Factors Related to Loss of Root Canal Filled Teeth

Daniel J. Caplan, DDS, PhD; Jane A. Weintraub, DDS, MPH

Abstract

Objectives: *This case-control study characterized factors related to loss of root canal filled (RCF) teeth among members of the Kaiser Permanente Dental Care Program, a dental health maintenance organization based in Portland, Oregon.* ***Methods:*** *Individuals were identified who were enrolled continuously from January 1, 1987, through December 31, 1994, underwent initial root canal therapy on a permanent tooth (excluding third molars) in 1987 or 1988, had a clinical examination within two years after endodontic access, and were at least 21 years old at access. Patients who lost the RCF tooth by December 31, 1994, were defined as cases (n=96); those who did not were defined as controls (n=120). Computerized data, dental radiographs, and chart entries were reviewed to ascertain variables of interest, and multivariable logistic regression was used to describe differences between the groups.* ***Results:*** *RCF teeth of cases had fewer proximal contacts at access than RCF teeth of controls (odds ratio=2.7; 95% CI=1.4, 5.1). Cases were older (odds ratio=1.4; 95% CI=1.1, 1.9 per 10-year increase) and more likely to have had a facial injury than controls (odds ratio=3.6; 95% CI=1.2, 10.5). Cases also had more missing teeth (odds ratio=1.5; 95% CI=1.0, 2.1) and more plaque (odds ratio=1.7; 95% CI=1.0, 2.6).* ***Conclusions:*** *Conditions evident during treatment planning may help dentists assess patients' chances of losing an RCF tooth. [J Public Health Dent 1997;57(1):31-9]*

Key Words: root canal therapy, endodontics, tooth loss, epidemiology, retrospective studies, treatment decision making.

Through dental caries, fracture, or trauma, teeth can be damaged to the extent that patients are given only two treatment options: root canal therapy (RCT) and subsequent restoration of the tooth, or extraction. While some choose extraction, many opt for RCT to extend the life of the tooth. Undergoing RCT does not, however, preclude future loss of the tooth. Endodontically treated teeth can be lost due to caries, periodontal disease, nonrestorable fracture, or iatrogenic damage, among other reasons (1,2).

Although RCT is often initiated to extend the life of a tooth, the literature contains little information that either evaluates factors related to loss of root canal filled (RCF) teeth or quantifies the gain in tooth longevity resulting from the choice of RCT over extraction. Several studies of endodontic success have been published (2-6); however, these focus on postendodontic symptoms and radiographic evidence of periradicular pathosis—outcomes that may or may not relate to loss of the tooth. Epidemiologic studies have reported multivariable analyses describing factors related to loss of at least one tooth or all remaining teeth over a defined period (7-9); however, these investigations have not examined the endodontic status of the lost teeth.

Only a few articles have specifically addressed the loss of RCF teeth. Vire (1) prospectively classified reasons for loss of RCF teeth among patients in a military dental clinic. Of 116 such teeth extracted over a one-year period, 59 percent were for prosthetic reasons, 32 percent for periodontal reasons, and 9 percent for endodontic reasons. Sjögren et al. (2) reported that of 68 RCF teeth extracted over an 8–10-year period in a cohort of Swedish dental school patients, 4 percent had been perforated during post preparation, 3 percent were endodontic failures, 31 percent had root fractures, 16 percent were extracted due to caries, 15 percent were lost to periodontal disease, and 31 percent were extracted for unknown reasons. Eckerbom et al. (10), in a multivariable analysis, reported that among patients seen in a Swedish hospital dental clinic, RCF teeth with preoperative periapical periodontitis, a root filling more than 2 mm from the radiographic apex, or a screw-type post were more likely to be lost over a five- to seven-year period than were RCF teeth without these features.

Thus, RCF teeth can be lost for many reasons, some of which are unrelated to the "success" or "failure" of the endodontic procedure. Still, since RCT is usually performed to prolong a tooth's life, dentists should have some indication of the factors related to loss of RCF teeth. If loss of RCF teeth is mostly related to factors that can be determined during treatment planning, thorough attention to these factors could minimize overtreatment of teeth with questionable overall prognoses. If loss of these teeth is mostly associated with endodontic procedural or postobturation restorative variables, reevaluation of endodontic or restorative procedures may be indicated. In either case, the information could then be passed on to patients, who could use it as a basis for making more informed decisions regarding their care.

This paper describes a hypothesis-generating case-control study designed to characterize factors related to loss of RCF teeth over a six- to eight-year period in a sample of insured dental patients. A secondary goal was to assess whether factors that can be determined prior to endodontic therapy are associated more strongly with

Send correspondence to Dr. Caplan, Department of Dental Ecology, School of Dentistry, University of North Carolina, CB #7450, Chapel Hill, NC 27599-7450. Internet: dan_caplan@unc.edu. No reprints will be available from the authors. Dr. Weintraub is Lee Hysan Professor, Department of Dental Public Health and Hygiene, University of California, San Francisco. Supported by Permanente Dental Associates and NIDR grant 5T32DE07191-05. This paper appears as part of Dr. Caplan's doctoral dissertation, entitled, "Factors Related to Loss of Root Canal Treated Teeth," kept on file by the Graduate School, University of North Carolina. Manuscript received: 1/16/96; returned to authors for revision: 3/26/96; accepted for publication: 5/28/96.

tooth loss than are factors ascertainable only after RCT has been initiated.

Methods

Prior to data collection, approval for the study was obtained from Human Subjects Committees at the Kaiser Permanente Center for Health Research (CHR) and the University of North Carolina School of Public Health.

Selection of Study Sample. The sample was drawn from among the population of enrollees in the Kaiser Permanente Dental Care Program (KPDCP), a dental health maintenance organization located in Portland, Oregon. Enrollees are current or retired employees (or their dependents) of companies that have obtained dental insurance through KPDCP. In turn, KPDCP maintains a contract with Permanente Dental Associates (PDA), a group of dental care providers who serve only KPDCP members. Currently, KPDCP has over 144,000 enrollees (11), and PDA employs 105 general dentists and specialists practicing in 12 clinics in the Portland area.

Since January 1, 1987, KPDCP has operated several computerized databases, one of which contains patient-specific demographic and insurance information, and another that contains dental treatment data, including procedure codes, procedure dates, tooth numbers, and unique identification numbers for patients and providers. The latter database was used to identify patients who underwent RCT on a permanent nonwisdom tooth in 1987 or 1988 and to determine whether these teeth had been lost before the end of 1994.

First, all individuals continuously enrolled in KPDCP from January 1, 1987, through December 31, 1994, were identified. Next, this "patient list" was restricted to those who had undergone any endodontic procedure in either 1987 or 1988. A "tooth list" was then created that contained, for each individual on the "patient list," all procedures from 1987 to 1994, inclusive, for any tooth that had received an endodontic procedure in 1987 or 1988.

Procedures then were arranged by tooth number in chronologic order. The "tooth list" was pared by excluding third molars, primary teeth, and teeth for which the first endodontic code represented retreatment or apexification. At this point, patients with more than one tooth remaining on the "tooth list" were restricted to the one receiving the first endodontic procedure (chronologically), resulting in a list containing one tooth per patient. Finally, patients who were under 21 years of age or who had no clinical examination within two years after the initial endodontic procedure were excluded.

The list now contained all patients eligible for the study, each of whom had one tooth of interest. The patients were then separated into two groups: those with an extraction code for the tooth of interest prior to December 31, 1994, and those without such a code. A computerized random number generator arranged the patients in random order within each group.

A related investigation (12) addressed the relationship between the number of missing permanent nonwisdom teeth at access, or NMTA, and loss of the RCF tooth. To calculate the target sample size for both that investigation and the present study, a pilot study was conducted to approximate NMTA among both patients who lost the tooth by December 31, 1994 (cases), and those who did not (controls). A target of 110 cases and 110 controls was obtained based on 5 percent Type I error, 90 percent power, 61 percent of controls with NMTA ≥ 1, and an odds ratio of 3 (13).

Using the two groups of randomly ordered patients, dental charts were reviewed in sequence until the target sample size was approximated. Over the course of data collection, a total of 406 charts were requested. Of these, 11 were either missing or continuously in use, and five did not coincide with the database; the remaining 390 records were reviewed. One tooth of interest had never been accessed; one was a wisdom tooth miscoded in the database as a second molar; four had been accessed prior to the first PDA dental appointment; and 23 had been RCF previously, but had not been excluded earlier because the first endodontic procedure code in the treatment database was not a retreatment code. Data were collected for the remaining 361 individuals.

The treatment database did not contain obturation codes and thus provided no opportunity to distinguish obturated from nonobturated teeth. Since only teeth with completed RCT were to be evaluated, those that had been accessed but not obturated were eliminated. Of the 361 teeth of interest, 107 had not been obturated by December 31, 1994, leaving 254 obturated teeth, of which 112 had been lost by the end of 1994.

NMTA was obtained by counting the teeth present on the first Panorex radiograph after January 1, 1987, and adjusting by the number of permanent nonwisdom teeth reported in the treatment database as having been extracted between the date of access and the date of the radiograph. It was therefore necessary to exclude patients who either had no Panorex after January 1, 1987, or whose tooth had been accessed prior to that date. This reduced the final sample size to 216, including 96 cases and 120 controls.

Data Collection. The most recent radiograph in the area of the RCF tooth was examined to verify case/control status. The reason for extraction of lost RCF teeth was ascertained in accordance with an a priori written protocol based solely on dentists' treatment notes (i.e., radiographs and periodontal charts were not used in this determination). In addition, a number of variables that had a hypothesized association with loss of the RCF tooth were collected. Other potentially related factors (e.g., patient's education level) were not available from existing documentation and could not be collected.

Variables were classified as "preaccess factors" or "postaccess factors" depending on whether they could have been ascertained prior to initiation of RCT. A total of 37 preaccess and 10 postaccess factors were collected and are listed in Tables 1 and 2, respectively.

Computerized data were obtained by the first author (DJC) in conjunction with a CHR data analyst. Dentists' treatment notes were abstracted by DJC and three trained PDA dentists. Radiographs were analyzed by DJC. Periodontal charts, clinical examination forms, and health questionnaires were audited by one trained PDA dental hygienist.

Statistical Analysis. SAS version 6.08 was used for all analyses. Univariate distributions were examined and used as a guideline for choosing cut-points. Bivariate relationships between the independent variables and case/control status were analyzed via contingency tables.

TABLE 1
Preaccess Factors, Values, and Data Sources

Preaccess Factor	Values	Data Source
1. Age	Continuous (years)	Computerized database
2. Sex	Male, female	
3. Insurance copay*	High, low	
4. Lower tooth	Yes, no	Dentists' treatment notes
5. Anterior tooth	Yes, no	
6. Molar	Yes, no	
7. Elective RCT	Yes, no	
8. Symptomatic within 3 months prior to access	Yes, no	
9. Number of proximal contacts†	0, 1, 2	Immediate preaccess periapical radiograph of accessed tooth
10. Decayed	Yes, no	
11. Obvious periapical lesion on any root	Yes, no	
12. ≥4 decayed or filled surfaces from among occlusal, mesial coronal, distal coronal, mesial root, distal root	Yes, no	
13. 3 decayed or filled coronal surfaces	Yes, no	
14. ≥1 decayed or filled root surface	Yes, no	
15. Bridge abutment	Yes, no	
16. Cuspal coverage‡	Yes, no	
17. Number of missing nonwisdom teeth	Continuous (0–28)	First Panorex after Jan. 1, 1987
18. Number of missing first molars	Continuous (0–4)	
19. Number of pockets ≥5 mm on accessed tooth	Continuous (0–6)	Periodontal chart completed by hygienist before access
20. Proportion of teeth with at least one pocket ≥5 mm	Continuous (0.00–1.00)	
21. Stain	None, light, moderate, heavy	Clinical exam form completed by hygienist before access
22. Calculus	None, light, moderate, heavy	
23. Plaque	None, light, moderate, heavy	
24. Bleeding	None, light, moderate, heavy	
25. Brushing	Good, fair, poor	
26. Flossing	Good, fair, poor	
27. Heart/hypertension medication	Yes, no	Health questionnaire completed by patient before access
28. ≥1 medication of any kind	Yes, no	
29. History of excessive bleeding	Yes, no	
30. Diabetes	Yes, no	
31. Anxious while having dental treatment	Yes, no	
32. Expect to keep natural teeth thru-out lifetime	Yes, no	
33. Frequently consume sugar	Yes, no	
34. Taking fluoride tablets/vitamins or living in fluoridated area	Yes, no	
35. Ever worn denture/partial denture	Yes, no	
36. Ever had orthodontic treatment	Yes, no	
37. History of injury to face or jaws	Yes, no	

*High copay plans require 50% copay for endodontic and/or prosthetic treatment; low copay plans require 0–10% copay.
†Contact called absent if adjacent tooth missing, impacted, pontic, implant, or root tip.
‡Crown or bridge abutment.

TABLE 2
Postaccess Factors, Values, and Data Sources

Postaccess Factor	Values	Data Source
1. Specialty of obturating dentist	Endodontist, nonendodontist	
2. Dowel within 2 years of obturation	Yes, no	Computerized database
3. Initially crowned or abutted within 2 years of obturation	Yes, no	
4. ≥1 endodontic complication	Yes, no	
5. Number of canals found during RCT	Continuous (0–4)	
6. Number of days from access to obturation	Continuous	Dentists' treatment notes
7. Number of days from obturation to foundation	Continuous	
8. Root filling past radiographic apex of any root (overfill)	Yes, no	Immediate postobturation periapical radiograph of accessed tooth
9. Root filling >2 mm short of radiographic apex in any root (short fill)	Yes, no	
10. Root filling with obvious lateral or apical voids in any root	Yes, no	

Multivariable logistic regression was employed to generate main effects models describing the association between the independent variables and loss of the RCF teeth. Initially, a full model was generated that contained only preaccess factors. Since the number of cases (n=96) dictated the size of the full model, criteria were devised to limit the factors eligible for the multivariable analysis. To be eligible, a factor was required to have a moderately strong bivariate relationship with case/control status (P<.20), no greater than a 90/10 split in its univariate frequency distribution, and no more than 5 percent missing values.

After the assumption of linearity was verified for continuous and ordinal variables, collinearity was evaluated, and missing values were replaced by case and control means. A final "preaccess model" then was developed through backward selection. Beginning with the full model, variables with P>.05 (based on the Wald chi-square statistic) were eliminated until all remaining variables had P<.05. Variables previously eliminated then were allowed to reenter the model. A final model was chosen in which every variable had P<.05.

To assess the relationship between postaccess factors and loss of the RCF teeth, postaccess factors were given the opportunity to enter the final preaccess model. To remain, postaccess factors were required to have P<.05, controlling for the existing preaccess variables.

Results

Of the 96 teeth extracted by the end of 1994, 22 percent were removed due to periodontal disease, 20 percent to vertical root fracture, 16 percent to nonrestorable caries, 10 percent to nonrestorable fracture, 25 percent for other reasons, and 7 percent for unknown reasons. Figure 1 shows the cumulative percent extracted through eight years after access, by reason for extraction. In general, teeth extracted due to nonrestorable caries or for unknown reasons appeared to survive longer than other lost teeth. The median interval from access to extraction was just over three years, and 75 percent were lost by five years.

Table 3 presents bivariate relationships between preaccess factors and case/control status, in order of ascending P-value. RCF teeth of cases had fewer proximal contacts at access than did RCF teeth of controls (P<.05). The mean age for cases was seven years greater than that for controls, and cases had more missing teeth and more missing first molars than controls. Cases were less likely than controls to feel anxious during dental treatment, and a greater proportion of cases' RCF teeth were bridge abutments at access.

Cases were more likely than controls to be taking at least one medication of any kind, to have been diagnosed with diabetes, and to report taking heart or hypertension medications. Cases were more likely than controls to have previously worn a denture or partial denture and to have had "moderate" or "heavy" plaque as opposed to "none" or "light" plaque. Finally, cases were less likely than controls to expect to keep their natural teeth throughout their lifetime.

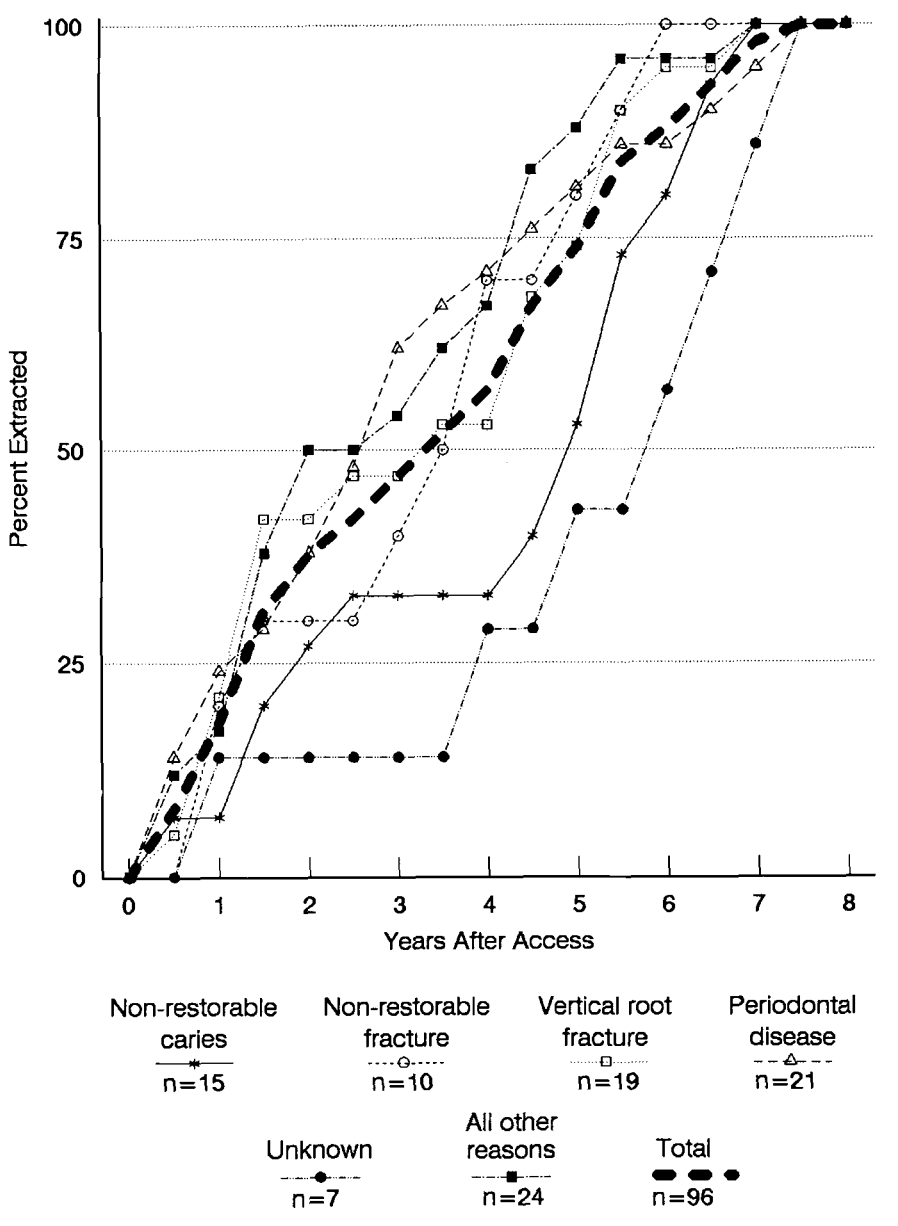
Table 4 presents similar data for the postaccess factors. None of these variables had a statistically significant bivariate relationship with case/control status.

Fourteen preaccess and two postaccess variables were eligible for the multivariable analysis. At this point, two controls missing 23 and 24 teeth at access were excluded because these values were more than four standard deviations from the control mean. The final regression model (Table 5), which contains only preaccess factors, was constructed using data from 96 cases and 118 controls.

Controlling for other variables in the model, RCF teeth with fewer than two proximal contacts at access had almost three times the odds of being lost as did teeth with two proximal contacts. Older age was associated with tooth loss, and individuals with a history of facial injury had over three times the odds of losing the tooth as did those with no such history. Patients missing more teeth at access were more likely to lose the RCF tooth, as were those with more plaque.

Since third molars are often extracted for preventive reasons, many second molars should be expected to have only one proximal contact. Observed differences in the number of

FIGURE 1
Time from Access to Extraction, by Reason for Extraction



proximal contacts between cases and controls thus could have resulted from different proportions of second molars in the two groups. However, the case and control groups had similar percentages of second molars (22% vs 18%, respectively).

Discussion

As with all retrospective studies, data quality was dependent on the legibility and completeness of documentation. Since computerized records were used to identify the sample and determine the provision of intracanal dowels and cuspal coverage post-operatively, any miscodings during original data entry could have affected the findings. In addition, self-reported data are subject to prevarication and recall bias.

Generalizability is limited, since the sample was composed of those who were employed (or were dependents of employed individuals) and had dental insurance for eight consecutive years. Determinants of health care utilization include demographic, socioeconomic, and attitudinal variables (14,15), and insured populations are more likely to use dental services than are noninsured populations (16,17). Additionally, of the roughly 75,000 members of KPDCP in January 1987, only about 29,000 (39%) were insured continuously for the next eight years. Enrollees with this extent of continuous coverage might differ substantially from those without in terms of stability of employment, education, age, and other factors potentially related to tooth loss and/or general health.

The sample included only patients who chose and completed endodontic therapy. We do not know what patient and provider preferences were acting at the time the decision was made to save the tooth, and one cannot predict the outcome of RCT on teeth for which extraction was chosen. Furthermore, patients who had the tooth accessed but not obturated might differ from those who completed endodontic therapy in terms of socioeconomic or attitudinal factors.

Several variables were not used in multivariable analyses because they had either too many missing values (e.g., anxious during dental treatment) or too imbalanced a distribution to provide meaningful results (e.g., diabetes). Associations between these factors and tooth loss potentially could be found in studies with greater sample sizes or prospective designs.

Even if missing values had not been an issue, the present design precluded ascertainment of many factors that could influence tooth loss. Income, education, history of tobacco use, and attitude toward keeping teeth were unavailable from existing records, as were factors such as providers' skill level, presence or absence of opposing teeth, and whether the tooth was a retainer for a removable partial denture. Still other variables were merely estimated from radiographs (e.g., ≥4 decayed or filled tooth surfaces). More detailed information about these factors might have affected the findings.

Potential misclassifications existed for several variables. The most recent radiograph in the area of the RCF tooth helped verify the case/control status originally assigned based on entries in the computerized database. However, a tooth could have been extracted after the most recent radiograph but prior to the end of 1994; if there had been a miscoding at extraction, outcome misclassification could have resulted. This error could occur only for those who truly lost the tooth, since a tooth miss-

TABLE 3
Preaccess Factors, by Case/Control Status

	Cases		Controls		
Preaccess Factor	*n*	% or Mean (SD)	*n*	% or Mean (SD)	*P*-value
Number of proximal contacts	95		117		.000
2		43		72	
1		47		25	
0		9		3	
Mean age	96	51.6 (12.7)	120	44.6 (11.7)	.000
Mean number of missing nonwisdom teeth	96	5.4 (5.0)	120	3.1 (4.0)	.000
Mean number of missing first molars	96	1.4 (1.3)	120	0.8 (1.1)	.002
Anxious during dental treatment*	83	16	112	34	.004
Bridge abutment†	96	14	120	3	.006
≥1 medication of any kind	96	49	120	31	.007
Diabetes†	96	8	119	2	.022
Heart/hypertension medication	96	20	120	9	.025
Denture or partial*	84	37	116	23	.037
Plaque‡	95	56	118	42	.039
Keep teeth for lifetime*	77	69	105	82	.041
≥4 DF surfaces	96	29	119	18	.066
Mean # of pockets ≥5 mm on tooth at access	92	0.84 (1.3)	113	0.53 (1.0)	.066
Mean proportion of teeth with at least one pocket ≥5 mm	92	0.26 (0.28)	113	0.19 (0.21)	.067
History of facial injury	92	14	119	7	.075
Cuspal coverage	96	24	120	15	.096
Lower tooth	96	51	120	41	.135
Anterior tooth	96	21	120	13	.143
Stain*‡	90	37	111	27	.144
Fluoridated water/tablets*	82	12	115	20	.149
Bleed excessively†	94	7	120	3	.177
Bleeding*‡	90	57	111	48	.209
Had obvious PA lesion*	92	67	112	59	.215
≥1 DF root surface	96	34	119	27	.236
Male	96	43	120	36	.304
3 DF coronal surfaces	96	71	119	65	.342
High copay plan	95	31	116	25	.372
Symptomatic	96	76	120	81	.394
Brushing¶	94	15	115	11	.443
Ortho treatment/braces*	85	8	116	10	.614
Elective RCT†	96	7	120	6	.666
Decayed	96	29	120	27	.684
Frequently consume sugar*	83	39	114	37	.807
Calculus‡	95	48	118	50	.819
Molar	96	44	120	43	.951
Flossing*¶	87	41	111	41	.993

*Ineligible for multivariable analysis: ≥5% missing values.
†Ineligible for multivariable analysis: ≥90/10 split in univariate frequency distribution.
‡Percent moderate or heavy as opposed to none or light.
¶Percent poor as opposed to good or fair.

ing on the most recent radiograph could not truly have been kept. Misclassifications of this type would tend to weaken observed associations, since the group designated as controls would actually contain both cases and controls.

Errors also could have occurred in the assignment of restoration type based on a preaccess radiograph rather than on clinical information, since certain amalgam fillings (especially four- or five-surface restorations) can appear to be crowns radiographically. Although most assigna-

TABLE 4
Postaccess Factors, by Case/Control Status

Postaccess Factor	Cases		Controls		
	n	% or Median	*n*	% or Median	*P*-value
Median number of days from obturation to foundation*	86	13	118	50	.062
Initially crowned or abutted within 2 years of obturation	96	12	120	21	.107
Obturated by nonendodontist	96	35	120	26	.128
Fill with obvious voids†	95	7	119	3	.188
Overfill	95	31	119	24	.315
Short fill	95	15	118	19	.364
Number of canals found during RCT	96		119		.373
1		48		37	
2		11		22	
3		33		33	
4		8		8	
Median number of days from access to obturation	96	44	120	57	.591
Dowel within 2 years of obturation	96	22	120	20	.737
≥1 endodontic complication	96	16	120	17	.837

*Ineligible for multivariable anlaysis: ≥5% missing values.
†Ineligible for multivariable analysis: ≥90/10 split in univariate frequency distribution.

TABLE 5
Final Logistic Regression Model for Loss of RCF Tooth

Variable	Parameter Estimate	Standard Error	*P*-value	Odds Ratio (95% CI)
Intercept	-1.430	.318	—	—
Number of proximal contacts (two=0, zero or one=1)	1.005	.322	.002	2.7 (1.4–5.1)
Age (continuous, centered at 50 years, per 10-year increase)	0.346	.140	.014	1.4 (1.1–1.9)
History of facial injury (no=0, yes=1)	1.288	.544	.018	3.6 (1.2–10.5)
Number of missing nonwisdom teeth (0–1)=0, (2–4)=1, (5–8)=2, (9–22)=3	0.391	.176	.026	1.5 (1.0–2.1)
Plaque (none or light=0, moderate=1, heavy=2)	0.507	.238	.033	1.7 (1.0–2.6)

n=214 (96 cases, 118 controls); sensitivity=67%; specificity=70%.

tions were probably correct, there is no guarantee of their accuracy. Misclassifications of this sort would not have occurred differentially between cases and controls; however, the observed impact of the misclassified variables could be lessened, resulting in their failure to remain in multivariable models.

Finally, the study's main objective was to determine what variables were most strongly related to loss of RCF teeth. The study could be considered "hypothesis-generating," since no variable was forced into the regression models. Despite this approach, no adjustments were made for multiple comparisons. Had such adjustments been made, fewer variables would remain significant and estimated parameter values would change.

Model Interpretation. The factor most strongly associated with tooth loss was the number of proximal contacts at access. At least four theories are consistent with this finding. First, adjacent teeth help distribute occlusal forces over a wider span, thus reducing the load borne by any individual tooth. Second, bridge abutments were defined as having fewer than two contacts, and these can be more difficult to clean than nonbridge abutments. Third, removable partial dentures (RPDs) often contain clasps on teeth bounded by an edentulous space, and RPD clasps not only stress the clasped teeth, but also are associated with enhanced plaque retention (18), periodontal disease, and caries (19). Fourth, RCF teeth are more likely to have two proximal contacts in mouths with fewer missing teeth, and these patients may have less oral disease, better hygiene, or place greater value on keeping their teeth than do patients with more missing teeth. This last possibility also helps explain the presence of NMTA in the model.

Older age was associated with loss of the RCF tooth. Because age was correlated with "heart/hypertension medication" and "proportion of teeth with at least one pocket ≥5 mm," both of which had strong bivariate associations with loss of the RCF tooth, the latter two variables did not remain in

the model. Several other multivariable models of tooth loss or edentulousness did not contain age, but did list indicators of periodontal disease, such as Russell's Periodontal Index (8) and number of teeth with periodontal pockets ≥6 mm (9). Perhaps in these models, inclusion of periodontal variables kept age from remaining, because age and periodontal status likely were correlated and because periodontal status, more than age, may be related to loss of at least one tooth or all remaining teeth.

The periodontal variables reported in the present study likely did not remain in the model because (1) few teeth would be treated endodontically if their periodontal status was highly suspect, and (2) poor overall periodontal status may not adequately represent the periodontal condition of the RCF tooth, especially since the tooth was deemed worthy of obturation. In other words, periodontal variables may not have appeared in the present model because the outcome under study was tooth specific. With periodontal variables explaining a smaller portion of the variance than in previous studies of tooth loss, age could be expected to explain some of that variance and thus remain in the model.

"History of facial injury" also remained in the final model. If the teeth under study had received RCT secondary to trauma, they more likely could have been lost than other RCF teeth due to their potential for resorption or subcrestal root fracture. However, the reason for initiation of RCT was not ascertained because the pilot study showed this to be underrecorded in the dentists' treatment notes.

Because it could not be determined whether the teeth under study had been traumatized prior to RCT, additional analyses were conducted to address this issue. Because teeth affected by trauma tend to be located in the anterior of the mouth, a bivariate contingency table was created between "history of facial injury" and "anterior tooth." Among those who had been injured, 29 percent had anterior teeth as the tooth of interest, compared to only 14 percent among those with no history of facial injury (P=.086), suggesting that at least some anterior teeth may have received RCT secondary to trauma. Furthermore, seven teeth appeared sound at access and thus were likely to have been traumatized. Five of these were anterior teeth, three of which were lost, while one of two posterior teeth was lost.

Finally, patients with more plaque were more likely to lose the RCF tooth than were those with less plaque. This finding is not surprising, since two common antecedents of tooth loss, periodontal disease and caries (20-23), are both caused by pathogens found in dental plaque.

Restoration of RCF Teeth. Postobturation restorative treatment has been the focus of several articles in the prosthodontic literature. Two widely referenced retrospective studies by Sorensen and Martinoff (24,25) analyzed the failure of 1,273 RCF teeth over a 1–25-year period. Failures were classified on the presence and type of intracanal dowel, the presence of cuspal coverage, and the type of abutment for which the tooth had been used. Here, "failure" included dislodgement of posts and castings, restorable fracture, and tooth loss. Major findings were that (1) intracanal dowels were associated with greater failure in single crowns and less failure in RPD abutments; (2) cuspal coverage was related to less failure in posterior teeth, but not in anterior teeth; and (3) bridge and RPD abutments were more likely to fail than were teeth with single crowns.

The present study and the Sorensen and Martinoff studies are difficult to compare. As previously mentioned, Sorensen and Martinoff included cementation breakdowns and restorable fractures as failures, while the present study used only tooth loss as the outcome of interest. Sorensen and Martinoff excluded teeth that had been RCF for less than one year, but 23 percent of the 96 lost teeth in the present sample were extracted within a year of obturation. Finally, information relating to dowel placement and postobturation cuspal coverage in the present study was obtained from a computerized database rather than from patient records.

Dentists may be unwilling to expend time and effort crowning teeth they think could fail for other reasons (e.g., they may only place crowns on teeth for which RCT has proven successful). The greater time between obturation and foundation placement among controls (Table 4) might indicate a postobturation observation period intended to assure the adequacy of RCT prior to initiation of definitive restorative treatment. This practice also could explain the greater success noted by Sorensen and Martinoff for crowned posterior teeth compared to those without cuspal coverage.

Table 3 shows that, bivariately, teeth that were bridge abutments at access were more likely lost than nonabutted teeth. This finding could result from increased stress on abutment teeth, but also might reflect the extreme measures taken by both dentists and patients to save teeth that they feel have greater than normal value. In fact, the treating dentist mentioned a compromised prognosis for six (35%) of the 17 teeth abutted at access, compared to only 21 (11%) of the 199 nonabutted teeth (P=.003). This difference suggests that while occlusal forces on RCF abutments might have an effect on tooth loss (26), the decision to provide endodontic therapy for an already compromised tooth also might be influential. Such documentation also could reflect dentists' prior adverse outcomes with RCF abutment teeth.

Finally, dentists who recommended extraction for the lost teeth were not calibrated with respect to the reason for (or the documentation of) that recommendation, and no attempts were made to evaluate provider-related clustering with respect to the reason for extraction. Still, from Figure 1 it appears that teeth extracted due to nonrestorable caries tended to remain in the mouth longer than did most other RCF teeth. One explanation is that the treating dentist generally removes existing decay from the tooth prior to obturation, implying that RCF teeth lost due to nonrestorable caries should have developed the condition entirely after obturation. The same cannot be said for RCF teeth lost due to fracture or periodontal disease. Cracks too small to be detected visually could be present in a tooth at obturation, and over time occlusal forces could initiate catastrophic fracture. Teeth also can have periodontal disease at obturation; of the 21 teeth lost for periodontal reasons, eight (38%) had been noted by the treating dentist as having had existing periodontal disease at access.

As stated by Shugars and Bader (27), " ... the profession has limited knowledge of the likelihood that cer-

tain commonly used treatments will yield specified outcomes." The present study addresses this issue by providing information that can help dentists and patients make more informed choices with respect to the RCT versus extraction decision. This knowledge is of particular importance to dentists practicing in public health clinics, given the frequency with which this decision must be made and the limited financial resources common to most publicly funded programs.

The results suggest that variables at the tooth level (number of proximal contacts), mouth level (number of missing teeth, plaque), and patient level (age, history of facial injury) are associated with loss of RCF teeth, implying that loss of a particular tooth is influenced by more than tooth-specific features. The findings also suggest that variables ascertainable at the time of treatment planning are related more strongly to subsequent loss of an RCF tooth than are endodontic or postobturation restorative factors. This finding implies that, after validation in other samples and adjustment for the present sampling fractions among cases and controls (28), the model shown in Table 5 could be used to assess a patient's relative likelihood of losing an RCF tooth.

It may be simplistic, unethical, or clinically unwise to recommend extraction over RCT based solely on threshold values for a patient's age, number of missing teeth, or plaque level. However, risk-based guidelines could be developed to aid providers in recommending treatment, especially in situations where both the patient and dentist are equivocal about the RCT versus extraction decision. Guidelines created in this manner should not be the lone criterion upon which the decision is based, but should supplement other factors considered by providers when making treatment recommendations (e.g., relative importance of the tooth in the overall treatment scheme). The patient's perceived value of the tooth also should be addressed (e.g., a poor prognosis may be more acceptable to patients who feel they "only need the tooth for a few years").

Prospective studies would permit the collection of potentially important variables that were unavailable or only estimated in the present study. Prospective studies also would allow for determination of patient and provider attitudes toward endodontic and restorative therapies. Patients could make a priori and a posteriori value judgments about the RCT versus extraction decision; findings could be incorporated into decision-analytic approaches concerning endodontic versus exodontic treatment, and related economic issues also could be investigated (29). Finally, using this insured population, it ultimately may be possible to design randomized clinical trials to test the effectiveness of various restorative therapies (e.g., assigning patients to receive either cast crowns or amalgam buildups on posterior RCF teeth).

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