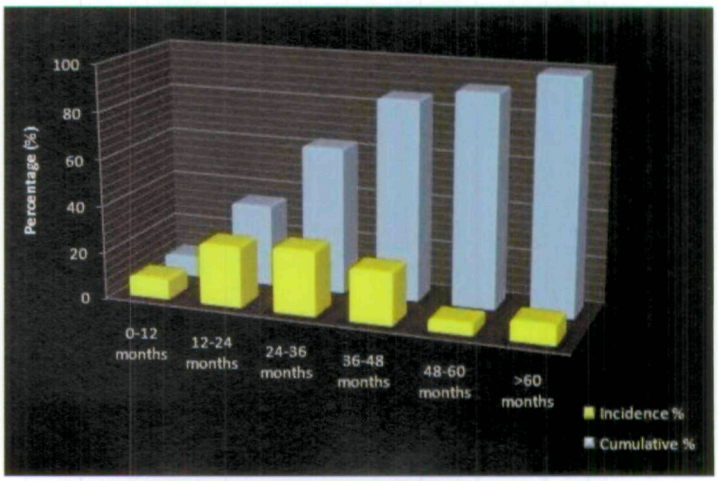

Figure 1. Distribution of radiographic failures (N=57) over time.

Table 2. ESTIMATED RADIOGRAPHIC SURVIVAL BY TIME (MOS)

Time (mos)	No. entering interval	No. withdrawing during interval	No. of terminal events (failures)	Probability of survival±(SD)
0-6	557	3	0	1.00±0.00
6.1-12	554	27	4	0.99±0.01
12.1-18	523	38	7	0.98±0.01
18.1-24	478	36	9	0.96±0.01
24.1-30	433	20	8	0.94±0.01
30.1-36	405	50	8	0.92±0.01
36.1-42	347	58	6	0.90±0.01
42.1-48	283	47	7	0.88±0.02
48.1-54	229	30	1	0.88±0.02
54.1-60	198	38	2	0.87±0.02
60.1-66	158	50	1	0.86±0.02

and survival of teeth. The analysis showed that age, gender, and type of molar had no effect on survival. There was, however, a significant effect ($P<.001$) of arch type on survival, with mandibular teeth at much higher risk of radiographic failure when compared to maxillary teeth with a likelihood ratio of 6.695 (Table 4).

Maxillary teeth have a survival probability of greater than 0.9 at all periods of follow-up. By comparison, the survival probabilities of mandibular teeth continue to decrease with time (Figure 3).

Discussion

The purpose of this investigation was to compare the success rates of a modified 1-minute formocresol pulpotomy technique with the standard 5-minute formocresol pulpotomy technique reported in the literature. The present investigation found that the modified technique resulted in high overall clinical (~99%) and radiographic (~90%) success rates.

The 5-minute application of formocresol has been arbitrarily assigned.[15] In a recent survey,[10] the investigators noted that more diplomates (22%) used application times shorter than the traditional 5-minute placement compared to 2005 directors (8%) and 1997 directors (0%). Few investigations have evaluated the outcomes of a decreased application time of formocresol to the pulps of primary teeth. Venham[13] used a 15 second application time and Garcìa-Godoy et al.[14] used 1- and 3-minute application times and evaluated their histologic effects. In a clinical investigation, Hyland assessed a 2-minute formocresol application in 34 teeth.[6]

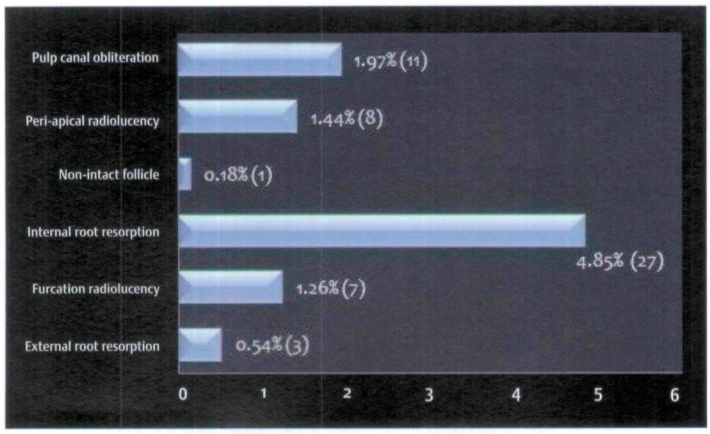

Figure 2. Distribution of radiographic failures.

In this study, a retrospective chart review was used to evaluate the outcomes of a 1-minute formocresol pulpotomy technique. It was predetermined that a sample size of 124 teeth was required to achieve a 90% power and a 0.05 alpha level. The sample size in the present investigation exceeded the predetermined sample size and included 557 teeth from 323 healthy patients requiring at least 1 pulpotomy with a 6-month minimum follow-up period.

Prefabricated stainless steel crowns were used to restore the teeth in this investigation. These restorations have consistently been reported to be more durable than other restorations in the primary dentition.[18-21] The modified technique described in the investigation was carried out on all the teeth by a single operator. Using a single operator offers the advantage of a strictly consistent and reproducible technique. A potential disadvantage is that the outcomes may be related to a superior operator rather than a superior technique.

One of the limitations of the present investigation includes the retrospective design relying on the accuracy of written records and that the study sample cannot be manipulated to include a control group. The Evidence-Based Medicine Levels of Evidence[22] indicates that the highest level of evidence (level 1a) is represented by a systematic review of randomized controlled trials (RCTs). RCTs, however, have the disadvantages of noncompliance and high dropout rates.[23] In fact, RCTs with greater than 20% dropout are considered "low quality" RCTs.[22] These disadvantages result in investigations with small sample sizes and short follow-up times.

The present study design allows for a larger sample size to be studied and, therefore, small differences to be detected. The present investigation far exceeded the predetermined sample size at a 90% power and 0.05% alpha level. Using 1 operator in the investigation allows for consistency in the technique being evaluated and allows for treatment outcomes to be examined over long periods of time. In pediatric dentistry, vital pulpotomies are carried out on a routine basis and long-term outcome evaluation becomes necessary.

Previous investigations that have studied decreased application times and clinical outcomes for shorter periods of time have demonstrated similar results. Hyland reported a similar clinical outcome (97%) after 6 months using full-strength formocresol over pulp stumps for 2 minutes.[6] The clinical success rate in this study at 6 months is higher than that obtained by Aktören, who reported a 90% success rate while assessing a 1-minute full-strength formocresol application.[24] A 2-year follow-up of the same technique

Table 3. RADIOGRAPHIC SUCCESS BY TOOTH TYPE OVER TIME

Time	0-12 mos N=34	12-24 mos N=90	24-36 mos N=86	36-48 mos N=118	48-60 mos N=71	>60 mos N=158	Total
Molar type							
First molars N (%)	14/16 (88)	31/32 (97)	26/27 (96)	35/36 (97)	20/20 (100)	43/43 (100)	**169/174 (97)**
Second molars N (%)	6/6 (100)	9/9 (100)	14/15 (93)	25/25 (100)	6/6 (100)	27/27 (100)	**87/88 (99)**
P-value	1.00	1.00	1.00	1.00	1.00	1.00	<.67
Maxillary molars N (%)	6/8 (75)	24/33 (73)	25/35 (71)	34/38 (89)	29/31 (94)	57/59 (97)	**175/204 (86)**
Mandibular molars N (%)	4/4 (100)	10/16 (63)	5/9 (56)	11/19 (58)	13/14 (93)	26/29 (90)	**69/91 (76)**
P-value	.50	.50	.40	.05	1.00	.30	**.05**
All molars N (%)	88	82	81	89	96	97	**90**

reported an 88% clinical success rate,[25] while the present investigation, with a larger sample size, showed a 99% success rate over the same time period.

The clinical success rate of the present study is comparable to previous investigations that use a 5-minute formocresol application technique.[8,11,26,27]

In the current investigation, the use of non-medicated cotton pellets prior to the use of formocresol was omitted, as in the study conducted by Thompson et al.[8] Thompson et al., in a retrospective investigation, used the same medicated cotton pledget technique to obtain hemostasis and obtained an overall clinical success rate of 98%.[8] The present study obtained a similar success rate (~99%) with a 1-minute application time and the clinical success rate at all stages of follow-up was greater than 99%.

The radiographic success rate of approximately 90% found in the present investigation is comparable to the radiographic success rates that have been previously reported. Earlier investigations have reported radiographic success rates ranging from 85% to 98%.[7,8,11,26,28,29] The radiographic criteria in assessing success and failure employed by Berger[27] and Waterhouse et al.[30] were similar to those used in the present investigation. Verco and Allen[26] also reported a slightly higher (92%) radiographic success rate in 1,006 primary teeth in children with a mean age of 7.0 years old. The investigators, however, did not state the length of the follow-up period over which this success rate was obtained.

The present investigation demonstrated higher radiographic success rates than previous investigations that employed a 1-minute formocresol application technique. At 6 months, Aktören[24] demonstrated a lower (85%) radiographic success rate while the present investigation demonstrated an 88% radiographic success rate in the same time period. In the 12- to 24-month follow-up period, the present investigation showed a slightly higher (82%) radiographic success rate compared to Aktören and Gençay, who reported an 80% success rate.[25] The present study followed the treatment outcomes for longer periods with larger sample sizes compared to previous investigations and still demonstrated more favorable success rates.

In the present study, the radiographic success rates varied among teeth. Although the probability of radiographic success for first molars was equal to the probability of radiographic success for second molars, there was a statistically significant difference ($P<.05$) between maxillary and mandibular molars in the 12- to 24-month observation period. Similar differences were noted in the 24- to 36-month and 36- to 48-month follow-up periods.

Similar differences in success rates over time between maxillary and mandibular molars were reported by Strange et al.[16] They reported a statistically significant difference ($P<.001$) between the radiographic success rate in maxillary (89%) and mandibular molars (74%). They also attributed this statistical difference to difficulty in interpreting maxillary radiographs, since maxillary sinuses obscured radiographic changes.[16] This explanation may also hold true for the present investigation. In fact, Magnusson used only primary mandibular molars in evaluating the presence or absence of internal root resorption and predicated this on the fact that radiographic changes are more readily evident in mandibular vs maxillary molars.[31]

Table 4. SURVIVAL ANALYSIS OF TREATMENT RELATED FAILURES

Variable	Likelihood ratio	Confidence limits	*P*-value
Gender (male vs female)	1.22	0.71-2.10	<.47
Age	0.99	0.98-1.01	>.42
Molar type (first vs second)	0.70	0.41-1.19	>.19
Molar type (mandibular vs maxillary)	6.70	2.87-15.63	<.001

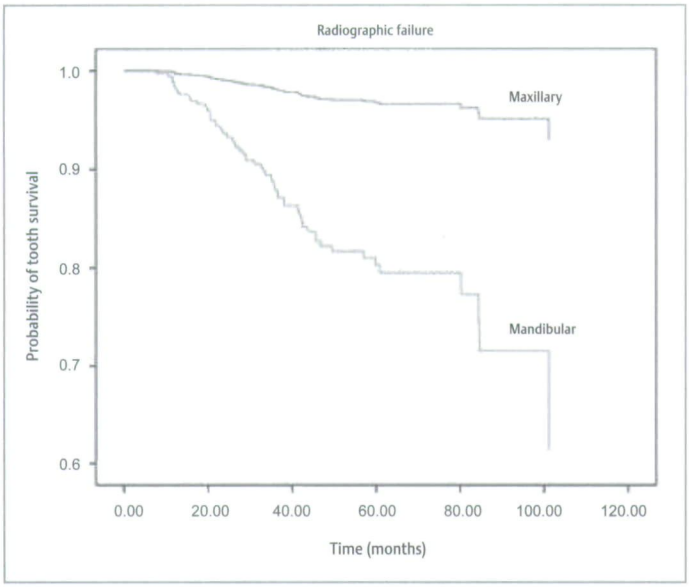

Figure 3. Survival analysis of mandibular and maxillary teeth.

Age, gender, and presence of first or second molars had no significant effect on success in the current study. The present investigation demonstrated, however, that mandibular teeth were 6.7 times ($P<.001$) more likely to fail when compared to maxillary teeth. This increased risk of failure in mandibular molars may be attributed to a similar pattern of failure observed in restorations. Restorations are more likely to fail in mandibular teeth than maxillary teeth. Holan et al. showed a higher failure rate (~14%) in primary mandibular molars than primary maxillary molars (10%) treated with formocresol pulpotomies and restored with stainless steel crowns. The statistical significance of this difference, however, was not calculated.[32] Also, despite using a rubber dam isolation technique while restoring teeth, mandibular teeth are more likely to be subject to moisture contamination, as saliva pools and collects in the posterior lingual region. Conversely, Thompson et al. reported no statistically significant difference in radiographic outcomes between maxillary and mandibular molars.[8]

The present investigation demonstrated a significant difference in radiographic success rates between mandibular first and second molars ($P<.05$). Primary mandibular second molars demonstrated a lower radiographic success rate than primary mandibular first molars. This is in contrast to the findings of Vij et al.,[33] who found that primary first molars were more prone to failure. Farooq et al. reported a lower success rate (63%) for formocresol pulpotomies in primary mandibular first molars than for any other molar (83-88%). They explained it as either a chance finding or that the mandibular first molar is the first posterior tooth requiring pulpal treatment at an early age and suggested that difficult patient management may compromise pulpotomy success.[34]

In the present study, the frequency of a normal-appearing pulp chamber and root canal configuration remained constant over time. This finding is similar to those of Thompson et al.[8] and Burnett and Walker,[35] but differs from many other published reports that demonstrate decreasing radiographic success rates over time.[7,27-29,36-38] Rølling and Thylstrup reported a 3-month radiographic success rate of 91%, which decreased to 70% at 36 months.[36] Fei et al., reported a success rate of 85% at 3 months that decreased to 71% at 12 months in a study comprising 27 human molars.[39] Farooq et al.,[34] reported that formocresol radiographic success rates decreased with time and that the largest number of failures occurred within the first 2 years. In his investigation, however, Redig reported that most radiographic failures occurred in the first 6 months.[28] The present investigation demonstrated that the greatest number of failures occurred between 24 to 36 months and, similar to the observations noted by a previous study,[8] an increase in radiographic failures with time was not illustrated.

In the present study, 39 treated teeth were extracted due to clinical and or radiographic failure. The average duration of time the teeth were extracted due to failure following treatment was 2.7 years after treatment. This was longer than that reported by Verco and Allen, where teeth were extracted at 1.3 years after treatment.[26] The present investigation demonstrated that, with the modified technique, teeth were retained for a longer period prior to failure.

The 2 most common radiographic failures in the current study were internal root resorption and obliteration of pulp canals. These findings are consistent with other investigations.[37,38,40]

Some investigators do not consider radiographic evidence of internal resorption to be a sign of failure.[37,38,40,41] The etiology of internal resorption is thought to result from chronic pulpitis[30,42] and that for internal resorption to be progressive there must be presence of necrotic tissue.[43] As a result, it is postulated that the presence of radiographic internal resorption indicates an unsuccessful treatment outcome. In spite of categorizing internal resorption as a radiographic failure in the present investigation, the teeth were not treated immediately if they were asymptomatic and did not present with additional clinical or radiographic failures at later recall dates. In the present study 41% (11/27) of cases with internal resorption progressed to osseous changes or clinical signs and symptoms and were extracted. The very low rate of internal resorption in the current investigation is likely due to the 1-minute application of formocresol. This short duration of application would result in less inflammation in the radicular pulp and, therefore, less internal resorption.

In the current investigation 41% of the teeth that presented with internal root resorption progressed to external root resorption, inter-radicular radiolucency or periapical radiolucency, over an average period of 17.5 months. A similar progression was reported by Hicks et al., who reported that approximately 2% of all pulpotomized teeth or 22% of teeth that presented with internal resorption showed internal resorption "that compromised the integrity of the root structure."[44] Maroto et al.,[41] Eidelman et al.,[5] and the present study's authors demonstrated that, even if internal resorption does not need treatment other than follow-up observations, it cannot be considered a successful outcome because it is a sign

of pulpal inflammation and may progress to clinical failures—as was the case in the present investigation.

In the present study it was found that pulp canal obliteration (PCO), also known as calcific metamorphosis, accounted for approximately 19% (11/57) of the radiographic failures or 2% (11/557) of all treated teeth. This is lower than the 22% calcific metamorphosis reported by Vargas et al.[45] Using a 4-minute application of formocresol, Willard found postoperative calcification in 24 of the 30 formocresol treated teeth over a 3-year period.[45] He explained that the calcification was a result of odontoblastic activity following treatment and that the pulp retained some degree of vitality.[46] The present investigation categorized PCO as a radiographic failure since it demonstrated a deviation from normal-appearing pulp. PCO is the result of extensive activity of odontoblast-like cells.[46] Reactionary dentine, a type of tertiary dentin, is formed when teeth experience an injury as an attempted repair process within the pulpal tissue.

It has been previously postulated that, after an initial attempt by the pulp tissue to "wall off" the bacterial and inflammatory insult, the protective processes fail and result in clinical failures.[30] This has been histologically verified by Waterhouse et al., who showed that reactionary dentin apposition occurred in all teeth that failed clinically or radiographically.[30] In the present investigation, approximately 2% of the treated teeth that showed total pulp canal obliteration progressed to inter-radicular radiolucency. Advanced pulp canal obliteration also prevents the possibility of root canal treatment in the event that the tooth needs to be re-treated. Previous investigations[8,26] reported a high radiographic success rate and those that reported comparable radiographic success rates[24,25] use radiographic criteria that do not include pulp canal obliteration as a criterion for failure.

This is in contrast to the current and previous investigations,[27,45] which have included increased radiopacity as one of the radiographic criteria for evaluating radiographic failure following pulpotomies. If pulp canal obliteration had been included as a normal response, in the present study the radiographic success rates would have been higher (92%), but pulp canal obliteration was designated as a deviation from the pulp's normal radiographic appearance. The inclusion of pulp canal obliteration as a failure enables comparisons to be made with previously described literature that includes pulp canal obliteration as one of the criterion for evaluating radiographic outcomes of formocresol pulpotomies.

In the current investigation, the modified technique was carried out by a single operator. Further studies in the form of prospective multi-center clinical trials to assess the outcomes of this technique by different operators may prove useful to evaluate the robustness of the success rates reported in this study.

Conclusions

Based on this study's results, the following conclusions can be made:

1. The modified 1-minute formocresol pulpotomy technique demonstrated a high overall clinical (99%) success rate.
2. The modified 1-minute formocresol pulpotomy technique demonstrated a high overall radiographic (90%) success rate. Overall, the cumulative survival rate of approximately 87% at 5 years was obtained.
3. The 2 most common types of radiographic failure were internal root resorption (~5%) and pulp canal obliteration (2%).
4. The modified 1-minute technique represents an effective and efficient alternative to the standard 5-minute formocresol pulpotomy technique based on a large sample size and a long follow-up period.

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