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Baseline Characteristics as Three-Year Predictors of Tooth Fracture and Crack Progression: Findings from the National Dental Practice-Based Research Network

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National Dental PBRN Collaborative Group

Abstract

Background: This practice-based study estimated the risk of tooth fractures and crack progression over three years, and correlated baseline patient-, tooth- and crack-level characteristics with these outcomes.

Methods: 209 National Dental Practice-Based Research Network dentists enrolled a convenience sample of 2,601 subjects with a cracked vital posterior tooth that were examined for at least one recall visit over three years. Data were collected at the patient-, tooth-, and crack-level at baseline, annual follow-up visits, and any interim visits. Associations between these characteristics and the subsequent same-tooth fractures and crack progression were quantified.

Results: 78 (3.0%; 95% CI: 2.4% – 3.7%) of the 2,601 teeth with crack(s) at baseline subsequently developed a fracture. 232 (12.3%; 95% CI: 10.9% – 13.8%) of 1,889 patients untreated prior to Y1 had some type of crack progression. Baseline tooth-level characteristics associated with tooth fracture: the tooth was maxillary, had a wear facet through enamel, a crack detectable with an explorer, on the facial surface, horizontal direction. Crack progression was associated with males and teeth having multiple cracks at baseline; teeth with a baseline facial crack were less likely to demonstrate crack progression. There was no commonality between characteristics associated with tooth fracture compared to characteristics associated with crack progression.

Conclusions: Development of tooth fractures and crack progression over 3 years were rare occurrences. Specific characteristics were associated with the development of tooth fracture and crack progression, although none were common to both.

Practical Implications: This information can aid dentists in assessing factors that place posterior cracked teeth at risk for adverse outcomes.

Keywords

Cracked teeth; tooth fracture; crack progression

Introduction:

Cracked teeth are highly prevalent in the adult population[1] and present a diagnostic and treatment conundrum[2] with roots in ancient times[3]. Deciding on the best treatment is much less clear for asymptomatic teeth than for teeth displaying symptoms[2,4].

Localized pain during chewing or biting, unexplained sensitivity to cold, and pain on release of pressure are all diagnostic tests used to determine if a tooth is cracked[5,6,7,8,9,10,11,12,13,14,15]. Ancillary analyses proposed to identify cracks include visual inspection (particularly with magnification), transillumination and staining[11,16,17], percussion, biting and thermal pulp tests[8,11,13], radiography[14,16], microscopy[18] (14X-18X), ultrasound[19], optical coherence tomography[20], quantitative light-induced fluorescence (QLF)[21] and quantitative percussion diagnostics (QPD)[22–24].

While some teeth with cracks can remain symptom-free and intact for extended periods, the risk of not intervening at the appropriate time can result in symptoms or more-catastrophic adverse outcomes that render the tooth non-restorable[5]. The conundrum is that it is difficult for dentists to determine accurately which cracked teeth are likely to suffer from harmful sequela[2].

Many cracked-tooth risk factors have been described in the literature, including age[25], tooth location[26],cuspal inclination[27], presence and type of restoration[15], restoration size[28], presence of occlusal interferences[12], bruxism[29],surface crack lines[30], and oral piercings[31]. However, these findings are based on case reports or personal observations, or studies with a low sample size. The Cracked Tooth Registry (CTR) in the National Dental Practice-Based Research Network (National Dental PBRN or the network, nationaldentalpbrn.org) was designed as the largest and most-comprehensive prospective clinical assessment of cracked teeth to ascertain their behavior over time and to correlate observable baseline characteristics to adverse outcomes, such as changes in symptoms, crack progression and tooth fracture.

In previous publications[32–36] the following findings were described. Baseline data of the CTR showed that patients who clenched or ground their teeth and had a molar tooth with a distal crack that blocked transilluminated light were most likely to demonstrate symptoms. Of the 435 cracked teeth treated restoratively at baseline such that the presence of internal cracks could be determined, 89% (N=389) had at least one internal crack and 87% (N=340) of the internal cracks extended into the dentin.

Pain due to a cold stimulus, in contrast to biting pain and spontaneous pain, was the most common symptom exhibited by patients with a cracked tooth. Of the 2,858 teeth enrolled in the study at baseline, 1,040 (36%) were recommended for treatment, primarily restorative. The presence of caries, biting pain and evidence of a crack on a radiograph were strongly associated with recommendation for treatment. At the one-year follow-up of 2,531 patients (89% of 2,858 enrolled), almost one-third of the patients had a change in their pain symptoms, with decreases in pain being double that of increases (21% [N=391] vs 9% [N=164]. Decreases in symptoms were more than twice as common among teeth that were treated than those not treated (45% [N=111] vs. 19% [N=310]). Changes in pain symptoms, specifically increases in symptoms, were not associated with an increase in the number of cracks in the affected tooth.

The primary outcome of interest for this particular analysis was tooth fracture incidence, since this is the most significant adverse outcome related to cracked teeth inevitably requiring treatment and in some cases extraction. The objectives of this 3-year study were to: 1) estimate the 3-year risk of tooth fractures and crack progression; and 2) correlate baseline patient-, tooth- and crack-level characteristics with these outcomes during the three-year follow-up period.

Methods:

Prior publications have detailed the study procedures, including enrollment and data collection at baseline[32] and subsequent follow-up visits[35]. Briefly, dentists in general

practice in the network[37] screened a convenience sample of subjects between 19 and 85 years old for the presence of at least one single, vital posterior tooth with at least one clinically observable external crack. Vitality of enrolled teeth was confirmed with cold e.g., refrigerant or ice, although other methods such as air, air/water spray, or electric pulp testing were also used. Upon enrollment, participating dentists selected and characterized one eligible cracked tooth in each subject. Each practice consented and enrolled as many eligible subjects as they could in eight weeks, up to a maximum of 20 subjects. The Institutional Review Board (IRB) of the lead investigators (TH & JF), as well as the IRBs for the six network regions, reviewed and approved the study. Patient enrollment proceeded in two phases: a pilot with 183 patients from 12 practices from April-July 2014, followed by a main launch from October 2014-April 2015.

Data collection training materials were developed for the participants and included the following definitions:

- Crack: An obvious break of the external contiguous structure of the tooth, but involves no loss of tooth structure (e.g., lost cusp).

- Partial tooth fracture: the loss of a portion of tooth structure coronal to the periodontal attachment.

- Complete tooth fracture: a fracture that includes both the coronal and radicular tooth structure below the periodontal attachment (e.g., a fracture that renders the tooth non-restorable).

Since partial or complete tooth fractures were outcome measures, cracked teeth with fractures at baseline were ineligible. Various patient-, tooth- and crack-level characteristics were collected, including the presence and type of pain (spontaneous, cold, biting), as well as treatment recommendations for patient's teeth. Data forms are publicly available at [http://nationaldentalpbrn.org/study-results/cracked-tooth-registry.php].

Patients were requested to return to their dentist annually for three years (Y1 – Y3). Any visit after baseline (Y0) and before the first annual recall (Y1) during which the cracked tooth was treated was recorded as an interim visit, and appropriate forms filled out. The Data Coordinating Center (DCC) notified the dental offices six months in advance of patient recall dates, and the offices sent reminders to the patients. Specific tracking procedures were used by the DCC for any patients the practices could not contact. Patients and practitioners received a nominal remuneration for the baseline and annual recall visits.

Recall visits were usually coincident with routine visits, billed to the patient's insurance. A six-month window was permitted for the first two annual recall visits, but the window was opened for Y3 to maximize final recall visits, with the result that some patients had 22 months in between the last 2 recall visits. However, the follow-up time between Y2 and Y3 visits was virtually the same as between earlier recall windows (12.4 months, IQ 11.6–14.3). The same data collected at enrollment (Y0) were collected at each yearly recall visit, including treatments recommended and performed. Overall, 209 practitioners enrolled 2,858 patients between 04/2014 and 04/015; Y3 visit dates ranged 03/2017 to 12/2018.

Analysis.

The primary outcomes were whether over the 3-year period: (1) the cracked tooth developed a partial or complete fracture; or (2) there was progression of cracks. Although both outcomes were evaluated at each annual recall, the interest was the 3-year risk of these outcomes. Specifically, after a tooth developed a fracture, it was censored, so subsequent fractures were not analyzed. We did not perform sequential analysis, e.g., did Y1 fractures predict Y2, because the objective was to identify baseline characteristics that predicted failure or crack progression within 3 years. Crack progression was defined as either an increase in the number of cracks or an increase in the number of surfaces involved in a crack. As crack progression could only be ascertained on non-treated teeth, teeth treated before Y1 (namely, at Y0 or an interim visit before Y1) were excluded from those analyses. A third outcome was whether crack progression was a precursor, or predictor, of subsequent tooth fracture. Descriptive statistics were calculated for continuous variables.

Frequencies were obtained separately according to whether a cracked tooth developed a fracture and whether there was any crack progression. In a univariable fashion, each patient-, tooth-, and crack-level characteristic was entered into a logistic regression model, one for development of fractures and one for crack progression. Each model used a generalized estimating equation (GEE) to adjust for the clustering of patients within the practice, implemented using PROC GENMOD in SAS with the CORR=EXCH option. All characteristics with $p<0.10$ after adjusting only for the clustering of patients within the practice were entered into a full model. This was followed with backward elimination to identify independent associations, separately, for the development of tooth fracture and crack progression, removing variables until all remaining variables in each model had $p<0.05$. After the development of these two models, the association of crack progression with future tooth fracture was similarly assessed. All odds ratios (OR) and p-values reported were adjusted for the clustering of patients within practitioners with GEE. All analyses were performed using SAS software (SAS v9.4, SAS Institute Inc., Cary NC).

RESULTS

A total of 2,601 patients (91% of 2,858 enrolled) from 199 practices attended at least one recall visit. Of the 2,601, 2,507 (96%) attended Y1, 2,236 (86%) attended Y2, 2,079 (80%) attended Y3, and 1,912 (74%) attended all three annual recall visits. Overall, 712 (27%) of the 2,601 were treated prior to Y1, leaving 1,889 patients to assess for crack progression. The mean age of the 2,601 patients was 54 years (SD = 11.7). The majority were female (64%; N = 1,653), non-Hispanic white (85%; N = 2,190), had some dental insurance (78%; N = 2,017), or had a bachelor's degree or higher (53%; N = 1,365). Approximately 44% (N=1,154) were symptomatic at baseline, meaning they had cold, biting or spontaneous pain. The distribution of these characteristics was virtually identical among both the total cohort with at least one annual recall (n=2,601), and those available for crack progression assessment (n=1,889), with the exception that fewer teeth in the latter cohort were symptomatic (37%; N = 699) compared to the former (44%; N= 1,145) ($p < 0.001$).

Overall, 78 (3%) of the 2,601 cracked teeth developed a fracture after baseline, and 232 (12% of 1,889 teeth not treated before Y1) had some type of crack progression after

baseline (Figure 1 shows timing). 301 cracked teeth had an outcome of interest: 223 (74%) showed only crack progression, 69 (23%) showed only fractures, and 9 (3%) had both crack progression and a fracture. Tables 1–3 present the characteristics that were analyzed for associations with the development of fractures and with progression of cracks.

Associations with fractures.

Characteristics independently associated with development of fractures after baseline (Table 4, "Final reduced model") included a tooth located in the maxillary arch (OR = 1.8; 95% CI: 1.2 – 2.8), a wear facet through enamel at baseline (OR = 2.2; 95% CI: 1.4 – 3.3), having a crack at baseline that was detectable with an explorer (OR = 1.9; 95% CI: 1.1 – 3.2), was in the horizontal direction (OR = 1.7; 95% CI: 1.1 – 2.7), or that involved the facial surface at baseline (OR = 2.0; 95% CI: 1.2–3.3) (Table 4). Overall characteristics with $p<0.1$ after adjusting only for clustering of patients within the practice that were entered into the full model, but failed to be found significant in the final model, were increasing age of patients, teeth with multiple cracks, presence of a non-carious cervical lesion (NCCL), and cracks that connected with a restoration or ran in an oblique direction.

Associations with crack progression.

Characteristics independently associated with crack progression after baseline (Table 4) were being male (OR = 1.4; 95% CI: 1.1 – 1.8) and having a crack at baseline that involved more than one surface (OR = 1.6; 95% CI: 1.2 – 2.3), while having a crack involving the facial surface at baseline was less associated with crack progression (OR = 0.74; 95% CI: 0.55 – 0.99). Characteristics with $p<0.1$ after adjusting only for clustering of patients within the practice that were entered into the full model, but failed to be found significant in the final model, were cracks that at baseline were on the occlusal surface or that connected with a restoration.

Crack progression and fractures.

A total of 42 fractures were observed during the Y2 or Y3 examination. Among 1,674 teeth with no crack progression after baseline, 37 (2.2%) developed a tooth fracture. However, among 215 teeth with crack progression, 5 (2.3%) developed a tooth fracture. There was no difference either before adjustment for clustering (2% whether or not crack progression, P = 0.9), or after adjusting for clustering (P = 0.8).

DISCUSSION

To the best of our knowledge, this is the first published report describing the progression of cracks in teeth that have been systematically followed over three years, especially in a large cohort of nearly 3,000 patients. Most other longitudinal studies pertain to cracked teeth that were treated restoratively[38,39,40] or endodontically[41,42]. Although there is a published study reporting on characteristics of cracked teeth, it is a cross-sectional investigation only[15].

Several baseline characteristics were associated with tooth fracture incidence, including the tooth having a wear facet through the enamel. This is consistent with a cross-sectional observational study of 51 patients and 763 teeth, in which teeth with excursive interferences

were 2.3 times more likely to have a concurrent crack[12]. An excursive interference implies parafunction from an oblique angle, creating shear or tensile forces that could lead to tooth fracture.

Cracks that ran in a horizontal direction were associated with tooth fracture incidence. Empirically, a fracture requires a connection between adjacent cracks so that a portion of the tooth breaks off. Since most cracks are vertical in direction, the presence of horizontal cracks could connect two longitudinal cracks.

Our results suggest that maxillary posterior teeth are more likely to fracture than mandibular posterior teeth. This was consistent with two previous studies[26,43], but in contrast to others that found mandibular molars were more likely to have cracks[38,44,45]. Perhaps related to the predilection for maxillary posterior teeth to fracture was our finding that facial surfaces were more likely to lead to fracture. From an anatomical perspective, the lingual cusps of maxillary molars are more substantial structures than the facial cusps of maxillary molars[46]. A parafunctional lateral jaw movement could result in a working-side interference on the inner incline of the facial cusps, providing the oblique occlusal force to the smaller and presumably weaker facial maxillary molar cusps, resulting in their fracture. A study comparing intact maxillary molars to maxillary molars with diagnosed cracked tooth syndrome found that the cuspal incline of the cracked teeth was significantly steeper than the cuspal incline on the non-cracked teeth. Furthermore, finite element analysis revealed that the maximum tensile stress was greater in teeth with steeper cuspal inclines[27]. Cuspal incline was not assessed in the current study.

A final characteristic associated with tooth fracture was found in teeth that had a crack discernable with an explorer. A crack with enough displacement to be detectable when sliding an explorer tip over the tooth surface is likely to be indicative of a significant disruption of the tooth structure that will eventually lead to a fracture.

Crack progression was significantly more common in male patients, perhaps because males can generate a higher bite force compared to females[47]. Tooth-level characteristics associated with an increased likelihood of crack progression included teeth with more than one crack at baseline. Having multiple cracks at baseline may imply that a tooth is predisposed, and that conditions are present for further crack formation.

It was surprising that cracks that blocked transilluminated light were not predictive of either crack progression or tooth fracture. Transillumination is typically recommended to aid in the diagnosis of cracked teeth[48], the implication being that the crack is extensive. However, cracks that block transilluminated light may remain within the enamel and therefore may not be indicative of a structurally compromised tooth[18].

Unexpectedly, there was no association between characteristics that were predictive of crack progression and those predictive of tooth fracture. The only characteristic in common between these two main outcomes of interest in the final model was the presence of a crack on the facial surface, but its association with the outcome acted in opposite directions; a facial crack was associated with a reduced risk of crack progression, but an increased risk of tooth fracture. A possible explanation for this[34], is that dentists are adept at identifying teeth

at risk of further adverse outcomes and intervening with treatment, particularly restorative treatment, to intercept tooth fracture. This is supported by the fact that only 3% of cracked teeth progressed to fracture in 2,601 patients. Therefore, characteristics that may have predicted both crack progression and fracture were instead preemptively treated before the crack progression led to a fracture.

Limitations of this study include that neither patients nor subject teeth were randomly selected and therefore may not represent the full spectrum of individuals with cracked posterior teeth. While this is not ideal, it likely led to the high retention rate observed, as practices were able to select patients who were most likely to be retained. Another limitation is that some of the data collected are subjective and amenable to different interpretations, even though all study personnel underwent training before participating.

The study also includes several strengths, including a high number of patients drawn from a large number of practices demonstrating geographic and practice setting diversity, evaluated longitudinally, with a high rate of recall.

Conclusion:

A cohort of 2,601 patients from 199 practices with at least one vital cracked tooth was followed for three years to ascertain the development of tooth fracture and crack progression. Overall, fractures and crack progression were rare, as only 78 (3%) developed a fracture, and 232 (12% of 1,889 teeth not treated before the Y1 examination) had some type of crack progression. Characteristics associated with tooth fracture included location in the maxillary arch, a wear facet through enamel, cracks being detectable by an explorer at baseline, and cracks that ran in a horizontal direction, or which were on the facial surface. Characteristics associated with crack progression included male gender and teeth with multiple cracks at baseline. Teeth with a crack on the facial surface at baseline were less likely to demonstrate crack progression. There was no overlap between characteristics that significantly predicted tooth fracture as compared to characteristics that significantly predicted crack progression.

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* The majority of fractures (71, 91%) were partial fractures. Fractures can develop more than 1 time, 8 (10%) were so marked.
**Increase in the cracks can only be ascertained on untreated teeth, can happen more than 1 time. 30 (14%) had increases in cracks multiple times; 8 (16%) had increases in crack surfaces multiple times. Only 27 (12% of 232) had both increases in the number of cracks and the number of crack surfaces.

Figure 1:
Timing of fracture development and crack progression.

Table 1.

Patient-level characteristics of subjects with a cracked tooth at baseline according to whether fractures developed or whether there was any crack progression[1] during 3 years of follow-up (FU).

Baseline patient characteristics	All patients with any FU visit (N = 2,601) N[2]	Patients who developed a tooth fracture (N = 78) N	Row %[3]	Patients who were not treated before Y1 exam (N = 1,889) N	Crack progressed (N = 232) N	Row %[3]
Gender						
Female	1,653	43	3%	1,206	124	10%
Male	947	35	4%	682	91	13%
cluster adjusted p[4]			*P = 0.12*			***P = 0.01***
Race[5]-ethnicity						
White	2,190	63	3%	1,577	186	12%
Black	118	2	2%	83	5	6%
Asian	46	2	4%	37	4	11%
Hispanic	162	7	4%	126	14	11%
Other	51	4	8%	42	3	7%
cluster adjusted p			*P = 0.4*			*P = 0.5*
Age (years)						
< 35	165	3	2%	118	6	5%
35 – 44	387	9	2%	272	39	14%
45 – 54	744	19	3%	540	62	11%
55 – 64	838	25	3%	599	68	11%
65 and older	466	22	5%	359	40	11%
cluster adjusted p [trend]			***P = 0.03***			*P = 0.6*
Dental insurance						
None	584	20	3%	462	49	11%
Any	2,017	58	3%	1,427	166	12%
cluster adjusted p			*P = 0.5*			*P = 0.6*
Education						
< Bachelor's degree	1,221	38	3%	924	95	10%
Bachelor's or higher	1,365	40	3%	953	119	12%
cluster adjusted p			*P = 0.8*			*P = 0.8*
Region						
Western	379	13	3%	248	36	15%
Midwest	340	11	3%	220	38	17%
Southwest	493	15	3%	378	35	9%
South Central	512	14	3%	378	32	8%
South Atlantic	445	14	3%	346	24	7%
Northeast	432	11	3%	319	50	16%
cluster adjusted p			*P = 0.98*			*P = 0.3*

Baseline patient characteristics	All patients with any FU visit (N = 2,601) N[2]	Patients who developed a tooth fracture (N = 78) N	Row %[3]	Patients who were not treated before Y1 exam (N = 1,889) N	Crack progressed (N = 232) N	Row %[3]
Symptomatic						
No	1,447	39	3%	1,190	134	11%
Yes	1,154	39	3%	699	81	12%
cluster adjusted p			*P= 0.2*			*P = 0.8*

[1] Crack progression: Increases in number or cracks or number of surfaces on a crack involved in the crack.

[2] Column Ns not summing to column total N above due to missing data.

[3] Percent with column heading within level of patient characteristic.

[4] Significance of differences in proportions adjusted only for the clustering of patients within the practitioner using GEE.

[5] Race groups are all non-Hispanic.

Table 2.

Tooth-level characteristics of subjects with a cracked tooth at baseline according to whether fractures developed or whether there was any crack progression[1] during 3 years of follow-up (FU).

Baseline tooth-level characteristics	All patients with any FU visit (N = 2,601) N[2]	Patients who developed a tooth fracture (N = 78) N	Row %[3]	Patients who were not treated before Y1 exam (N = 1,889) N	Crack progressed (N = 232) N	Row %[3]
Molar	2,116	67	3%	1,509	170	11%
Premolar	485	11	2%	380	45	12%
cluster adjusted p[4]			*P = 0.2*			*P = 0.9*
Maxillary	1,078	40	4%	778	87	11%
Mandibular	1,523	38	2%	1,111	128	12%
cluster adjusted p			*P = 0.09*			*P=0.9*
2 or more external cracks	1,669	59	4%	1,210	153	13%
1 external crack	932	19	2%	679	62	9%
cluster adjusted p			***P = 0.01***			*P = 0.9*
Wear facet thru enamel	615	32	5%	436	50	11%
No wear facet thru enamel	1,986	46	2%	1,453	*165*	11%
cluster adjusted p			***P = 0.002***			*P = 0.7*
Exposed roots	587	21	4%	451	59	13%
No exposed roots	2,014	57	3%	1,438	156	11%
cluster adjusted p			*P = 0.3*			*P = 0.6*
Caries present	260	8	3%	56	5	9%
No caries present	2,341	70	3%	1,033	210	11%
cluster adjusted p			*P = 0.9*			*P = 0.8*
NCCL[5] present	227	14	6%	184	19	10%
No NCCL present	2,374	64	3%	1,705	196	12%
cluster adjusted p			**P = 0.04**			*P = 0.4*

[1] Crack progression: Increases in number or cracks or number of surfaces involved in the crack.

[2] Column Ns not summing to column total N above due to missing data.

[3] Percent with column heading (increased number of fractures or development of fractures) within the level of tooth characteristic:

[4] Significance of differences in proportions with column heading adjusted only for clustering of patients within practitioner using GEE.

[5] NCCL: Non-carious cervical lesion.

Table 3.

Crack-level characteristics of subjects with a cracked tooth at baseline according to whether fractures developed or whether there was any crack progression[1] during 3 years of follow-up (FU).

Baseline crack-level characteristics	All patients with any FU visit (N = 2,601) N[2]	Patients who developed a tooth fracture (N = 78) N	Row %[3]	Patients who were not treated before Y1 exam (N = 1,889) N	Crack progressed (N = 232) N	Row %[3]
Has at least 1 crack that …						
… stained	2,118	67	3%	1,541	179	12%
None stained	483	11	2%	348	36	10%
cluster adjusted p[4]			*P = 0.3*			*P = 0.4*
… detectable with an explorer	1,811	64	4%	1,279	141	11%
None detectable with an explorer	790	14	2%	610	74	12%
cluster adjusted p			***P = 0.006***			*P = 0.2*
… blocked transilluminated light	1,724	57	3%	1,226	162	13%
None blocked transilluminated light	877	21	2%	663	53	8%
cluster adjusted p			*P = 0.2*			*P = 0.2*
… connected with a restoration	1,909	65	3%	1,366	169	12%
None connected with a restoration	692	13	2%	523	46	9%
cluster adjusted p			***P = 0.04***			*P = 0.05*
… connected with another crack	111	7	6%	69	9	13%
None connected with another crack	2,490	71	3%	1,820	206	11%
cluster adjusted p			*P = 0.14*			*P = 0.5*
… crack extended to root	266	8	3%	207	24	12%
None extended to root	2,335	70	3%	1,682	191	11%
cluster adjusted p			*P = 0.9*			*P = 0.9*
Crack directions						
… in horizontal direction	805	35	4%	556	76	14%
None in horizontal direction	1,796	43	2%	1,333	139	10%
cluster adjusted p			***P = 0.01***			*P = 0.3*
… in vertical direction	2,439	73	3%	1,768	203	12%
None in vertical direction	162	5	3%	121	9	7%
cluster adjusted p			*P = 0.9*			*P = 0.6*
… in oblique direction	254	14	6%	185	18	10%
None in oblique direction	2,347	64	3%	1,704	197	12%
cluster adjusted p			***P = 0.045***			*P = 0.11*
… in more than 1 direction	517	23	4%	347	53	15%
All cracks in same direction	2,084	55	3%	1,542	162	11%
cluster adjusted p			*P = 0.06*			*P = 0.2*
Crack surfaces						
… involved mesial	1,168	33	3%	814	105	13%

Baseline crack-level characteristics	All patients with any FU visit (N = 2,601) N[2]	Patients who developed a tooth fracture (N = 78) N	Row %[3]	Patients who were not treated before Y1 exam (N = 1,889) N	Crack progressed (N = 232) N	Row %[3]
None involved mesial	1,433	45	3%	1,075	110	10%
cluster adjusted p			*P = 0.7*			*P = 0.6*
… involved occlusal	1,164	39	3%	821	117	14%
None involved occlusal	1,437	39	3%	1,068	98	9%
cluster adjusted p			*P = 0.4*			***P = 0.004***
… involved distal	1,307	39	3%	916	109	12%
None involved distal	1,294	39	3%	973	106	11%
cluster adjusted p			*P = 0.97*			*P = 0.7*
… involved facial	1,306	51	4%	899	110	12%
None involved facial	1,295	27	2%	990	105	11%
cluster adjusted p			***P = 0.009***			*P = 0.07*
… involved lingual	1,330	43	3%	958	117	12%
None involved lingual	1,271	35	3%	931	98	11%
cluster adjusted p			*P = 0.5*			*P = 0.8*
… involved >1 surface	1,219	42	3%	864	123	14%
None involved more than 1 surface	1,382	36	3%	1,025	92	9%
cluster adjusted p			*P = 0.2*			***P = 0.005***

[1] Crack progression: Increases in number or cracks or number of surfaces involved in the crack.

[2] Column Ns not summing to column total N above due to missing data.

[3] Percent with column heading (increased number of fractures or development of fractures) within level of tooth characteristic.

[4] Significance of differences in proportions with column heading adjusted only for clustering of patients within practitioner using GEE.

Table 4.

Independent associations between baseline characteristics and the two main outcomes (fracture and crack progression) measured in the Cracked Tooth Registry (CTR) study.

	Adjusted only for clustering		Full Model[2]		Final reduced model[3]		
	Odds Ratio	P[1]	Odds Ratio	P	Odds Ratio	95% Confidence Interval	P
Developed fracture(s)							
Patient age (per 10 years)	1.3	0.03	1.2	0.11	x	x	x
Has 2 or more cracks	1.8	0.01	1.0	0.97	x	x	x
Maxillary	1.5	0.09	1.7	0.04	1.8	1.2 – 2.8	1.10
Wear facet thru enamel	2.3	0.002	2.0	0.007	2.2	1.4 – 3.3	0.003
Non-carious cervical lesion	2.3	0.04	1.7	0.16	x	x	x
Has crack that … is detectable with explorer	2.0	0.006	1.7	0.036	1.9	1.1 – 3.2	0.02
… connects with a restoration	1.8	0.04	1.6	0.17	x	x	x
… in horizontal direction	1.9	0.01	1.6	0.16	1.7	1.1 – 2.7	0.04
… in oblique direction	2.0	0.045	1.3	0.4	x	x	x
… in >1 direction	1.7	0.06	1.0	0.98	x	x	x
… involves facial surface	1.9	0.009	1.8	0.02	2.0	1.2 – 3.3	0.006
Crack progression							
Male patient	1.4	0.01	1.4	0.02	1.4	1.1 – 1.8	0.02
Has crack that … connects with restoration	1.4	0.05	1.3	0.07	x	x	x
… involves occlusal surface	1.5	0.004	1.0	0.9	x	x	x
… involves facial surface	0.76	0.07	0.74	0.05	0.74	0.55 – 0.99	0.047
… involves >1 surface	1.6	0.005	1.5	0.2	1.6	1.2 – 2.3	0.004

[1] P: Adjusted for clustering of patients within a practice using generalized estimating equations (GEE); all characteristics with P<0.1 are listed.

[2] Full model: All characteristics with P<0.1 after adjusted only for clustering of patients with GEE were entered in the model.

[3] Backwards elimination was used, removing variables until all remaining had p<0.05.

[4] X:P>0.05, not retained in model.