Risk indicators for posterior tooth fracture

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ABSTRACT

Background. Identifying posterior teeth that are at heightened risk of developing cusp fracture is an inexact science. Risk indicators based on controlled observations are not available, and dentists' assessments vary.

Methods. The authors conducted a case-control study of cusp fracture in restored posterior teeth. They evaluated 39 potential risk indicators identified in previous uncontrolled studies for an association with fracture in 200 patients with fractures and 252 patients without fractures. These risk indicators delineated patients' clinical characteristics and behaviors, as well as clinical characteristics of individual teeth. The authors used logistic regression to develop models identifying risk indicators associated with fracture, both between case and control subjects and between case and comparison teeth in case subjects.

Results. Two risk indicators appeared in both models. The presence of a fracture line and an increase in the proportion of the volume of the natural tooth crown occupied by the restoration substantially increased the odds of fracture ($P < .001$). Additional risk indicators were unique to the case subject–control subject model, including subject age and other measures related to the relative size of the restoration or to loss of dentinal support. Neither patient behaviors such as clenching, grinding and biting hard objects nor occlusal characteristics such as guidance, cusp anatomy and general wear patterns were strong predictors of fracture risk.

Conclusions. Among posterior teeth with restorations, two clinical features were strongly associated with the risk of cusp fracture: presence of a fracture line in the enamel and proportional volume of the restoration.

Clinical Implications. Dentists assessing the risk of fracture should consider a detectable fracture line or a high ratio of restoration-to-total-crown volume as important indicators of elevated risk.

JADA CONTINUING EDUCATION ARTICLE 2

We recently reported incidence rates of complete cusp fracture in posterior teeth, estimating both overall and tooth type–specific incidence.[1] In this report, we continue our examination of posterior cusp fracture by presenting the results of a case-control study designed to identify risk indicators for such fracture. Information concerning risk indicators is scarce because available studies are all uncontrolled case series, which, by their design, do not permit comparisons of fractured teeth with sound teeth. Such comparisons are necessary to establish objectively which characteristics of fractured teeth differ from those of sound teeth and, thus, are associated with fracture.

Presence of a fracture line in the enamel and proportional volume of the restoration were strongly associated with the risk of cusp fracture.

The existing literature identifies a number of putative risk indicators for fracture. The most frequently mentioned risk indicator is a large intracoronal restoration,[1-6] with fewer than 10 percent of fractures occurring in teeth without restorations.[1,4-6] The effects of restorations are thought to be associated with a reduced amount of dentin supporting the cusps of a restored tooth.[5,6] Larson and colleagues[7] reported that proportional isthmus width is one measure of "lost dentinal support" associated with in vitro fracture resistance. Numerous studies also have reported an association between endodontic treatment without subsequent cusp protection and tooth fracture,[4,8-12] although it may be more frequently associated with incomplete and complete vertical fractures than with complete cusp fractures.[4,8,10,11]

Other risk indicators for complete cusp fracture that have been mentioned in the literature include bruxism and worn teeth[2,5,13,14]; steep cuspal anatomy[2,4,5]; traumatic occlusal relationships[2,5]; isolated tooth position[5]; sharp cavity preparation internal line angles[15]; and specific habits, foods and sweets.[16] Specific age patterns have not been strongly associated with complete cusp fracture,[17] with various studies reporting patient age distributions reflecting both younger[5] and middle-to-older ages.[4,18] However, because no control subjects were included in these studies, it is likely that each distribution was influenced by the age distribution of patients from whom the data were collected.

The lack of definitive information in the literature regarding risk indicators for cusp fracture is reflected in the variation among dentists with regard to their ratings of importance of various risk indicators for fracture and their assessments of the relative risk of fracture of individual teeth.[19] This study, the first to our knowledge to include a direct comparison group, quantifies the odds of complete cusp fracture associated with specific tooth and patient-level clinical indicators, as well as patient-level behaviors and extraoral characteristics. Thus, it provides information that should help dentists more accurately assess the risk of fracture of one or more cusps in individual teeth.

The lack of definitive information is reflected in the variation among dentists with regard to their ratings of importance of various risk indicators for fracture.

SUBJECTS AND METHODS

Data collection. We conducted a case-control study at the same site as our previous study of the incidence of fractured teeth,[1] a large dental group practice in Portland, Ore. For one year, we asked patients who were found to have a fractured tooth to participate in the study after informing them of the study's purpose. We also asked similar numbers of patients who did not have a fractured tooth to participate as control subjects. All informed consent procedures, as well as the study procedures and design, were approved by institutional review boards at the investigators' institution and at the study site.

Participation consisted of permitting us to collect clinical data, alginate impressions and occlusal records; completing a questionnaire; and approving the use of data and radiographs from the clinical record. Two dental auxiliaries conducted the clinical examinations; they had been trained and standardized before the start of data collection. The examinations were performed in dental operatories without magnification, special lighting or drying of the teeth.

For case subjects (that is, those with a fractured tooth), the dental auxiliaries collected descriptive clinical data for the fractured (case) tooth and for a comparison tooth, which was the contralateral tooth or its acceptable substitute. A contiguous first molar and first premolar could be substituted for a missing or crowned second molar and second premolar, and vice versa.

We recruited control subjects from the same patient population as case subjects and enrolled them at approximately the same rate. We selected the tooth type (for example, molar, premolar) for which clinical data would be collected to maintain a distribution approximately similar to that for case teeth enrolled to date at the same site. No matching was performed between case and control subjects. We collected clinical data for between two and four teeth for each control subject (that is, all maxillary or mandibular premolars or molars) to maximize the statistical power of the analysis.

A minimum of two teeth of the selected tooth type had to be present and uncrowned for the control subject to be eligible for enrollment. The clinical data collected for case and comparison teeth included the presence or absence of mobility, Class V restorations, cervical defects, craze lines, tactilely detectable fracture lines, subsurface discoloration and endodontic access preparations. In addition, we noted the restorative material and restored surfaces, whether the tooth supported a partial denture, and canine or group guidance for left and right function.

We categorized restorations as being complex if they involved two or more surfaces, with one surface being a proximal surface; we categorized all other restorations as simple. In most, but not all, instances, the clinical examination took place before any treatment of the fractured tooth. When treatment had been administered, we sought information describing the pre-existing restoration from recent radiographs and clinicians' comments.

All subjects completed a 14-item questionnaire that elicited demographic data, as well as information about behaviors, experiences and symptoms that might be associated with tooth fracture. Behaviors included bruxism, clenching, chewing ice or other hard foods, and biting or holding objects in the mouth. Experiences included previous tooth fracture, recent blows to the face and being warned about possible tooth fracture by a dentist. Symptoms included pain while chewing and sensitivity to hot and cold.

One of four dental students who had been trained and standardized before data collection analyzed the casts, bite records and radiographs. The students made all measurements at a central location to record additional characteristics of subjects and teeth. For subjects, the dental students examined the general extent of faceting from the bite record to characterize occlusal wear as light, moderate or heavy. For teeth, the students analyzed radiographs to determine the presence of pins, an opposing crown and endodontic fillings. If an endodontic filling was present, the student combined this information with the endodontic-access observation made clinically to categorize a tooth as having had any endodontic treatment. The students examined casts to determine the presence of capped cusps (that is, replaced or covered by a restoration), and noted teeth with one or more unrestored cusps that had cuspal inclines of less than 30 degrees (that is, “flat”).

The students determined the relative volume proportion, or RVP, of a restoration by calculating the area of a restoration as a proportion of the coronal area in two dimensions (that is, occlusal [from the cast] and cross-sectional [from the radiograph]) and then multiplying these two proportions together. Occlusal areas were determined electronically from scanned images of the cast and radiograph. For the purpose of calculating occlusal surface areas, students assumed that missing cusps reflected standard anatomical relationships. In addition, they used the scanned occlusal images to determine the isthmus width (measured on a line between cusps) and the mean and maximum isthmus widths if two were present.

Similarly, for each tooth with a restoration, the students calculated the mean distance and the shortest distance between the restoration margin and all cusp tips. From these measures, they calculated the proportion of the mean intercuspal distance represented by the restoration isthmus or isthmuses.

Subjects. Because the raw distributions of fractures confirmed our earlier findings that unrestored teeth suffered fractures only infrequently,[1] we examined risk indicators for fracture among only those teeth with restorations. Similarly, because we wished to investigate risk indicators for fracture associated with teeth that otherwise would not require intervention, we excluded teeth with caries. For these reasons, we limited the analyses to subjects with fractured teeth that were restored before the fracture occurred and did not have a carious lesion associated with the fracture.

Of 249 case teeth for which data were collected, three had not been restored. When carious teeth were eliminated, one of 201 had not been restored. To maintain the essential premise in case-control studies that control observations have had the same opportunity for exposure to potential risk indicators, we included only restored noncarious comparison teeth in control subjects in the analyses (that is, 749 control teeth in 252 control subjects).

The authors performed bivariate analyses of each tooth and subject characteristic according to fracture status.

Data analysis. We conducted two separate analyses. One analysis compared the characteristics of case subjects and case teeth (that is, those with fractures) with characteristics of control subjects and comparison teeth. The other analysis compared characteristics of case and comparison teeth in case subjects. The first analysis represented the principal comparison, with the second comparison of case and comparison teeth in case subjects regarded as confirmatory for tooth characteristics. We performed bivariate analyses of each tooth and subject characteristic according to fracture status. We determined statistical significance using Cochran-Mantel-Haenszel tests and *t* tests using SUDAAN[20] software, which adjusts for the correlated nature of the data (teeth within subjects).

For the principal analysis, we used SUDAAN logistic regression to identify characteristics associated with fracture. Because of the number of observations available and the number of independent variables we wished to test, we were not able to develop models for different types of posterior teeth or for specific cusps within a tooth type. Instead, we included control variables for tooth type in the analyses.

We used backward-selection methods, first entering all categorical variables and then elimi-

TABLE 1

DEMOGRAPHIC CHARACTERISTICS OF CASE AND CONTROL SUBJECTS.

SUBJECTS	SEX (PERCENTAGE)		RACE (PERCENTAGE)			MEAN (SD*) AGE (YEARS)
	Male	Female	White	Asian	Other	
Cases (n = 200)	47	53	91	4	5	49.6 (11.3)
Controls (n = 252)	35	65	87	5	8	39.9 (13.5)
P value	.02		.41			.0001

* SD: Standard deviation.

TABLE 2

COMPARISONS OF FRACTURE RISK–RELATED BEHAVIORS AND SYMPTOMS IN CASE AND CONTROL SUBJECTS.

BEHAVIOR OR SYMPTOM	PERCENTAGE OF CASE SUBJECTS (n = 200)*			PERCENTAGE OF CONTROL SUBJECTS (n = 252)*			*P* VALUE
	Almost Never	Occasionally	Frequently	Almost Never	Occasionally	Frequently	
Grind When Asleep	61	31	9	65	24	11	.16
Clench or Grit Teeth	41	43	17	44	44	12	.43
Chew Ice	63	28	10	64	27	19	.94
Chew Hard Foods	21	62	18	24	67	9	.03
Bite or Hold Objects	73	24	3	68	29	3	.48
Pain While Chewing	67	29	5	78	19	2	.02
Sensitivity to Hot	55	38	8	63	35	3	.02
Sensitivity to Cold	36	55	10	39	51	10	.78

* Rows may not total 100 percent because of rounding.

nating those that showed weak or no relationships with fracture in a series of small groups. We then added all continuous variables and, again, eliminated those with the weakest relationships. Because there were multiple opportunities for colinearity (strong relationships between risk indicators), we tested all groups of eliminated variables to ensure that they did not contribute to the explanatory power of the model.

Before conducting the principal analysis, we truncated the range for some continuous variables to eliminate extreme values, and converted one continuous variable to a four-category variable (intercuspal restoration width) to facilitate its analysis. We also eliminated one highly skewed variable from the analysis (presence of pins), because few restorations in either group contained pins. In reporting the results of the regression analyses, for some risk indicators, we present the odds ratio associated with a clinically meaningful difference in the value of the indicator, rather than the odds ratio associated with the difference between the minimum and the maximum values in the analysis.

By necessity, the within-case-subject analysis could compare only tooth-level characteristics between case (fractured) and comparison teeth. We used conditional logistic regression (SAS

TABLE 3

COMPARISONS OF RISK INDICATORS IN CASE AND CONTROL SUBJECTS.

SUBJECT CHARACTERISTIC	PERCENTAGE OF CASE SUBJECTS (n = 200)	PERCENTAGE OF CONTROL SUBJECTS (n = 252)	*P* VALUE
Canine Guidance	71*	61*	.02
Previously Fractured Tooth	75	42	< .0001
Recent Blow to Face	2	4	.12
Dentist Warned of Possible Fracture	32	17	.0002
Light General Wear	17	25*	.05
Proportion of Posterior Teeth With Restorations	79	66	< .0001
Proportion of Posterior Teeth With Crowns	10	7	.01

* Data were unavailable for one subject.

PHREG procedure, SAS Institute, Cary, N.C.), entering all available variables for teeth of subjects in whom the case and comparison teeth had been restored before the fracture occurred.

RESULTS

Table 1 shows the demographic characteristics of the case and control subjects. Case subjects were significantly older than control subjects, and were more likely to be male. The two groups had similar racial compositions.

Table 2 presents the distributions of fracture risk–related symptoms and behaviors for case and control subjects. The distributions differed significantly for three symptoms and one behavior. Larger percentages of case subjects reported experiencing tooth sensitivity to hot foods and liquids frequently and experiencing occasional or frequent pain while chewing. Larger percentages of case subjects also reported chewing hard foods frequently. However, reports of bruxism and clenching behaviors did not differ significantly between case and control subjects. Similarly, the behaviors of chewing ice and biting or holding hard objects in the mouth were not significantly different between case and control subjects.

Tables 3 and 4 show the distributions of clinical risk indicators for case and control subjects and for teeth, respectively. More than two-thirds of these risk indicators reflected statistically significant differences between case and control subjects and between teeth, and most of these differences were in the expected direction (that is, the case subjects or teeth were more likely to exhibit the putative at-risk condition). In addition, case subjects exhibited canine guidance on the affected side significantly more frequently than did control subjects, and more case teeth than control teeth were classified as mobile.

Table 5 (page 889) presents the results of the principal and confirmatory regression analyses. For the principal analysis of case and control subjects, the strongest categorical risk indicator was the presence of a tactilely detectable fracture line, which raised the odds of fracture by about 75-fold. Presence of a Class V restoration and a notation about fracture risk in the subject's dental record were each associated with about sevenfold increases in the odds of fracture.

The RVP was a strong risk indicator, with a 10 percent increase in the volume proportion of a restoration associated with a sixfold increase in the odds of fracture. Indication of an elevated frequency of pain on chewing (occasionally compared with never, or frequently compared with occasionally) increased the odds of fracture by about 70 percent. A one-category increase in intercuspal restoration width (from < 30 percent to 30 to 39 percent; from 30 to 39 percent to 40 to 49 percent; or from 40 to 49 percent to ≥ 50 percent) increased the odds of fracture by 16 percent. One capped premolar or two capped molar cusps were associated with a more-than-twofold reduction in the odds of fracture, while a 10-year increase in the patient's age increased the odds of fracture by about 70 percent.

The remaining risk indicators were paradoxical in their effect. A recent blow to the face was asso-

TABLE 4

COMPARISONS OF RISK INDICATORS IN CASE AND CONTROL TEETH.

TOOTH CHARACTERISTIC	PERCENTAGE OF CASE TEETH WITH CHARACTERISTIC	n*	PERCENTAGE OF CONTROL TEETH WITH CHARACTERISTIC	n*	*P* VALUE
General					
Notation of fracture risk in record	7	200	1	743	.002
Mobility	3	200	< 1	749	.02
Endodontic treatment	6	200	2	749	.02
Removable prosthetic abutment	3	200	2	749	.83
Flat cusp angulation	40	200	44	749	.21
Opposing tooth is crowned	18	200	11	749	.01
Related to Dentinal Support					
Subsurface discoloration	43	200	20	749	< .0001
Restoration involves proximal surface	87	199	53	745	< .0001
Class V restoration	23	200	5	749	< .0001
Cervical defect	6	200	1	749	.01
Fracture line	36	200	1	749	< .0001
Craze lines	26	200	24	749	.99
One or more cusps covered	13	128	9	746	.17
Proportion of cusps covered	5	128	4	746	.30
Pins present	0	199	1	749	.06
Occlusal restoration area	42	124	27	718	< .0001
Cross-sectional restoration area	66	130	43	700	< .0001
Relative volume proportion	29	123	14	688	< .0001
Minimum distance from restoration to cusp tip (mm†)	3.2	128	3.2	714	.99
Mean distance from restoration to cusp tip (mm)	4.2	128	4.5	714	.053
Widest isthmus width (mm)	7.9	119	6.3	648	< .0001
Mean isthmus width (mm)	7.3	119	5.8	648	< .0001
Intercuspal restoration width	46	133	40	648	< .0001

* Because of missing data for some variables, the total number of teeth varies.
† mm: Millimeter.

ciated with an almost tenfold reduction in the odds of fracture. A 1-millimeter increase in the shortest distance from the restoration margin to the cusp tip increased the odds of fracture by 31 percent, and a 10 percent increase in the proportion of posterior teeth with restorations decreased the odds of fracture by 29 percent.

The confirmatory—or within-case-subject—model identified two tooth-level risk indicators as significant predictors of fracture: presence of a fracture line and RVP. Both of these indicators also were strongly associated with the risk of frac-

TABLE 5

LOGISTIC REGRESSION MODELS FOR CASE AND CONTROL SUBJECTS AND TEETH.			
RISK INDICATOR	**ODDS RATIO**	**95% CONFIDENCE INTERVAL**	**PERCENTAGE (OR MEAN) IN CASE GROUP**
	Subjects		
Increasing Risk			
Fracture line	75.19	25.1 to 225.3	36
Class V restoration	6.89	2.3 to 20.3	23
Notation of fracture risk in dental record	6.69	1.2 to 39.0	7
RVP* (10% increase)	5.84	3.0 to 11.3	29
Pain when chewing (frequently vs. occasionally or occasionally vs. never)	1.71	1.6 to 5.5	5 (frequently); 29 (occasionally)
Age (10-year increase)	1.65	1.1 to 2.4	49.6 (mean, years)
Intercuspal restoration proportion (one-category increase)	1.82	1.4 to 2.9	46
Distance from restoration to cusp tip (1-mm increase)	1.31	1.2 to 1.5	4.3 (mean, mm†)
Decreasing Risk			
Posterior teeth with restoration (10% increase)	0.71	0.59 to 0.85	80
Proportion of cusps covered (addition of one premolar/two molar cusps)	0.42	< 0.01 to 0.3	13
Recent blow to face	0.08	0.02 to 0.35	2
	Teeth in Case Subjects		
Fracture line	7.6‡	2.9 to 19.5	36
RVP (10% increase)	455.4‡	13.0 to 1.6×10^5	29

* RVP: Relative volume proportion.
† mm: Millimeter.
‡ Hazard ratio (rather than odds ratio).

ture in the principal analysis that used both case and control subjects.

DISCUSSION

The two regression models in our study (comparing case and control subjects and case and comparison teeth in case subjects) had in common two risk indicators for cusp fracture: the presence of a fracture line and the RVP of the restorations. Both of these risk indicators have face validity, and large intracoronal restorations in particular have been cited frequently as both a risk indicator and a risk factor.[1-7] However, this finding provides the first confirmation from a controlled study of the importance of the relative size of the restoration in determining the risk of fracture, and the importance of tactilely detectable enamel fracture lines in signaling enhanced risk.

Relative volume proportion. The RVP is a measure of relative—as opposed to absolute—restoration size. Thus, it can be considered an inverse measure of the amount of original tooth material (dentin and enamel) remaining. The risk indicators available for inclusion in the model consisted of several measures related to absolute and relative restoration size, including mean and maximum isthmus width measures, mean and minimum margin-to-cusp-tip measures, mean intercuspal restoration proportion, subsurface discoloration, and presence and proportion of capped cusps.

RVP emerged as the most powerful of these risk indicators in both multivariate analyses; this supports the assumption that propensity for cusp fracture is best determined via a three-dimensional assessment of the total amount of dentinal support remaining for these cusps,[5,6] rather than a two-dimensional assessment of dentinal support (such as that provided by attention to isthmus width or margin-to-cusp measurements). The vast majority of restorations in the case teeth were amalgams; only three principal restorations were resin-based composites. The available data did not permit us to determine when case or control restorations had been placed, so we were unable to determine if restoration age is an independent risk indicator.

Enamel cracks in posterior teeth have long been thought to be a possible precursor of cusp fracture. A recent observational study showed associations between such cracks and the presence of restorations and excursive interferences.[21] Because a case-control study design does not permit assessment of case teeth before they have fractured, we cannot be sure that the fracture lines were evident before the cusp fractured. For this reason, we tested preliminary principal models that excluded the fracture-line variable, and found that the exclusion did not materially change the risk indicators included in the model or their relative strengths of association with fracture. This suggests that this risk indicator was not masking, or serving as a surrogate for, other risk indicators.

Increased fracture risk was associated with increased age, frequent pain while chewing and a dentist's note in the patient's dental record about the risk of fracture.

Subject-level characteristics. The principal model included several additional risk indicators, most of which are subject-level characteristics. Increased fracture risk was associated with increased age, frequent pain while chewing and a dentist's note in the patient's dental record about the risk of fracture. Pain may be a function of fracture lines, which also were associated with increased fracture risk, while age may be a function of decreasing dentin resiliency or cumulative nontraumatic occlusal stress.

Alternatively, patient age may be a surrogate for restoration age, which, in turn, may reflect differences in cavity design over time of both principal restorations and Class V restorations (with respect to sharp internal angles and unsupported enamel), as well as differences in expansion characteristics of restoration materials. Although the available literature does not offer strong evidence of age as a risk indicator for cusp fracture,[17] previous studies, as noted above, did not include control groups. That we found an association between a notation of fracture risk in patients' records and cusp fracture suggests that dentists' subjective impressions of the fracture risk of individual teeth have some validity.

Two additional subject-level characteristics—having a larger proportion of posterior teeth with restorations and having experienced a recent blow to the face—were associated with a decreased risk of fracture. Explanations for these two associations are less apparent. The protective effect of facial blows, which were reported by only 2 percent of case subjects and 4 percent of control subjects, may be an anomaly related to the skewed distributions for this measure. Although the same explanation could apply to the proportion of posterior teeth restored, it is less credible. The bivariate relationship is opposite from the expected direction, with case subjects exhibiting a greater proportion of restored posterior teeth than control subjects. Thus, it is more likely that the appearance of this risk indicator signals an overspecification of the effects of other risk indicators in the model; in effect, the model has too many measures of the same basic phenomenon, which is dentinal support.

Tooth-level characteristics. The remaining three variables in the model addressed tooth-level characteristics: the presence of a Class V restoration, intercuspal restoration proportion and shortest distance from restoration to cusp tip. All of these variables assess aspects of the extent of dentinal support, and their inclusion in addition to the RVP indicator attests to the importance of dentinal support when assessing fracture risk. However, the distance measure indicates that when the shortest distance from margin-to-cusp tip is increased, the tooth is at increased risk of developing a fracture. This finding is exactly opposite from the expected relationship (that is, increasing the distance from margin-to-cusp tip reduces the fracture risk), which was apparent in the bivariate analysis. Again, the relatively small effect (30 percent reduction in the odds of fracture) suggests that this risk indicator entered the model as a correction for overspecification of other indicators related to dentinal support.

Confirmatory regression model. The confirmatory regression model included only the RVP and fracture-line risk indicators. The reduced number of indicators is a function of the smaller sample size of comparison group teeth (n = 200 rather than n = 752) and the lack of subject-level risk indicators for entry into the model. With a smaller number of comparison teeth in the analysis, some differences between case and comparison teeth may not be statistically significant. Because case and comparison teeth in these analyses come from the same individual and are paired, subject characteristics cannot differ between cases and controls.

We should note that several patient behaviors anecdotally assumed to place patients at higher risk of developing cusp fracture, such as clenching, grinding, chewing ice and biting or holding hard objects, showed no associations with fracture in this study. Also, the three potential risk indicators related to occlusion that we evaluated in this study were not strongly associated with fracture. Canine guidance, assumed to be protective, was more frequent in case subjects than in control subjects in bivariate analyses.

The study results confirm the relationship between fracture and dentinal support.

Our assessment of the extent of tooth wear showed no differences in the proportions of case and control subjects with light wear, and the proportion of case teeth with flat cusp angulation, which also is assumed to be protective, was not significantly different from the proportion of comparison teeth with flat cusp angulation. However, the occlusal characteristic perhaps most often associated anecdotally with cusp fracture—traumatic occlusion of the involved cusp—could not be assessed in this study because the fractured cusp was no longer in occlusion.

The results of this study should be useful to clinicians when assessing a tooth's risk of fracture because they shed light on which risk indicators are valid markers of elevated risk. The relationship between fracture and dentinal support, long noted in uncontrolled studies, has been confirmed. The results demonstrate that commonly used markers of inadequate dentinal support, such as the intercuspal width proportion, have some validity; however, of perhaps more importance is the observation that a quantitative three-dimensional measure of dentinal support, the RVP, appears to be more strongly associated with the risk of fracture. Thus, when assessing risk, clinicians should consider the depth as well as the width of restorations.

Furthermore, the study results clearly show that fracture lines that are detectable with an explorer should be considered strong indicators of elevated risk of fracture. Finally, the study results suggest that age is related to the likelihood of fracture, but we were unable to show that patient behaviors and patient-level occlusal characteristics are useful as risk indicators. It may be that these behaviors and characteristics are not related to risk, but it is also possible that the study did not have sufficient power to detect them because they are influential in only a small proportion of all fracture incidents.

CONCLUSION

In general, case-control studies cannot definitively identify causes of a condition, and some of the risk indicators in our models clearly are not causal (such as the presence of a fracture line or a notation by a dentist addressing fracture risk). However, the majority of the indicators in our case-control model do address the concept of dentinal support, which clearly is predisposing for fracture, and may well be more important to patient treatment than are the actual causes of fracture.

The situation is akin to a tree that has been partially gnawed by a beaver, and later is felled by a windstorm. The proximate cause, the windstorm, is of less clinical significance regarding prevention than is the predisposing factor of loss of support caused by the gnawing beaver. Recognizing the risk associated with loss of dentinal support may be more important to the ultimate prevention of cusp fracture than is identifying which of a variety of possible proximate causes is most likely to operate in a given patient. ■

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