Descriptive Models of Restorative Treatment Decisions

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Abstract

Objectives: *This study developed descriptive models of dentists' restorative treatment decisions for individual teeth. Such models could be useful in personnel planning, in assessing the effects of dental treatment programs, and in furthering understanding of dentists' decision-making processes.* ***Methods:*** *Logistic regression was used to construct models of the probability of individual teeth receiving a recommendation for restorative treatment. Independent variables for the models were data from epidemiologic oral examinations and self-administered questionnaires of subjects who were seeking treatment at a dental school. Data for the dependent variable, the probability of treatment, were collected from multiple dentists' treatment plans of these subjects. Separate models were constructed for molar, premolar, and anterior teeth. An assessment of the models' utilities in a different population consisted of comparing the treatment probabilities estimated by the models with those actually experienced by a community sample of 317 individuals who visited dentists in the 18 months following our examination.* ***Results:*** *Constructed models for molar, premolar, and anterior teeth returned kappa values of 0.60, 0.62, and 0.65, respectively, for the original data set. The models were less accurate in identifying which teeth received treatment among subjects in the community sample, with kappas of 0.10, 0.18, and 0.20, respectively.* ***Conclusions:*** *Models of dentists' restorative treatment decision making based on clinical and nonclinical data can determine the probability of treatment for individual teeth with reasonable accuracy. Hence, the approach holds promise for developing measures of normative treatment need. However, the models are not accurate predictors of dichotomous decisions by individual dentists regarding treatment interventions. Both differences in the subject samples used to develop and assess the models and individual dentist idiosyncrasies may contribute to this inaccuracy. [J Public Health Dent 1998;58(3):210-19]*

Key Words: dentists, decision making, knowledge, attitudes, practice, observer variation, treatment planning.

This paper describes the development of a model of dentists' treatment decision making that was conceived as a means of improving our ability to measure a population's dental treatment needs. Population estimates of professionally determined, or normative, treatment need (1) are key elements in need-based personnel models (2). Such estimates also may serve as oral health status measures (3,4), with oral health expressed in terms of dentists' determinations of the need for treatment, rather than dentists' judgments about "better oral health" that form the basis of a currently available oral health status instrument (5). Clearly, such an oral health status measure would be useful in evaluating the effects of resource allocation decisions, as well as delivery and financing programs.

To begin the development of measures of normative treatment need, we focused on professionally determined need for restorative dental treatment, which represents the majority of expenditures for dental treatment. Unfortunately, dentists' restorative treatment decisions have long been known to exhibit a substantial degree of variation (6). This variation poses problems for attempts to quantify normative restorative treatment need. Because a condition prompting some dentists to recommend treatment is perceived by other dentists as an acceptable condition not requiring intervention, consensus on need would be difficult to achieve.

One approach to resolving this problem is to construct a descriptive model of dentists' restorative treatment decisions that would use data collected from field examinations as the independent variables. For any given tooth, this model would estimate the mean probability that a dentist selected randomly from the population of all dentists would recommend treatment. Estimated probabilities of treatment could then be summed across teeth and subjects in a population sample to determine population restorative treatment needs. Knowledge of the factors associated with dentists' treatment decisions also could be helpful in furthering our understanding of dentists' treatment decisions in general (7). This paper describes the construction of such a descriptive model of restorative treatment needs, as well as a subsequent assessment of its utility in identifying individual teeth that will be treated by dentists.

Methods

Our approach to these tasks was both practical and strictly empirical. We used data obtained from community practitioners and dental school subjects to construct an exploratory descriptive model of dentists' restorative treatment decisions. We then assessed the utility of the model by applying it to a group of patients from the same community to determine how well it identified which teeth were actually treated by individual dentists. By basing the model on data that we obtained from dentists and subjects in

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the local area surrounding the University of North Carolina School of Dentistry, we chose to emphasize practicality over external validity. While this decision limits generalization of the model, we felt that establishing the feasibility of the approach by constructing and assessing an exploratory descriptive model was of more immediate importance than ensuring generalizability.

Model Construction. To construct the model, we needed to determine the probability of dentists recommending restorative treatment given a variety of clinical and nonclinical conditions and characteristics. We first asked multiple dentists to prepare restorative treatment plans for subjects from whom we had also collected data describing clinical and nonclinical conditions and characteristics. The treatment plans were reviewed to determine the probability that a tooth would receive a recommendation for treatment, i.e., the proportion of dentists recommending treatment. We then constructed logistic regression models that associated the characteristics of each tooth with the probability of a recommendation for treatment.

Subject Characteristics. The subject characteristics we measured for possible use in the predictive model were selected for their face validity or on the basis of evidence in the literature that they influenced dentists' treatment decisions (6,7). The characteristics were measured by means of a clinical examination (Table 1) and a subject questionnaire (Table 2). The clinical measures we used were designed for application in field epidemiologic surveys, as the intended purpose of the model was to estimate population treatment needs based on samples examined in the field. The individual tooth clinical measures were obtained by examination. Subject level clinical measures, which were calculated from these individual tooth data, were made available for modeling because overall subject oral status may influence tooth level treatment decisions (6,7). Most clinical and questionnaire measures originally included multiple response categories. However, as the final analyses would be based on logistic regression models, preliminary analyses were employed to select optimal dichotomous response categories. Where more than two categories were necessary to represent the distribution fully, dummy variables were created for modeling purposes. The response categories and dummy variables are indicated in Tables 1 and 2.

The epidemiologic examinations

TABLE 1
Subject Characteristics (Explanatory Variables) Collected by Clinical Examination

Variables	Dichotomous Response Categories	
Tooth level		
Worst amalgam margin score*		
Dummy 1	0	All other
Dummy 2	2–3	All other
Dummy 3	4–5	All other
Dummy 4	>5	All other
Average amalgam margin score		
Dummy 1	0	All other
Dummy 2	2–3	All other
Dummy 3	4	All other
Dummy 4	5	All other
Dummy 5	>5	All other
Caries present†	Yes	No
Tooth fracture present	Yes	No
1–2 mm mobility present	Yes	No
More than 1/3 of clinical crown missing	Yes	No
Restoration fracture present	Yes	No
Overhang or open contact present	Yes	No
1 or more cusp replaced with amalgam or composite	Yes	No
Questionable dentin support‡	Yes	No
Subject level		
Number of restorations		
Dummy 1	<5	All other
Dummy 2	5–9	All other
Dummy 3	10–12	All other
Dummy 4	13–16	All other
Dummy 5	>16	All other
Number of restored surfaces		
Dummy 1	<10	All other
Dummy 2	11–17	All other
Dummy 3	18–30	All other
Dummy 4	31–40	All other
Dummy 5	>40	
Number of crowns		
Dummy 1	0	All other
Dummy 2	1–2	All other
Dummy 3	3–4	All other
Dummy 4	>4	All other
Number of carious teeth		
Dummy 1	0	All other
Dummy 2	1	All other
Dummy 3	2	All other
Dummy 4	>2	All other

*Scores on Mahler photographic scale of marginal condition (8): "worst" is score for worst area on margin; "average" is score for typical margin.
†As detected using standard visual/tactile criteria (9).
‡Amalgam margin within 1 mm of cusp tip, or pronounced amalgam shadow.

through which the clinical characteristics were obtained were conducted in dental school operatories by one experienced examiner. Intraexaminer reliability was not assessed due to the examiner's necessary subsequent exposure to the dentists' treatment recommendations. The self-administered questionnaire was completed at the time of the epidemiologic examination, and omissions or questions were resolved through query. Subjects, volunteers who had given their informed consent and were compensated, were drawn from the pool of patients seeking treatment at the dental school. Criteria for selection included numerous restored teeth, few missing teeth, and no systemic illnesses or conditions that might necessitate modifications in treatment recommendations. The models described here are based on 49 subjects.

Dentists' Treatment Plans. A detailed description of the procedures for obtaining dentists' treatment plans for the subjects has appeared in a previous publication (10). These methods are summarized here. Subjects sat for consecutive individual examinations by three to six dentists during an afternoon at the dental school. Most subjects participated in more than one treatment planning session, with the result that the number of dentists' treatment plans for a given subject ranged from three to 22. A mean of 6.8 dentists examined each subject. Subjects did not participate after dental school restorative treatment commenced. The dentists were 51 compensated volunteers recruited through personal contacts and presentations at local society meetings. They all were active general practitioners with a mean of 13.5±9.8 years in practice, with 82 percent having graduated from the local dental school.

Dentists individually examined the subjects in dental school operatories. They were furnished health histories, periodontal charting information, and full-mouth radiographs. A recorder was present in the operatory to capture the dentist's treatment recommendations in terms of surfaces and material and dentists' stated reasons for treatment recommendations. Dentists were asked to regard the subjects as new patients visiting their practices for the first time, and were urged to conduct their typical new patient examinations, asking any questions that they usually asked under similar circumstances and discussing treatment alternatives, if applicable. Dentists had the option of establishing a "monitor" notation in the hypothetical patient chart rather than recommending

TABLE 2
Subject Characteristics (Explanatory Variables) Collected by Questionnaire

Variable	Dichotomous Response Categories	
Age	>50 years	50 years/less
Sex	Male	Female
Race	White	Nonwhite
Education level 2	HS grad	All other
Education level 3	Some college	All other
Education level 4	College grad	All other
Have "regular" dentist	Yes	No
Years with regular dentist 1	<1 year	All other
Years with regular dentist 2	1–3 years	All other
Years with regular dentist 3	>3 years	All other
Plan to see different dentist	Yes	No
Regular visit pattern	Yes	No
Last visit to dentist	<1 year	1+ years
Preventive service at last visit	Yes	No
Dental insurance	Yes	No
Oral health rating	v. good/good	Fair/poor
Have no concerns about teeth	Yes	No
Concern over pain	Yes	No
Concern over decay	Yes	No
Concern over loose teeth	Yes	No
Concern over missing teeth	Yes	No
Concern over ability to chew	Yes	No
Have pain while biting	Yes	No
Food sticks between teeth	Yes	No
Fear going to dentist	Yes	No
Dentist has warned that tooth might fracture	Yes	No
Dentist has suggested crowning a tooth	Yes	No
Dentist has suggested replacing missing tooth	Yes	No
If I visited dentist today, he/she would recommend		
Check-up/cleaning	Yes	No
Filling	Yes	No
Extraction	Yes	No
Gum treatment	Yes	No
Root canal	Yes	No
Denture	Yes	No
If treatment was recommended, I would have it done		
Check-up/cleaning	Yes	No
Filling	Yes	No
Extraction	Yes	No
Gum treatment	Yes	No
Root canal	Yes	No
Denture	Yes	No
Usually accept dentist's recommendation automatically	Yes	No
Accept dentist's recommendations if affordable	Yes	No

definitive treatment. Some dentists routinely reviewed and discussed their findings and preliminary treatment recommendations with each subject before reporting a final treatment plan. Other dentists would discuss recommendations for certain teeth with subjects. A few dentists formulated their treatment recommendations without any discussion with the subject (11). Restorative treatment was defined as a recommendation for a restoration for a specific tooth. Other recommended treatment was recorded, but not entered into the analyses reported here (e.g., extractions, endodontics, periodontal treatment, prosthodontics).

Analysis. Preliminary inspection of the dentists' treatment plans indicated that molar teeth were recommended for treatment approximately four times more frequently than anterior teeth and twice as frequently as premolar teeth. Therefore, separate logistic models were constructed for anterior, premolar, and molar teeth. All models were based on the probability that a tooth would be recommended for treatment, operationalized as the percent of examining dentists who indicated they would treat the tooth. Using an events/trials syntax to model the response (12), the events variable was the number of recommendations for treatment of a given tooth, the trials variable was the number of dentists examining the tooth, and the explanatory variables were both individual tooth and subject level characteristics. The models were based on 2,043 examinations of 390 molars, 2,039 examinations of 363 premolars, and 3,341 examinations of 574 anterior teeth in the 49 subjects.

For the three tooth-type models, the same model development sequence was followed. First, all explanatory variables were inspected, and those with distributions more skewed than 80 percent/20 percent were excluded from the initial analyses to avoid computational problems related to collinearity at an early stage in the fitting process. Excluded variables were allowed to enter at a later stage if they contributed, so their explanatory role was not lost. As noted, during preliminary development of the variables, some variables with multiple response options were collapsed to meet the 80/20 criterion. Second, three excluded conditions were assigned treatment probabilities of 1.0. These conditions were dental caries determined epidemiologically (9), fractured cusp, and fractured restoration. Although these conditions exhibited low prevalences, there is universal or near-universal agreement that they require treatment.

Third, all eligible clinical and questionnaire variables were entered into initial forward stepwise logistic regression analyses with entry set at $P=.03$. Fourth, all possible balanced interactions (10% or greater double positives) between entered dichotomous explanatory variables were evaluated in stepwise models that forced all variables that entered the initial models, and then allowed interactions to enter at $P=.01$. Fifth, a subsequent set of stepwise models forced all significant explanatory variables, and then allowed originally excluded variables with distributions up to 95 percent/5 percent to enter at $P=.01$. Sixth, a backward stepwise regression at $P=.05$ concluded the model building process. These final models were then rerun using SUDAAN software to calculate confidence intervals for odds ratios that were adjusted for the clustering of teeth within subjects and multiple assessments of the same tooth by multiple dentists (i.e., the patient was the primary sampling unit for the estimation of standard errors and the determination of confidence intervals) (13). An earlier assessment of extent of correlation of teeth within subjects suggested that the effects of this adjustment were small (14). Thus, adjustments at each step in the stepwise procedure were not considered necessary.

Model performance was evaluated by the kappa statistic, which was applied to 5x5 tables in which both actual and predicted probabilities of treatment were collapsed into categories of 0–0.15, 0.16–0.30, 0.31–0.69, 0.70–0.84, and 0.85–1.0. Both the teeth for which the logistic regressions generated estimated probabilities of treatment and the teeth with a priori treatment probabilities of 1.0 (i.e., epidemiologically determined caries, and fractured teeth and restorations) were included in the tables. This approach was preferred over a simpler approach that would categorize estimated and actual treatment probabilities of 50 percent or greater as positive, and those less than 50 percent as negative. In typical distributions of agreement among dentists concerning recommended treatment, agreement is absolute or near absolute for most teeth, especially those without restorations (10). Only for a minority does the probability of treatment fall in the middle of the distribution. Thus, a multicategory analysis of agreement that requires greater precision at the extremes should yield a more realistic assessment of model performance.

Model Assessment. We assessed the utility of the models in terms of their ability to identify which teeth would actually be treated or recommended for treatment by individual dentists. We collected baseline subject characteristic data from a convenience sample of community-dwelling adults, used the models to estimate which teeth would receive treatment if the subjects visited dentists in the subsequent year, and then compared the estimates of treatment with actual treatment reported by the subjects' dentists.

Community Sample Examinations. The study design for this assessment of the model's utility required unusually strong cooperation from participants. Because the study was longitudinal and demanded several responses from participants, both loss to follow-up and incomplete compliance were particular concerns. To help ensure high levels of compliance, we recruited subjects through community organizations, with participation payments accruing to the organization rather than the individual subject. Further, participation payments escalated with each completed successive response by a given participant. This approach not only helped ensure some commitment to continued cooperation because subjects were volunteering to help their community organizations; it also allowed us to depend on the staff of the participating community organizations both to select dependable subjects at the outset and to help organize follow-up efforts to maximize participation and, hence, income for the organization. The approach was approved by the dental school's human subjects committee.

A total of 412 adults were examined in 11 examination sessions held at 10 community organizations (two elementary school PTAs, three churches, one synagogue, and four community agencies—Red Cross, Habitat for Hu-

manity, Interfaith Council, Literacy Council). We attempted to select a diverse group of organizations to ensure broad community representation. Participants had been prescreened by organization representatives to be in good health, to present with few missing teeth, and to be likely to visit a dentist in the subsequent year. No other criteria were employed. Four examiners participated in four training sessions, then completed the clinical examinations as well as 42 replicate examinations of 40 subjects. Mean interexaminer reliability at the conclusion of training was 98 percent agreement for tooth status calls (carious, restored, sound), 94 percent agreement for similar calls for individual surfaces, and 98 percent for calls within one score for worst and average amalgam margins. For the assessments made during the examination session, mean percent agreement was 97 percent for tooth status (kappa= 0.93), 96 percent for surface status (kappa=0.91), 86 percent for ±1 score for worst and average amalgam margins, and 98 percent for ±2 scores. The data collected in the clinical examinations and questionnaires was the same as those collected for the development of the models (Tables 1 and 2).

Treatment Received. We used a series of mailed requests to community sample participants and their dentists to obtain the information on actual treatment received over the following 18 months. We mailed cover letters and response postcards to all participants at six, 12, and 18 months, asking them to indicate whether they had visited a dentist, and if so, to identify the dentist and describe the treatment they received in general terms (e.g., exam, cleaning, fillings). When a participant indicated a visit, we sent a request and response postcard to the identified dentist requesting the details of the treatment recommended or provided to the patient (i.e., tooth number, material, surfaces, date, and whether the treatment was recommended or provided). We offered to reimburse the person completing the response card (usually a receptionist) a token amount for the time required to pull the patient record and copy the information. Prior to the first round of postcard requests, we had visited the two local dental societies where we described the project and asked for members' cooperation if they received a card.

Table 3 summarizes the overall response to the postcard requests. In a few instances, we received only one postcard response from a subject, most frequently to the 12-month request, less often at six months. In these instances, participants' experience with dentists for the remainder of the 18-month period is unknown. We included these subjects in the analysis. Overall, 97 percent of participants supplied information regarding their visit status, and 90 percent of those had visited the dentist at least once. Among those participants indicating a visit, we received information describing the specifics of treatment provided or recommended from 89 percent of the dentists to whom requests were sent. The 358 participants reporting visits identified 114 dentists. Fourteen of these dentists had participated in the treatment planning sessions associated with the development of the model.

Analyses. The subjects included in the analyses were those 317 participants from the community sample for whom dentists had supplied information regarding any restorative treatment provided or recommended. We applied the model to the baseline data for these subjects to obtain estimates of treatment probability for each of 8,587 teeth. We compared the probability estimates with the treatment actually received or recommended. To establish a treatment/no-treatment cut point in the 0–1 distribution of probability values, we adjusted the critical value for the estimated probability of treatment to maximize the sum of the sensitivity (Sn) and specificity (Sp) values. Agreement of estimated treatment for a tooth with actual treatment was evaluated in terms of kappa, sensitivity and specificity, and positive and negative predictive values. We also constructed new descriptive models based on the community sample data using procedures similar to those described for the original models. The only difference occurred in the syntax of the models. Because we were modeling a simple treatment/no treatment event with one observation per tooth, we used a dichotomous response variable rather than the events/trials syntax. We compared these new models to the original models in terms of the predictors that entered and the direction of their effects.

TABLE 3
Summary of Postcard Responses

Category	*n*	% of Total Sample	% of Previous Category
Subjects examined at baseline	412	100	—
Examinees responding with postcard(s) indicating dental visit status over subsequent 18 months	398	97	97
Responding examinees who reported having one or more dental visits	358	87	90
Responding examinees for whom dentists supplied information about indicated visits	317	77	89

Results

The three final original models for molars, premolars, and anterior teeth are shown in Tables 4–6. The kappa values indicating the extent of agreement between the predicted and actual treatment probability categories are at the low end of the "substantial" agreement range (premolars and anteriors) and the high end of the "moderate" range (molars) (15). The left-hand portion of Table 7 summarizes the factors entering the three models, indicating that all three models include tooth-level clinical factors as well as subject-level clinical and extraoral factors.

In contrast, the application of the model to the community sample indicated that the models were relatively weak in identifying which teeth among participants in the community sample would receive treatment or treatment recommendations over the next 12–18 months. Table 8 presents

TABLE 4
Predictive Model for Molar Teeth

Factor	Beta	SE	Odds Ratio	95% CI
Worst amalgam margin score >5	1.11	0.19	3.03	2.09, 4.40
Tooth has restored cusp(s)	0.58	0.21	1.79	1.18, 2.70
Tooth has questionable dentin support	0.60	0.26	1.82	1.09, 3.03
Patient has 1–4 crowns	0.80	0.19	2.23	1.53, 3.23
Patient has 21–50 restored surfaces	–0.38	0.18	0.68	0.48, 0.97
Patient reports food sticks between teeth	–0.66	0.24	0.52	0.32, 0.83
Patient has no concerns about teeth	–1.48	0.24	0.23	0.14, 0.36
Patient accepts dentist recommendation if affordable	–0.44	0.17	0.64	0.46, 0.90
Dentist has recommended a crown	0.70	0.20	2.01	1.36, 2.98
Patient is a college graduate	–0.90	0.21	0.41	0.27, 0.61

Kappa=0.60. Teeth with epidemiologically determined caries, fractures, and fractured restorations were excluded from the model, but included in the analysis of agreement with an assigned treatment probility of 1.0.

TABLE 5
Predictive Model for Premolar Teeth

Factor	Beta	SE	Odds Ratio	95% CI
Worst amalgam margin score >5	1.37	0.33	3.94	2.06, 7.51
Patient has 5–9 restorations	–0.76	0.24	0.47	0.29, 0.74
Patient has no crowns	–1.12	0.22	0.33	0.21, 0.50
Patient has more than 2 carious teeth	–0.53	0.23	0.59	0.38, 0.92
Patient reports pain as problem	–0.64	0.15	0.53	0.39, 0.71
Patient reports missing teeth as problem	0.33	0.15	1.39	1.04, 1.86
Patient has no concerns about teeth	–1.60	0.28	0.20	0.12, 0.35
Patient reports regular visits	–0.78	0.16	0.46	0.34, 0.63
Patient has had visit within past year	–1.00	0.19	0.37	0.25, 0.53
Patient thinks dentist would recommend exam	1.04	0.23	2.83	1.80, 4.44
Patient thinks dentist would recommend crown	0.91	0.22	2.48	1.61, 3.82
Patient is college graduate	–1.19	0.20	0.30	0.21, 0.45
Interaction: worst margin x no crowns	0.92	0.45	2.51	1.04, 6.06
Interaction: worst margin x visit within year	–1.11	0.32	0.33	0.19, 0.62
Dummy variable for missing questionnaire data	3.03	0.33	20.69	7.55, 39.52

Kappa=0.62. Teeth with epidemiologically determined caries, fractures, and fractured restorations were excluded from the model, but included in the analysis of agreement with an assigned treatment probility of 1.0.

the kappa, sensitivity, specificity, and positive and negative predictive values for the molar, premolar, and anterior models. While better than chance (i.e., none of the confidence intervals for the kappa values included 0), this application of the models does not come close to duplicating the strong performance seen in model developmental.

The right-hand portion of Table 7 summarizes the new models constructed from the community sample data using the same approach as the original model construction. These models tend to include fewer factors overall, and for molars and anteriors, no tooth-level clinical factors. Most of the factors that did enter also appeared in the original models.

Discussion

Model Development. The descriptive models performed well in identifying the likelihood of treatment of the teeth in the original developmental data set, i.e., the data used in constructing the models. Even here, however, the extent of agreement was only between "moderate" and "substantial," which indicates that the models were unable to mirror perfectly the distributions of treatment decisions. Quite probably, the idiosyncratic nature of the treatment decision-making process, together with the inability to capture all factors used by dentists in making these decisions will always limit this agreement to some extent. It is worth noting that these are exploratory models. The models could have been constructed using a variety of methods, including alternative approaches to stepwise selection and adjustment for clustering, and each method might well result in a slightly different set of explanatory factors. However, it is unlikely that these alternatives would alter the basic performance of the models.

The factors that entered these models and the directions of their effects were, for the most part, logical and not unexpected, further strengthening the case for the model design. It should be kept in mind that epidemiologically determined (i.e., clinically obvious) caries, fractured cusps, and fractured restorations were factors that were not modeled, but rather were assigned a treatment probability of 1.0. Thus, they do not appear among the factors entering the models. Since one or more of these factors was present for 5.4 percent (n=72) of all teeth in the models, they represent an important, but far from dominant, basis for practitioners' treatment recommendations. In fact, in other analyses we have shown that treatment recommendations for teeth with clinically obvious caries are not automatic (16).

Not surprisingly, one of the strong-

TABLE 6
Predictive Model for Anterior Teeth

Factor	Beta	SE	Odds Ratio	95% CI
Tooth is restored	0.93	0.38	0.38	1.20, 5.34
Patient has no carious lesions	1.41	0.21	4.1	2.71, 6.18
Patient has 1–2 crowns	1.39	0.25	4.01	2.46, 6.65
Dentist has warned of possible fracture	2.07	0.39	7.92	3.69, 17.02
Dentist has suggested crowning a tooth	–1.51	0.34	0.22	0.11, 0.43
Patient's last visit was for check-up	1.64	0.29	5.16	2.92, 9.10
Patient reports regular visits	–1.31	0.27	0.27	0.16, 0.46
Patient rates oral health as good/very good	–2.81	0.42	0.06	0.03, 0.14
Patient has seen same dentist for 1–3 years	1.63	0.33	5.10	2.67, 9.75
Patient thinks dentist would recommend filling	2.20	0.39	9.03	4.20, 19.38
Patient would accept crown	0.76	0.24	2.14	1.34, 3.42
Patient is a college graduate	–2.04	0.34	0.13	0.07, 0.25
Interaction: possible fracture x 1–3 years	–3.95	0.74	0.02	0.01, 0.08
Interaction: good oral health x regular visits	1.67	0.41	5.31	2.38, 11.87
Interaction: recommend filling x tooth restored	0.98	0.37	2.66	1.29, 5.50
Interaction: tooth restored x college grad	1.08	0.43	2.94	1.27, 6.84
Dummy variable for missing questionnaire data	3.03	0.33	20.69	7.55, 39.52

Kappa=0.65. Teeth with epidemiologically determined caries, fractures, and fractured restorations were excluded from the model, but included in the analysis of agreement with an assigned treatment probility of 1.0.

est associations with treatment for posterior teeth, both molars and premolars, was the worst amalgam margin score. As we have shown in previous analyses of this data set, teeth with existing treatment were far more likely to be recommended for additional treatment than teeth without any treatment (10). These models show that restorations in general and, specifically, the worst portion of the visible amalgam margin drive a good deal of that treatment activity for posterior teeth.

What is surprising at first consideration is the absence of virtually all other tooth-level clinical characteristics. For molars, two other characteristics did enter, both associated with the extent of the existing restoration and, hence, the ill-defined concept of dentinal support. Although not reported in these analyses, crowns were frequently the type of restoration recommended when either of these two factors was positive. For anterior teeth, the only tooth level clinical factor that entered was the presence of a restoration, again demonstrating the "cycle of rerestoration" phenomenon noted in posterior teeth (17). Probably our design feature of only allowing variables with at least a 95 percent/5 percent distribution to enter limited the variety of tooth-level clinical characteristics in the model. For example, the presence of an overhang/open contact was eligible only for the "second chance" entry; two other clinical factors, mobility and crown volume, were ineligible.

That treatment recommendations are based on much more than the clinical condition of the tooth in question is quite apparent in the number of subject-level factors that enter the models. A few consistent factors may reflect the relatively small number of subjects on which the models were based more than any underlying relationship with the dentists' determinations of the need for treatment. Subjects with college educations were less likely to have any teeth recommended for treatment, and those reporting no concerns about their teeth were less likely to receive treatment recommendations for molars and premolars. Those subjects reporting regular visit patterns, recent last visits, and most recent visits for check-ups were less likely to receive treatment recommendations. While this relationship is not surprising, relatively few subjects with this type of visit history were among the original sample, which was selected from patients seeking treatment at the dental school.

Clearly, subjects' reports of previous dentists' recommendations and subjects' attitudes about dentists' recommendations were associated with the likelihood of receiving treatment recommendations. Subjects reporting that previous dentists had recommended treatment directly or indirectly were more likely to receive treatment recommendations; for molars only, subjects who expressed some reservations about accepting treatment recommendations were less likely to receive them. Although the issue cannot be resolved in these analyses, it is likely that, at least for elective treatments, subjects' attitudes may be formed on two levels. First, for those dentists who consult with a patient prior to developing treatment recommendations, some of the elective recommendations may never be made. Second, by not accepting previous treatment recommendations for elective treatment, a patient may present as an unpromising prospect for such recommendations. Note, for example, that the presence and absence of crowns elsewhere in the mouth was a positive and negative factor, respectively, for treatment recommendations for molars and premolars.

Model Assessment. When the model was used to identify which teeth would be treated or recommended for treatment among a group of subjects who visited dentists in the

TABLE 7
Summary of Original and New Models

Factors	Final Original Models			New Community Sample Models		
	Molar	Premolar	Anterior	Molar	Premolar	Anterior
Tooth level clinical factors*						
Tooth restored			++		++	
Worst amalgam margin score >5	++	++				
Cusp(s) restored	++					
Questionable dentin suport	++					
Crown present					--	
Patient level clinical factors						
1–2 crowns	++		++	--		--
No crowns		--				
Some carious activity		--				
No caries			++			
21–50 restored surfaces	--					
5–9 restorations		--				
<5 restorations					++	
No amalgam restorations				--		--
Patient level extraoral factors						
Good oral health self-rating			--			
No concerns about teeth	--	--		--	--	--
Problem with pain		--			--	
Problem with missing teeth		++				
Problem with food sticking	--			++		
Concern about appearance						++
Regular visit pattern		--	--			
Last visit was check-up			--			--
Last visit was within year		--				
1–3 years with same dentist			++		--	
>5 years with same dentist						++
Dentist would recommend crown		++				
Dentist would recommend filling			++			
Dentist would recommend exam		++				--
Would accept crown if recommended		++			++	
Only accept treatment if affordable	--					
Accept treatment if necessary				--		
Dentist has suggested crown	++		--			
Dentist has warned of fracture			++			--
College graduate	--	--	--			--
High school graduate					++	

++ This factor increases the likelihood of a treatment recommendation.
-- This factor decreases the likelihood of a treatment recommendation.
*Teeth with epidemiologically determined caries, fractures, and fractured restorations were excluded from these analyses.

community, the level of agreement between estimated and actual treatment was poor. The models were able to identify correctly a little over one-half of the teeth that were treated or recommended for treatment in the patient sample. Further, identifying even these teeth was not very efficient, as only around 15 percent of all the teeth that the models indicated would be treated actually received such treatment. The models were more successful in identifying teeth that would not receive treatment. About three-quarters of such teeth were identified, and the identification was efficient, with few false positives. While this latter performance is encouraging, the fact remains that the utility of models of dentists' treatment decisions lies primarily in their ability to associate clinical characteristics with decisions to intervene, as it is these characteristics and patterns of characteristics that are hypothesized to cause dentists to recommend treatment (18).

Of course, some of this less-than-

TABLE 8
Performance of Original Models on Community Sample Data

Model*	Kappa	Sensitivity	Specificity	Positive Predictive Value	Negative Predictive Value
Molar teeth (n=2,574)	0.10	0.51	0.73	0.15	0.93
Premolar teeth (n=2,262)	0.18	0.57	0.81	0.16	0.97
Anterior teeth (n=3,751)	0.20	0.63	0.88	0.15	0.99

*Teeth with epidemiologically determined caries, fractures, and fractured restorations were excluded from the model, but included in the analyses of agreement with an assigned treatment probility of 1.0.

perfect performance is accounted for by the nature of the assessment. The models were constructed to estimate probabilities of treatment, i.e., theoretically the mean of all dentists' treat/do not treat decisions. Because each tooth in the community sample was only examined by one dentist, because dentists make dichotomous decisions rather than offer treatment probabilities, and because dentists are not entirely predictable on an individual level—i.e., they make idiosyncratic treatment decisions—some loss in precision in predictions is inevitable. The situation is analogous to an imperfect "gold standard," which can affect the apparent accuracy of a diagnostic test (19). However, two additional possible reasons for the relatively poor performance of the models in the community sample merit consideration.

The first consideration is whether the data describing the treatment actually received by the sample of community-dwelling adults was accurate. Failure of subjects to report visits would not affect this accuracy. Subjects reporting no dental visits were not included in the analyses. However, dentists' offices could either overreport or underreport treatment, with the latter being far more likely. Record entries could be missed, busy employees might simply rely on memory, and recommended treatment might not be known because it was not indicated in the treatment record. However, for the following reasons we think this type of underreporting occurred relatively infrequently. Postcards returned from dental offices tended to agree with subject postcards in terms of treatment received and dates of treatment. Further, in instances where the subjects indicated visits to the same office on two separate postcard responses, our second request for treatment data to the dental office asked for all treatment provided and recommended since the baseline examination date. Without exception, the treatment listed on the first query was listed again on the second response. Finally, the offices did report a substantial amount of recommended treatment; 26 percent of all restorations in the analyses were recommended but not provided, of which 57 percent were crowns.

The second consideration is that the general level of treatment needs and the dentist-patient relationship were different in the two groups of subjects. Most of the subjects participating in the multiple examinations upon which the models are based had been admitted to the dental school predoctoral program, which means they had substantial needs. The mean probability of a tooth being recommended for treatment was 0.26. In contrast, among the subjects in the community sample used for the validation study—i.e., those with dental visits—the probability for treatment or a treatment recommendation for an individual tooth was 0.06. While this fourfold difference in treatment needed may not in itself render the models inaccurate, it is probable that the sheer level of need may lead to altered dentist behaviors.

The dentist-patient relationship can also affect dentist behavior. Obviously, subjects on whom the models were based had not established any relationships with the dentists who examined them for the project. In contrast, 94 percent of the 317 subjects in the community sample had a regular dentist. Seventy percent of these patients had had a visit within the previous six months, and 86 percent claimed they kept to a regular pattern of visits. In the sample of dental school subjects, 53 percent indicated a visit within the past six months, and fewer than half claimed a regular pattern of visits.

This difference in dentist-patient relationships may be associated with the inability of the models to predict recommended treatment accurately. It is possible that in the community sample, much of the easily "predictable" treatment had already been provided over the years, with the current treatment recommendations being more a function of individual dentist's idiosyncratic behavior. It also is possible that due to the circumstances of the research study—i.e., the dental school environment, "new" patients, and higher levels of need—dentists examining the dental school subjects were more thorough, and their recommendations more comprehensive. Certainly, dentists have been shown to be more likely to recommend replacement of restorations provided by others (7). Finally, it is likely that recommendations for treatment made for and declined by subjects in previous visits would be less likely to be repeated and, hence, not reported in conjunction with the visits for which we collected data.

The performance of the models in the community population notwithstanding, the analyses described here do provide some of the only information available describing both clinical and nonclinical factors associated with dentists' restorative decision making. Among teeth without clinically detectable caries, and fractured teeth and restorations, a variety of clinical and nonclinical factors are associated with dentists' recommendations for treatment of individual teeth. While this statement would seem obvious, surprisingly, it has not been well documented. Few analyses of factors associated with the receipt of treatment have been reported (6). Still fewer have been multivariable analyses of tooth-by-tooth decisions. Most of the literature examining dentists' treatment decisions has focused on quantifying the variation present among dentists (6). Exploration of the reasons for this variation has not been empha-

sized. Thus, these models are among the first to document relationships between specific clinical and nonclinical conditions and the likelihood of treatment. Knowledge of these relationships should be useful in designing strategies to improve the appropriateness of care by reducing the extent of variation in dentists' treatment decisions.

References

1. Sheiham A, Maizels J, Cushing G. The concept of need in dental care. Int Dent J 1982;32:265-70.
2. Goodman H, Weyant R. Dental health personnel planning: a review of the literature. J Public Health Dent 1990;50:48-63.
3. Spencer J. The estimation of need for dental care. J Public Health Dent 1980;40:311-27.
4. Bader J. Health services research in dental public health. In: American Public Health Association and American Association of Public Health Dentistry. A research agenda for dental public health. J Public Health Dent 1992;52:23-6.
5. Marcus M, Koch A, Gershen J. Construction of a population index of adult oral health status derived from dentists' preferences. J Public Health Dent 1983;43: 284-94.
6. Bader J, Shugars D. Variation in dentists' clinical decisions. J Public Health Dent 1995;55:181-8.
7. Bader J, Shugars D. Understanding dentists' restorative treatment decisions. J Public Health Dent 1992;52:102-10.
8. Mahler D, Marantz R. Clinical assessments of dental amalgam restorations. Inter Dent J 1980;30:327-34.
9. Radike A. Criteria for diagnosis of dental caries. In: Proceedings of the conference on clinical testing of cariostatic agents. Chicago, IL: American Dental Association, 1968:87-8.
10. Bader J, Shugars D. Agreement among dentists' recommendations for restorative treatment. J Dent Res 1993;72:891-6.
11. Redford M, Gift H. Dentist-patient interactions in treatment decision-making: a qualitative study. J Dent Educ 1997;61: 16-21.
12. Stokes M, Davis C, Koch G. Categorical data analysis using the SAS system. Cary, NC: SAS Institute Inc., 1995.
13. Shah B, Barnwell B, Hung P, LaVange L. SUDAAN user's manual, Release 5.50. Research Triangle Park, NC: Research Triangle Institute, 1991.
14. Bader J, Shugars D, Bhapkar M. Design effect considerations in tooth-based analyses [Abstract]. J Dent Res 1994;73: 270.
15. Landis J, Koch G. The measurement of observer agreement for categorical data. Biometrics 1977;33:159-74.
16. Bader J, Shugars S, Rozier R. Relationship between epidemiologic coronal caries assessments and practitioners' treatment recommendations in adults. Community Dent Oral Epidemiol 1993;21:96-101.
17. Brantley F, Bader J, Shugars D, Nesbit S. Does the cycle of rerestoration lead to larger restorations? J Am Dent Assoc 1995;126:1407-13.
18. Bader J, Shugars D. What do we know about how dentists make caries-related treatment decisions? Community Dent Oral Epidemiol 1997;25:97-103.
19. Deneef P. Evaluating rapid tests for streptococcal pharyngitis: the apparent accuracy of a diagnostic test when there are errors in the standard of comparison. Med Decis Making 1987;7:92-6.