

# Outcomes of root canal treatment in Dental Practice-Based Research Network practices

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This study sought to quantify the incidence of root canal treatment (RCT) failure and identify its predictors in root canals that were performed or referred by general dentistry practices in a practice-based research network (PBRN). This retrospective cohort study involved 174 endodontically treated teeth. Mean duration from initial therapy to follow-up was 8.6 years. Permanent restorations were ultimately placed in 89% of teeth, although 18% of teeth were ultimately extracted anyway. Receiving a permanent restoration was

a significant predictor of treatment failure (in other words, patients who did not receive a permanent restoration were more likely to experience RCT failure), whether failure was determined clinically or radiographically. This study of PBRN practices suggests a higher failure rate compared with studies that utilized highly controlled environments or populations with high levels of dental insurance.

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Estimates of the success of non-surgical root canal treatment (RCT) have varied widely. Many studies and endodontic textbooks have reported very high success rates; however, RCT outcome studies usually have been conducted in academic settings or among patient populations with high levels of dental insurance coverage.<sup>1-5</sup> As a result, it may not be possible to apply these results to community-based private practices. RCT outcome studies are warranted for these community settings.

In addition, these studies have shown wide variations in terms of how treatment failure is defined. Some studies have relied entirely on information gleaned from radiographs. Others have excluded extracted or fractured teeth, using the justification that extractions, fractures, and restoration failures were not directly caused by the RCT and therefore should not be included as part of the assessment.<sup>5</sup> It could be instructive to conduct RCT outcome studies within actual community settings using multiple definitions of failure, to better assess

how the definition of treatment failure affects interpreting the results.

Practice-based research networks (PBRNs) offer a venue for conducting RCT outcome studies in community private practice settings. PBRNs have existed in the U.S. since the 1970s.<sup>6</sup> These networks bring dentists and academic researchers together to develop and answer relevant research questions that can directly impact routine clinical practice. These networks offer unique advantages when conducting research about routine clinical care and when investigating how to improve the quality of clinical care, while fostering the sharing of information between practitioners.<sup>7-10</sup>

Traditionally, clinical research has been conducted in academic settings; however, less than 1% of the U.S. population receives its health care in that type of setting.<sup>11</sup> Studies that are initiated and developed by non-academic practitioners and conducted in their offices (as is the case with PBRNs) should produce results that are more relevant to these clinicians and should lead to improved clinical treatment in

a shorter amount of time in these non-academic settings, compared to conventional clinical research performed in academic settings by academic dentists.<sup>7-9</sup> The Dental Practice-Based Research Network (DPBRN) originated in Alabama and expanded to include four other regions.<sup>12</sup> The Alabama portion of the DPBRN served as the setting for the present study.

This study sought to quantify the incidence of RCT failure in private practice settings, using three different definitions of treatment failure; to quantify the typical length of time required for an endodontically treated tooth to receive a permanent restoration in a private practice setting; to test the hypothesis that receipt of a permanent restoration is a significant predictor of treatment failure; and to test the hypothesis that other factors are significant predictors of treatment failure. A retrospective cohort study was designed to meet these objectives.

## Materials and methods

Practices in the community were identified based on the Alabama

portion of the DPBRN. Dentist practitioner-investigators were recruited through mailings to licensed dentists. As part of enrollment in the DPBRN, all practitioner-investigators complete a 101-item enrollment questionnaire about themselves and their practice characteristics. Surveys in the literature have demonstrated that DPBRN dentists have much in common with dentists at large.<sup>13</sup>

### **Recruitment methods**

Practices consisting of general dentists were identified for inclusion in the current study if they were enrolled in the DPBRN, had a practice address in Alabama, and performed or referred more than 20 root canals each month (based on a question posed in the enrollment questionnaire). From the 25 practitioner-investigators who met these criteria and expressed a desire to be included in the study, 13 were included in the study after a visit to the practice confirmed that the practice's dental charts would consistently include the treatment information and radiographs necessary for the study. A follow-up date was arranged for the research assistant to screen charts for potential cases. Because most practices had hundreds of charts, a random number generator was used to identify a random start for chart review.

### **Chart abstraction procedures**

A research assistant whose background included training as a certified dental assistant was trained in chart abstraction, using dental charts from dental schools and private practices. Following several training sessions, she achieved standardization in proper abstraction procedures specific to this study and achieved high intra-rater reliability. This research assistant contacted all

of the offices, screened the charts, abstracted and entered data, and scanned radiographs.

Dental charts were used to abstract dates of all visits in which any treatment was administered to endodontically treated teeth. RCT was defined as ADA codes 3310, 3320, or 3330; in addition, the researchers recorded the tooth or areas treated; ADA codes for all procedures performed on that tooth; a description of the procedure code (to ensure that the code matched its description); whether the tooth served as an abutment for a removable partial denture (RPD), overdenture, or fixed partial denture; whether the RCT was done by going through an existing prosthetic crown; whether the RCT was performed by a general dentist or an endodontist; the date of data entry; and the patient's demographic characteristics.<sup>14</sup> Data were gathered from a total of 174 teeth in 84 subjects.

### **Measurements made from radiographs**

Two endodontic faculty evaluators (KT and MB) made measurements from radiographs taken before and after each RCT procedure. No identifying information was provided with these radiographs so as to mask any characteristics of the subjects. All but one of the preoperative radiographs were periapical; the other was a panoramic radiograph. Of the postoperative films, 78% were panoramic and 22% were periapical. Each evaluator made a determination as to whether the resolution of the radiograph was sufficient to make an accurate measurement. Of the 174 endodontically treated teeth, 115 had radiographic measurements made. The excluded radiographs were either panoramic radiographs

with inadequate resolution or films whose imaging of periapical structures was insufficient.

The two evaluators were calibrated on the use of the periapical index (PAI) (1–5 scale) using an authorized reference set provided by Orstavik.<sup>15</sup> Evaluation of the study radiographs was done independently, although the evaluators re-evaluated any disagreements jointly and reached a consensus. All radiographs were digitized before measurements were taken. From these images, the evaluators recorded the number of pre- and post-RCT proximal contacts (either 0, 1, or 2) and pre- and post-RCT measurements of the PAI.

Pre- and post-RCT bone loss were measured by using a digital subtraction laboratory. A measurement was made from the crestal bone height to the root apex, which served as the numerator. The denominator was calculated by measuring the distance from the cemento-enamel junction to the root apex.

Using the pre-RCT radiograph only, the evaluators recorded whether there was radiographic evidence of caries at access. Using the post-RCT radiographs only, the evaluators recorded whether there was any radiographic evidence of recurrent caries adjacent to the restoration that restored the RCT; whether the RCT filling was inadequate; the presence of a permanent restoration; and if the restoration was inadequate.

### **Definitions of failure and follow-up period**

One measure of failure was whether the endodontically treated tooth was ultimately extracted. Such occurrences were documented, as were the number of days between the date that RCT was completed and the date when the extraction was performed.

**Table 1.** Number (and percentage) of endodontically treated teeth that failed, according to definition of failure and the tooth's characteristic or clinical circumstance ( $n$  = endodontically treated teeth;  $n_1$  = radiographically measured teeth).

Characteristics	Teeth that were extracted (%)	Teeth that experienced clinical failure (%)	Teeth that displayed evidence of radiographic failure (%)
Overall ( $n = 174$ ; $n_1 = 115$ )	31 (18)	35 (20)	30 (26)
<b>Gender of RCT patient</b>			
Female ( $n = 86$ ; $n_1 = 53$ )	16 (19)*	20 (23)*	15 (28)*
Male ( $n = 88$ ; $n_1 = 62$ )	15 (17)	15 (17)	20 (32)
<b>Race of RCT patient</b>			
Non-white ( $n = 13$ ; $n_1 = 10$ )	4 (31)*	4 (31)*	4 (40)*
White ( $n = 161$ ; $n_1 = 105$ )	27 (17)	31 (19)	31 (30)
<b>Tooth type</b>			
Anterior ( $n = 30$ ; $n_1 = 19$ )	2 (7)†	3 (10)†	3 (16)†
Premolar ( $n = 57$ ; $n_1 = 36$ )	11 (19)	12 (21)	11 (31)
Molar ( $n = 87$ ; $n_1 = 60$ )	18 (21)	20 (23)	21 (35)
<b>Tooth received a permanent restoration during follow-up</b>			
No ( $n = 20$ ; $n_1 = 9$ )	8 (40)†	9 (45)‡	5 (56)*
Yes ( $n = 154$ ; $n_1 = 106$ )	23 (15)	26 (17)	30 (28)
<b>Tooth was an RPD abutment at the time RCT was initiated</b>			
No ( $n = 169$ ; $n_1 = 112$ )	28 (17)†	32 (19)*	33 (29)*
Yes ( $n = 5$ ; $n_1 = 3$ )	3 (60)	3 (60)	3 (67)
<b>Tooth was a bridge abutment at the time RCT was initiated</b>			
No ( $n = 163$ ; $n_1 = 109$ )	30 (18)*	34 (21)*	34 (31)*
Yes ( $n = 11$ ; $n_1 = 6$ )	1 (9)	1 (9)	1 (17)
<b>RCT was performed by accessing through an existing crown</b>			
No ( $n = 97$ ; $n_1 = 65$ )	18 (19)*	21 (22)*	20 (31)*
Yes ( $n = 77$ ; $n_1 = 50$ )	13 (17)	14 (18)	15 (30)
<b>Number of proximal contacts at the time RCT was initiated</b>			
None ( $n = 0$ ; $n_1 = 5$ )	0 (0)‡	0 (0)‡	4 (80)
One or two ( $n = 0$ ; $n_1 = 110$ )	19 (17)	21 (19)	31 (28)

A second measure of failure known as *clinical failure* was applied to endodontically treated teeth that were extracted or received endodontic retreatment (ADA codes 3346, 3347, 3348, or 3410). The *clinical survival time* was defined as the number of days between the completion of RCT

and either the date when clinical failure occurred or, when clinical failure did not occur, the date of the last clinical visit.

A tooth was classified as a *radiographic failure* if the endodontically treated tooth had been extracted, received endodontic retreatment, or had a PAI score of

3, 4, or 5 based on the post-RCT radiograph. The *radiographic survival time* was defined as the number of days between the completion of RCT and either the date that radiographic failure occurred or, when radiographic failure did not occur, the date of the tooth's last radiograph.

Characteristics	Teeth that were extracted (%)	Teeth that experienced clinical failure (%)	Teeth that displayed evidence of radiographic failure (%)
<i>Tooth had radiographic evidence of caries at the time of RCT access</i>			
No ( $n = 0$ ; $n_1 = 97$ )	16 (16)*	18 (19)*	29 (30)*
Yes ( $n = 0$ ; $n_1 = 18$ )	3 (17)	3 (17)	6 (33)
<i>Periapical index score at the time RCT was initiated</i>			
1 ( $n = 0$ ; $n_1 = 26$ )	3 (12)*	4 (15)*	7 (27)*
2 ( $n = 0$ ; $n_1 = 33$ )	2 (6)	3 (9)	6 (18)
3 ( $n = 0$ ; $n_1 = 37$ )	10 (27)	10 (27)	14 (38)
4 ( $n = 0$ ; $n_1 = 17$ )	3 (18)	3 (18)	7 (41)
5 ( $n = 0$ ; $n_1 = 2$ )	1 (50)	1 (50)	1 (50)
<i>Recurrent decay was present adjacent to the restoration on the post-RCT radiograph</i>			
No ( $n = 0$ ; $n_1 = 99$ )	9 (9)‡	11 (11)‡	24 (22)‡
Yes ( $n = 0$ ; $n_1 = 7$ )	2 (29)	2 (29)	3 (43)
Missing ( $n_1 = 9$ )§			
<i>The endodontic fill was judged to be poor based on the post-RCT radiograph</i>			
No ( $n = 0$ ; $n_1 = 90$ )	9 (10)‡	10 (11)‡	19 (21)‡
Yes ( $n = 0$ ; $n_1 = 16$ )	2 (13)	3 (19)	8 (50)
Missing ( $n_1 = 9$ )§			
<i>Restoration had an overhang or open margin on the post-RCT radiograph</i>			
No ( $n = 0$ ; $n_1 = 104$ )	9 (9)‡	11 (11)‡	25 (24)‡
Yes ( $n = 0$ ; $n_1 = 2$ )	2 (100)	2 (100)	2 (100)
Missing ( $n_1 = 9$ )§			

\* Not statistically significant

‡ Statistically significant at  $p < 0.05$

‡ Could not be tested because the regression estimation algorithm would not converge

§ Clear determinations could not be made from a post-RCT radiograph in terms of the presence of recurrent decay, quality of the endodontic fill, or whether the restoration had an overhang or open margin

### Statistical methods

All analyses were done using SAS (SAS Institute, Inc.). Statistical significance refers to probabilities of less than 0.05. To account for the fact that individual RCTs were clustered within individual patients and dental practices (which might correlate outcomes), generalized

linear mixed models (GLIMMIX procedure) were used to implement logistic regression analyses of these outcomes (extractions, clinical failure, and radiographic failure) (see Tables 1 and 2). Associations with time to failure (that is, associations between the predictor variables and the outcome of interest) were evalu-

ated using an analogous multiple linear regression model, also implemented with GLIMMIX in order to account for correlated observations.

The GLIMMIX procedure implements models (including random effects) to account for correlated observations. A pseudo-likelihood estimation approach is used to fit

**Table 2. Results from three multiple logistic regressions in which three different measures of failure were used as the outcomes for analysis.**

Outcome	Explanatory variable	Odds ratio (95% CI)	<i>p</i> value	Regression	Generalized $\chi^2$ (per df)
Tooth was extracted	Permanent restoration	3.7 (1.2; 11.5)	0.03	170	128.2 (0.79)
Tooth was extracted or received endodontic retreatment	Permanent restoration	4.1 (1.4; 12.2)	0.01	170	138.5 (0.85)
Tooth had radiographic evidence of failure	Permanent restoration	6.1 (1.2; 31.4)	0.03	113	104.5 (0.99)

statistical models to data that are not necessarily normally distributed. This approach allows the models to account for correlations among observations—which may occur when multiple observations are made on the same sampling unit (that is, multiple teeth within the same patient)—and for non-constant variability among groups.

Using *t*-tests, the mean ages of patients with and without clinical failure of teeth and those with and without radiographic evidence of failure were compared.

**Results**

**Characteristics of the practices**

All 13 of the practitioner-investigators who participated had been in general practice from 11–39 years; 92% (*n* = 12) were male; 85% (*n* = 11) were non-Hispanic Caucasian, while the remaining 15% (*n* = 2) were non-Hispanic African-American. Among the practitioner-investigators who participated in the study, 23% (*n* = 3) devoted 1–10% of patient contact time to performing RCT procedures, while 8% (*n* = 1) spent 11–20% of their time on these procedures; the remaining 69% (*n* = 9) devoted no time to these performing these procedures. All of the practitioner-investigators reported spending at least 51% of

their patient contact time performing restorative dentistry procedures that are not related to dental implants (for example, amalgams, composites, crowns, bridges, posts, foundations); one practice reported that the figure was closer to 90%.

Practitioner-investigators reported that the median waiting time for a treatment procedure appointment was five days (range = 2–30 days). When asked to characterize their practice workload during the previous 12 months, three practitioner-investigators reported that their practice was “too busy to treat all people requesting appointments”; four responded that they “provided care to all who requested appointments, but the practice was overburdened”; four responded that they “provided care to all who requested appointments, and the practice was not overburdened”; and two responded that they were “not busy enough—the practice could have treated more patients.”

The racial mix of patients in these practices varied widely. One practice reported that more than 90% of patients were black or African-American, while three practices reported less than 10%. The percentage of practice revenues derived from patient self-payments (rather than a dental insurance source)

varied widely as well; five practices responded that 21–30% of revenues were derived from self-pay; two said 31–40%; three said 41–50%; two said 71–80%; and one said that 81–90% of revenues were derived from self-pay.

**Characteristics of the RCT-treated patients**

Among the patients who received RCT, 55% were female. A total of 94% of patients who received RCT were non-Hispanic Caucasian; the remainder were non-Hispanic African-American. Patients ranged in age from 18–85, with a mean age of 49.2 (SD ± 12.9) at the time of RCT.

**Characteristics of the RCT-treated teeth**

Of the 174 teeth that received RCT, 17% (*n* = 30) were anterior teeth, 33% (*n* = 57) were premolars, and 50% (*n* = 87) were molars. For 44% (*n* = 77) of all teeth, the initial RCT was accessed by going through an existing prosthetic crown. At the time RCT was initiated, 3% (*n* = 5) of teeth served as abutments for RPDs; 6% (*n* = 11) were fixed partial denture abutments at the time that the RCT was initiated. There were no overdenture abutments.

Of the 115 teeth with radiographic data, 64% (*n* = 74) had

two proximal contacts at the time of initial RCT access, while 31% ( $n = 36$ ) had one proximal contact and 4% ( $n = 5$ ) had none. Of these 115 teeth, 16% ( $n = 18$ ) had radiographic evidence of dental caries (on the pre-RCT radiograph) in the tooth area that was accessed for RCT. Twenty-three percent ( $n = 26$ ) of these teeth with radiographic data had a pre-RCT PAI score of 1; 29% ( $n = 33$ ) had a score of 2; 32% ( $n = 37$ ) had a score of 3; 15% ( $n = 17$ ) had a score of 4; and 2% ( $n = 2$ ) had a score of 5.

The mean (SD) percentage of bone loss at the time of the RCT was 16.7 (7.8), with a range of 0.5–41. At the time of the post-RCT radiograph, the mean percentage had increased to 17.8 (8.4). The difference in bone loss between pre- and post-RCT was not statistically significant.

Endodontists performed RCT on 52% of teeth; the remaining 48% were done by general dentists. This varied by tooth type. Thirty percent of anterior tooth RCTs were done by endodontists, compared to 51% of premolars and 60% of molars ( $\chi^2$  test; 2 df; value = 7.94;  $p < 0.02$ ).

Based on the post-RCT radiograph of teeth that had not been extracted, the evaluators judged that 15% of teeth ( $n = 2$ ) had a poor RCT restoration (that is, with an overhang or an open margin). At the time that RCT was initiated, only 1% of patients received a prescription for antibiotics.

#### **Treatment received after RCT**

A total of 89% of teeth ( $n = 154$ ) ultimately received a permanent restoration; in 50% of these cases ( $n = 77$ ), the restoration was placed within 37 days of the completion of RCT. Among those teeth that received a permanent restoration, the mean (SD) number of days to

permanent restoration was 215.4 (609.1), with a range of 0–6,289 days. When two outliers were excluded from the calculation (one tooth that went 2,210 days before restoration and another that went 6,289 days), the mean (SD) number of days to permanent restoration was reduced to 158.5 (285.7).

Based on the results of the survey (after excluding the two outliers), permanent restorations were completed sooner when RCT was done by an endodontist (mean (SD) of 140.8 (239.1) days) than when RCT was done by a general dentist (mean (SD) of 177.8 (329.9) days), but this difference was not statistically significant. Of the 81 teeth treated by general dentists, 22 received RCT in one appointment, compared to 80 of the 93 teeth treated by endodontists. This difference was statistically significant ( $p < 0.05$ ).

Based on the post-RCT radiographs of teeth that had not been extracted, 7% of the teeth had recurrent caries and 2% of the restorations were judged to be poor by the evaluators.

#### **Survival time and failure rate of RCT-treated teeth**

Among all 174 teeth, the mean (SD) length of the period from initial treatment to follow-up was 8.6 (5.1) years. When limited to those teeth that were not extracted and showed no evidence of clinical or radiographic failure, the mean (SD) length of the follow-up period was 8.8 (5.1) years, with a range of 1.2–28.6 years.

A total of 18% of teeth were extracted at some point after RCT had been completed. Among these extracted teeth, the mean (SD) time from RCT to extraction was 6.7 (4.5) years, with a range of 0.3–16.8 years. Twenty percent of teeth were judged as having clinical evidence

of failure (that is, extraction or endodontic re-treatment). Among these teeth with clinical failure, the mean (SD) clinical survival time was 7.3 (5.0) years, with a range of 0–18.0 years.

Among those teeth that had preoperative and postoperative radiographs of satisfactory quality ( $n = 115$ ), 30% ( $n = 35$ ) were judged as having radiographic evidence of failure; these teeth had a mean (SD) survival time of 7.3 (4.2) years, with a range of 0.8–21.8 years. Among all teeth with any data, 27% ( $n = 47$ ) were extracted, failed clinically, and/or demonstrated radiographic evidence of failure.

#### **Characteristics related to failure rate**

Using three definitions of treatment failure, the characteristics of patients and teeth were analyzed to quantify their relationships to the probability of RCT failure (see Table 1). Neither patient gender or race were significantly associated with failure. The patient's age was significantly associated with clinical and radiographic failure but not with extraction. The mean (SD) age of those with one or more teeth showing clinical failure was 50.5 (11.8), compared to 52.4 (13.0) for those without clinical failure ( $p < 0.05$ ;  $t$ -test). The mean age (SD) of those who had one or more teeth with radiographic evidence of failure was 49.7 (10.6), compared to 54.5 (13.0) for patients with no radiographic evidence of failure ( $p < 0.05$ ;  $t$ -test).

The receipt of a permanent restoration was a statistically significant predictor of failure (that is, patients who did not receive a permanent restoration were more likely to experience RCT failure), as was whether RCT was performed on a tooth that also served as an abutment for

an RPD at the time that RCT was initiated. Radiographically, two factors were associated with failure: the number of proximal contacts at the time RCT was initiated and whether the endodontic fill was judged to be poor (see Table 1).

### Results from the multiple logistic regression

Table 2 shows the results of three logistic regressions that used three different outcomes for analysis. All regressions were adjusted for subject age, gender, race, and type of tooth, although these variables were not statistically significant.

One variable (whether the tooth received a permanent restoration) was statistically significant and had a substantive effect size (large odds ratio), regardless of which definition of failure was used. The point estimates for its odds ratios ranged from 3.7–6.1, depending on the outcome used for analysis.

Other variables (not shown in Table 2) also were statistically significant for some definitions of failure. Whether the endodontically treated tooth was an abutment for an RPD preoperatively was significantly associated with failure due to extraction and with clinical failure (extraction or endodontic retreatment), with permanent restoration, subject age, subject gender, subject race, and tooth type also in the regression. Additionally, whether the endodontically treated tooth had at least one proximal contact preoperatively was significantly associated with radiographic evidence of failure, with permanent restoration, subject age, subject gender, subject race, and tooth type also in the regression.

### Discussion

#### Treatment success rates

The present study suggests a lower percentage of RCT success than

those found in the literature. A success rate of 90–95% is commonly cited as a clinical expectation and some studies have observed success rates at this level.<sup>16</sup> A systematic review of the literature from 1966–2004 identified 306 articles that involved the outcomes of RCT, 51 of which included at least 100 teeth.<sup>17</sup> The review observed a radiographic success rate of approximately 82% over a five-year follow-up period; during that time, approximately 95% of teeth remained functional (that is, they were not extracted).<sup>17</sup>

The sample size in the present study exceeded the “100 teeth” threshold used in the 2004 literature review.<sup>17</sup> Although the small sample size in this study was a limitation, a key advantage of this study was that it used a community-based sample of practices. Traditionally, clinical research studies have been conducted only in academic settings (whose dentists, patients, and clinical circumstances may not be applicable outside of those settings) or in settings that included only patients with dental insurance. The sample of “real-world” general dentistry practices in the present study—with RCTs performed by general dentists and endodontists and the inclusion of both insured and uninsured patients—suggests a composite failure rate (either extraction, clinical failure, or radiographic failure) of approximately 27% during a mean follow-up period of more than eight years after RCT.

Additional limitations in the present study included the retrospective nature of the design, the need to rely on panoramic radiographs for many of the postoperative assessments, and the fact that complete sets of radiographs often were not available. Nonetheless, the main conclusion of this study was that

the failure rate was substantial. Had radiographs been excluded from the study, the failure rate would have been 20% and the delayed placement of a permanent restoration would have remained the key predictor of failure. The results from this study justify additional investigation in community-based practices. Such an investigation should have a prospective study design and full measurements should be obtained using all three definitions of failure.

#### Definitions of treatment success

The literature has made many attempts to define success of endodontic treatment.<sup>18</sup> Some definitions have relied on tooth fracture, periapical changes determined from radiographs, the need for retreatment, or the receipt of retreatment. The clinical significance of these changes and their effect on subsequent treatment have not been without controversy.

Some studies have used tooth retention as a key measure of treatment success.<sup>1,2,19–21</sup> Clearly, a major justification for much of dental care (including RCT) is tooth retention; using tooth retention as a key outcome measure is consistent with studies that have used it as a measure of quality of care.<sup>22</sup>

Although the need to extract an endodontically treated tooth may not be due directly to the RCT, RCT nonetheless is the precipitating event leading to a chain of restorative treatments that themselves can act as direct causes of treatment failure. Approximately 18% of the teeth in this study were extracted at some point following RCT.

A study by Lazarski *et al* found a 4% overall incidence of extraction following RCT after a shorter mean follow-up period of 14.7 months.<sup>2</sup> This lower rate may

be due to the fact that the study population consisted entirely of subjects who had dental insurance. A large U.S. study with a follow-up period similar to that of the present study (approximately eight years) consisted exclusively of patients with continuous dental insurance coverage and observed a 3% tooth loss during that time.<sup>1</sup> A large 2007 study from Taiwan (also limited to persons with dental insurance) utilized more than 1.5 million teeth and observed a tooth loss rate of 7% after a five-year follow-up period.<sup>4</sup>

By comparison, in a community-based study by Tilashalski *et al*, only 36% of patients had dental insurance. The authors observed a higher tooth loss rate; 19% of endodontically treated teeth were extracted after a mean follow-up period of only 24.8 months. This study also confirmed that RCT was not performed on teeth that had substantial periodontal attachment loss.<sup>19</sup>

One explanation for the higher failure rate in the current study is the fact that 11% of endodontically treated teeth never received restorative treatment by the end of the follow-up period. Temporary restorations and obturated canal systems are not impervious to bacteria and coronal leakage is an important factor in treatment failure.<sup>23</sup> Many previous studies excluded from enrollment or analysis all teeth that had not received definitive restorations. According to the literature, failure to place an adequate coronal restoration results in a lower success rate.<sup>2,24-26</sup> However, in a 2007 study, clinicians deliberately chose not to restore the tooth based on the patient's preoperative endodontic status, which suggests confounding between preoperative periapical status and whether a permanent restoration is placed.<sup>27</sup>

Among the 89% of teeth in the current study that actually received a permanent restoration at some point during follow-up, the mean time to restoration was 215.4 days after RCT. This finding indicates the value of conducting observational community-based studies and the value of including all teeth that receive RCT, rather than limiting the study to those that receive permanent restorations. The time to restoration after RCT was much less than ideal and was a key predictor for retention of the endodontically treated tooth.

The present study used populations with less dental insurance coverage and located in a community-based setting. Based on the results, the possibility of higher failure rates should enter into treatment planning discussions when RCT is considered for these populations.

Other investigators have observed a higher failure rate among endodontically treated teeth that were abutments for RPDs, with differences in failure rates varying, depending on whether the RPD was retained by a clasp or some other design.<sup>28,29</sup>

While periodontal bone loss is a key factor when considering RCT (and has been associated with an increased risk for tooth loss), the present study found no association between tooth extraction following RCT and preoperative bone loss.<sup>30</sup> It is reassuring that none of the teeth in the current study had severe bone loss (the mean bone loss was only 16%). This finding is consistent with the notion that by avoiding teeth with severe periodontal bone loss, the treatment plans for RCT in community practices are appropriate in that regard.

### Conclusion

This practice-based study suggests a higher failure rate for RCT than

those found in studies based either in academic environments or among populations with dental insurance. It also suggests that any delay between RCT and the restoration of an endodontically treated tooth could lead to failure and that the restoration of an endodontically treated tooth is a key predictor of the treatment's ultimate success. These factors should be considered when RCT is considered in community settings.

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### Disclaimer

The opinions and assertions contained herein are those of the authors and are not to be construed as necessarily representing the views of the respective universities or the National Institutes of Health. The informed consent of all human subjects who participated in this investigation was obtained after the nature of the procedures had been explained fully.

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