Compliance as a Prognostic Indicator. II. Impact of Patient's Compliance to the Individual Tooth Survival

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Background: Existing evidence concerning the validity of an appropriate regular periodontal maintenance (PM) regimen and the role of patient compliance is controversial and inconsistent. The objectives of this study are to identify the impact of patient compliance (complete versus erratic) on alveolar bone loss and tooth survival.

Methods: A retrospective study was conducted using data from 295 patients with ≥20 years of observation, which included treatment and ≥15 years of maintenance therapy, in a private practice in Yamagata, Japan. Subject-level variables and tooth-level variables were recorded at the initial visit, the reevaluation visit, and the final visit. In total, 7,502 teeth in 295 subjects met inclusion criteria and were divided into two groups: non-molar teeth (n = 5,585) and molar teeth (n = 1,917). A tooth-level multivariate survival model and multiple logistic regression model using the method of generalized estimating equations were constructed to analyze the effects of compliance and periodontal maintenance intervals on tooth loss and alveolar bone loss, respectively.

Results: Of 7,502 teeth, 284 molar teeth and 364 non-molar teeth were lost. Molar teeth had an approximately 30% reduction in risk of tooth loss for complete compliance, with 2-year compliance classification achieving statistical significance ($P = 0.033$), and 30% compliance classification approaching statistical significance ($P = 0.072$). Complete compliers under 30% compliance classification showed over 50% reduction in the risk of alveolar bone loss among non-molars ($P = 0.015$).

Conclusion: Complete patient compliance with increased frequency of periodontal maintenance is important for improved dental prognosis through reduction of tooth loss among molars and minimization of alveolar bone loss among non-molars. *J Periodontol 2010;81:1280-1288.*

KEY WORDS

Alveolar bone loss; compliance; periodontal disease; prognosis; tooth loss.

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Periodontal maintenance (PM) is recognized as an integral part of current periodontal therapy, and it is known to have a significant impact on periodontal prognosis and eventual tooth survival.[1] Several long-term studies have revealed various prognostic factors in patients receiving treatment for periodontitis, which include tooth type (non-molar teeth versus molar teeth); furcation involvement; tooth mobility; alveolar bone loss; and most importantly, patient compliance with the recommended PM.[2-6]

Effectiveness and efficacy of PM and the role of patient compliance have been tested by several retrospective and prospective cohort studies, and those studies demonstrated that patients with a history of periodontitis who comply with regular PM intervals experience less attachment loss and lose fewer teeth compared to patients who completely fail to receive PM following active periodontal therapy.[7-11] However, data from our previous study and other studies suggest that no clear association exists between erratic compliance with PM and the decreased incidence of tooth loss when the study excludes totally non-compliant patients.[12-14]

A retrospective cohort study by Chambrone and Chambrone[13] in a private practice in Brazil used a patient-based analysis with a multiple logistic regression model that adjusted for confounding variables including PM intervals,

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age, and smoking. They tested 120 subjects with chronic periodontitis who had been treated and maintained for ≥10 years. In this study, gender, frequency of recall visits, and period of PM were not associated with increased periodontal-related tooth loss. These results confirmed that the period of PM and frequency of recall visits are not associated with periodontal tooth loss. McGuire and Nunn[2,3] also conducted a retrospective cohort study in a private practice in the United States using a tooth-based approach to survival analysis with adjustment for confounding variables, including initial prognosis and commonly taught clinical parameters. Their results agreed that compliance, as defined by Wilson et al.,[15] did not significantly affect tooth survival. In our previous study, we evaluated the relationship between patient compliance and tooth loss.[12] Our outcome assessment was based on the experience of subject-level tooth loss (one or more teeth lost during PM). Compliance was defined in two ways, and under both definitions patients with complete compliance were more likely to experience tooth loss than patients with erratic compliance, with the greatest increased risk for tooth loss observed among complete compliers by the first definition of missing <30% of recall visits. Our data suggest dentists' decisions to extract teeth at maintenance visits may result in greater tooth loss.

However, recent data from Greece demonstrate that subjects whose compliance was erratic had a risk of undergoing tooth extraction that was >1.52 times that for subjects whose compliance was complete, based on the retrospective cohort study in a private practice for 280 subjects with severe periodontitis.[5] Furthermore, Checchi et al.[16] demonstrated that erratic compliers were 5.6 times more likely to lose teeth compared to complete compliers.

Does increased patient compliance to PM decrease tooth loss? The existing evidence is often controversial, and it seems that lack of consensus still exists with regard to the validity of an appropriate regular maintenance regimen and the role of patient compliance.[17] One of the reasons can be the application of endpoint characteristics used in previous studies when demonstrating the validity of regular maintenance regimens.[18] Tooth loss is occasionally referred to as the true endpoint characteristic in dental longitudinal studies and the landmark of tangible patient benefit. However, when the accumulating evidence of dental implant treatment or periodontal disease–systemic health interactions influences the recommendation to extract a tooth, the validity of those endpoint characteristics becomes questionable.

It is suggested that the use of a long-term, retrospective study design that includes both tooth-level data and subject-level data with well-defined inclusion and exclusion criteria, which takes into account both surrogate and true endpoints, may provide some answers to the role of the interval of PM and patient compliance in tooth prognosis and eventual tooth survival. The objectives of this study are to demonstrate the impact of patient compliance (complete versus erratic) on periodontal tooth prognosis and tooth survival, and to understand for the first time the validity of appropriate regular maintenance. We developed multivariate models that included both subject-level variables and tooth-level variables and used the method of generalized estimating equations (GEE) in a long-term (≥20 years) retrospective study with a relatively large cohort to investigate the effects of compliance and PM interval on a surrogate endpoint (alveolar bone loss), and we applied the marginal approach to multivariate survival analysis to investigate the effects of compliance and PM interval on a true endpoint (time until tooth loss).

MATERIALS AND METHODS

Data from 505 patients (including treatment) that were evaluated in the previous study[12] were selected from the patient records of a private office in Japan. Details of the study design, inclusion and exclusion criteria, experimental population, and classification of either complete or erratic patient compliance are described in a previous paper.[12] This study complied with ethical provisions for medical research set out in the Helsinki Declaration of 1975, as revised in 2000. Patients provided informed consent to the treating dentist (TK) before treatment was administered. In this study, the minimal follow-up time was set at 20 years from the initial visit for all patients, with a minimum of 15 years of maintenance therapy. In addition, third molars were not included in this analysis. All 505 charts and their radiographs were reviewed. Of these subjects, 210 subjects did not match the inclusion and exclusion criteria of this study, particularly follow-up of ≥20 years. In total, there were 7,502 teeth in 295 subjects that met all the inclusion and exclusion criteria. The teeth that fit these criteria were then divided into two groups: non-molar teeth (5,585 teeth) and molar teeth (1,917 teeth).

Baseline conditions of the subject population, including maintenance period; age; gender; smoking status; number of teeth at initial visit and re-evaluation visit; decayed, missing and filled teeth (DMFT); bleeding on probing; plaque index; and overall periodontal disease condition, were analyzed. Individual tooth-based baseline conditions including probing depth, furcation involvement, mobility, malposition, history of root canal therapy, and alveolar bone loss level were categorized to either non-molar teeth or molar teeth and further analyzed. All patients were diagnosed, treated, and maintained accordingly under the supervision of one clinician (TK) at the same private practice for the course of this study. Probing depth was measured at six sites and recorded in the periodontal chart and categorized as 1 (1 to 3 mm), 2 (4 to 6 mm), and 3 (≥7 mm). Plaque index and bleeding on probing were also dichotomously evaluated at six sites per tooth. Furcation involvement was recorded by using a Nabers probe and classified according to Hamp et al.[19] Individual tooth mobility was evaluated by Miller classification. All measurements were recorded at reevaluation and at final PM visit. The bone loss analysis that was used for this study involved evaluating the standardized periapical radiographs of all the teeth in the mouth at the initial visit and the final PM visit. The level of alveolar bone loss for this study was measured on both the mesial and distal aspect. The site of greater alveolar bone loss was used and classified by the Schei score.[20] Periodontal classification was based on the classification system from the American Academy of Periodontology.[21] The classification of compliance was according to our previous paper.[12]

Maintenance regimens consisted of 3-month or 6-month intervals for 30- to 60-minute appointments based on the periodontal condition of each patient. All patients who demonstrated any periodontal pockets of ≥4 mm at the time of the reevaluation visit were assigned to 3-month intervals of maintenance. Otherwise, the patients were assigned to 6-month intervals for maintenance visits. The protocol of maintenance visits included the following: 1) an update of medical history and changes of medications, 2) a periodontal examination, 3) subgingival plaque and calculus removal using hand instruments and an ultrasonic scaler, 4) professional mechanical tooth cleaning, 5) supragingival plaque and calculus removal using a handpiece, 6) a fluoride varnish, 7) reinforcement of oral hygiene, and 8) data input to the computer, update of radiographs, and intraoral photographs when necessary. If further treatment needs arose during maintenance therapy, the appropriate treatments, such as the extraction of a hopeless tooth, restorative treatment, endodontic therapy, and periodontal treatment, were provided under the direct supervision of the same clinician (TK). In this study, any visits for the purpose of necessary treatment besides regular maintenance were not counted as maintenance therapy.

Statistical Analyses

Statistical analysis was conducted by using two statistical software packages.[‡§] Summary statistics were computed for both initial patient-level and tooth-level characteristics, including maintenance period, age, gender, smoking status, probing depth, furcation involvement, mobility, malposition status, history of root canal therapy, and alveolar bone loss level according to the patient compliance status (complete versus erratic). Furthermore, exploratory analysis included investigation of possible associations among the compliance status and initial patient-level and tooth-level characteristics by using chi-square tests of independence for categorical variables and Mann-Whitney *U* tests for continuous variables.

To evaluate the effect of patient compliance on the progression of periodontal disease for both non-molar teeth and molar teeth over time, alveolar bone loss level was used as an outcome measure and classified as "no change" versus "worsening" for the change of category in Schei score at the final maintenance visit. Because of the lack of independence of teeth within each patient's mouth, analysis of the categorical change over time was conducted using the method of GEE for correlated outcomes with the fit models including compliance as an independent variable with adjustment for potential confounding with stratification of analysis by non-molar teeth and molar teeth. Confounding subject-level variables included maintenance period, age, gender, smoking status, number of teeth at initial visit and reevaluation visit, percent of teeth with bleeding on probing, plaque index, and overall periodontal disease condition. Confounding tooth-level variables consisted of initial probing depth, initial furcation involvement for molar teeth, initial mobility, initial malposition tooth status, initial history of root canal therapy, and the level of initial alveolar bone loss.

Furthermore, to fully understand the impact of compliance on individual tooth loss, including multiple tooth loss within a patient, a multivariate Cox proportional hazards regression model was constructed by using the marginal approach for correlated outcomes by including compliance as an independent variable with adjustment for confounding variables stated previously. The general form of a Cox proportional hazards regression model is given by the following equation: $\lambda(t)=\lambda_0(t)\exp(\beta x)$. In this equation, β is a vector of regression coefficients corresponding to a vector of values given by x. The $\lambda_0(t)$ term corresponds to the "baseline" hazard (i.e., the hazard when x is a vector of zeros). The hazard refers to the instantaneous probability of failure and gives the relative risk that corresponds to the multiplicative increase in baseline hazard for a given value of x. The outcome measure for the analysis was the time from the start of the reevaluation phase of treatment to when an individual tooth was recorded as extracted over time, or until the last time the tooth was observed.

RESULTS

Baseline Analysis (Compliance Versus Erratic Compliance)

Of the 295 patients, 98 patients were complete compliers and 197 patients were erratic compliers in

‡ SPSS, SPSS, Chicago, IL.
§ SAS, SAS Institute, Cary, NC.

both classification schemes. Summary statistics for subject characteristics were calculated for baseline age, gender, and smoking exposure at initial visit, reevaluation visit, and final visit for both classifications of compliance. Our results demonstrate that among the subject population, there were no statistically significant differences in gender and smoking exposure at initial, reevaluation, and final visits between compliers and erratic compliers, regardless of the system of compliance classification (Table 1). Our results also demonstrate that over the course of PM, the number of smokers was reduced for both complete compliers and erratic compliers. The average age of compliers tended to be varied with a younger average age of erratic compliers in both compliance 1 and compliance 2 categories. These results confirm that complete compliers tend to be older, regardless of the system of compliance classification (Table 2). Overall, there were 7,502 teeth present at the time of the reevaluation visit, of which 1,917 teeth were molar teeth, and 5,585 were non-molar teeth (Table 3). Tables 4 and 5 demonstrate the distribution of baseline individual tooth clinical parameters for both non-molar teeth and molar teeth for complete compliers and erratic compliers in both classification schemes. Of 7,502 teeth, 284 molar teeth and 364 non-molar teeth, which were in this subset of patients when the study began, were lost during maintenance therapy (Table 3).

Multivariate Survival Analysis

Cox regression model for correlated outcomes was fit to the subset of patients in this study. This analysis evaluates the impact of different variables simultaneously as they relate to tooth survival (tooth loss). Variables entered were patient compliance for PM after ≥20 years of observation, which included treatment and ≥15 years of maintenance therapy, and confounders. Molar teeth and non-molar teeth were analyzed separately. The Cox regression model that included patient's compliance for two classification schemes is provided in Table 6. Our results revealed that molar teeth had an approximately 30% reduction in the risk of tooth loss for complete compliance, with 2-year compliance classification achieving statistical significance ($P = 0.033$), and 30% compliance classification approaching statistical significance ($P = 0.072$). In contrast, neither compliance classifications resulted in a statistically significant reduction in the risk of tooth loss among non-molars, although the trend for non-molars was similar to that for molars.

GEE Regression Analysis for Progression of Periodontal Disease

GEE multiple logistic regression model was constructed and fit with inclusion of maintenance period and significant confounders to analyze the impact of patient compliance on progression of periodontal disease (alveolar bone loss). Table 7 reveals the relationship of compliance to worsening in categorical change of Shei score over time while adjusting for significant confounders. Our data (Table 5) suggests that complete compliance resulted in an estimated reduction in the risk of alveolar bone loss of 27% (compliance 2) and 31% (compliance 1) among molars,

Table 1.

Patient Gender and Smoking Status at Initial Visit and Follow-Up Visits According to Compliance

	Compliance 1 (30%)			Compliance 2 (2-year)		
Clinical Variables	Complete Complier (%)	Erratic Complier (%)	P*	Complete Complier (%)	Erratic Complier (%)	P*
Gender						
Male	62 (63.3)	120 (61.9)		65 (66.3)	117 (60.3)	
Female	36 (36.7)	74 (38.1)	0.898	33 (33.7)	77 (39.7)	0.371
Smoking status at initial visit						
Smoker	22 (22.4)	35 (18)		15 (15.3)	42 (21.6)	
Non-smoker	76 (77.6)	159 (82)	0.435	83 (84.7)	152 (78.4)	0.215
Smoking status at reevaluation						
Smoker	17 (17.3)	29 (14.9)		12 (12.2)	34 (17.5)	
Non-smoker	81 (82.7)	165 (85.1)	0.621	86 (87.8)	160 (82.5)	0.308
Smoking status at final visit						
Smoker	12 (12.2)	23 (11.9)		9 (9.2)	26 (13.4)	
Non-smoker	86 (87.8)	171 (88.1)	0.999	89 (90.8)	168 (86.6)	0.344

* P values are based on chi-square tests of independence.

although neither achieved statistical significance. Furthermore, complete compliers under 30% compliance classification were found to have over 50% reduction in risk of alveolar bone loss among non-molars ($P = 0.015$), whereas 2-year complete compliers demonstrated only 28% reduction in the risk of alveolar bone loss among non-molars that failed to achieve statistical significance ($P = 0.215$).

DISCUSSION

This study analyzed the impact of different variables simultaneously as they related to tooth survival (tooth loss). Variables entered were patient compliance for PM after ≥20 years of observation, which included treatment and ≥15 years of maintenance therapy, and confounders. Furthermore, a GEE multiple logistic regression model was constructed and fit with inclusion of maintenance period and significant confounders to analyze the impact of patient compliance on progression of periodontal disease (alveolar bone loss).

The reduction in risk of tooth loss among complete compliers contradicts our earlier findings[12] of increased tooth loss among complete compliers compared to erratic compliers using the same classification schemes for compliance and patient population. This conflicting result can be explained by the inherent differences in the design and analyses between the two studies. For instance, the first study[12] only involved whether a patient lost any teeth over the course of 10 years of PM for the study, whereas the current study took into account all teeth lost within each subject and the time from enrollment in maintenance until each tooth was lost over the course of ≥15 years of PM for the study. The second study involved more sophisticated statistical analyses that took into account multiple tooth loss that the first study did not take into account. Even though the second study involved a subset of 295 patients of the original 505 patients, the change in approach by using multivariate survival analysis made a difference because a similar analysis to that performed in the first study (i.e., standard multiple logistic regression) applied to this subset revealed insignificant association between compliance by both definitions to any tooth loss, with point estimators trending toward an increased risk for compliance compared to the significant results obtained for molars in the current study and a decreased risk for tooth loss with compliance, with that result being statistically significant for compliance 2 and approaching statistical significance for compliance 1.

Historically, insufficient evidence exists of the role of PM to decrease tooth loss.[17] It can be suggested that it is caused by the inconsistent study design among previous studies.[2-16,22] First, some of the studies fail to use a multivariate approach that accounts for tooth-level data with the model adjusted for confounding by both subject-level and tooth-level variables.[7-9,15] Therefore, the relative weight of the length of the interval of PM (compliance) is largely unknown compared to other individual prognostic factors, such

Table 2.

Patient Age at Initial Visit by Compliance

Clinical Variables	Mean Age (years)	n	SD	P*
Compliance 1 (30%)				
Complete complier	43.5	98	10.87	
Erratic complier	41.3	194	11.43	0.184
Compliance 2 (2-year)				
Complete complier	43.6	98	11.51	
Erratic complier	41.2	194	11.10	0.076

* *P* values are based on independent samples *t* test.

Table 3.

Summary Frequency Distribution of the Lost Teeth and Surviving Teeth of Complete Compliers and Erratic Compliers for the Two Classification Schemes

Clinical Variables	Lost Teeth (n = 648)		Surviving Teeth (n = 6,854)	
	Non-molar (n = 364)*	Molar (n = 284)†	Non-molar (n = 5,221)	Molar (n = 1,633)
Compliance 1 (30%)				
Complete complier	118 (32.4%)	104 (36.6%)	1,732 (33.2%)	527 (32.3%)
Erratic complier	246 (67.6%)	180 (63.4%)	3,489 (66.8%)	1,106 (67.7%)
Compliance 2 (2-year)				
Complete complier	133 (36.5%)	103 (36.3%)	1,715 (32.8%)	515 (31.5%)
Erratic complier	231 (63.5%)	181 (63.7%)	3,506 (67.2%)	1,118 (68.5%)

* Difference between complete and erratic compliers for time until tooth loss without adjustment for confounders was not statistically significant for either compliance 1 ($P = 0.912$) or compliance 2 ($P = 0.498$). Testing was based on the robust log-rank test for survival.
† Difference between complete and erratic compliers for time until tooth loss without adjustment for confounders was not statistically significant for either compliance 1 ($P = 0.526$) or compliance 2 ($P = 0.436$). Testing was based on the robust log-rank test for survival.

Table 4.

Initial Tooth-Level Clinical Parameters by Compliance Status for Non-Molars

	Compliance 1 (30%)			Compliance 2 (2-year)		
Clinical Variables	Complete Complier	Erratic Complier	P*	Complete Complier	Erratic Complier	P*
Probing depth						
Mean	3.50	3.61		3.73	3.50	
95% CI	3.30 to 3.71	3.47 to 3.75	0.398	3.49 to 3.96	3.37 to 3.63	0.095
Crown-to-root ratio						
Mean	1.71	1.83		1.72	1.82	
95% CI	1.65 to 1.76	1.67 to 1.99	0.156	1.67 to 1.78	1.66 to 1.98	0.266
Mesial bone loss						
Mean	2.41	2.27		2.68	2.14	
95% CI	2.18 to 2.65	2.11 to 2.44	0.349	2.41 to 2.94	1.99 to 2.29	<0.001
Distal bone loss						
Mean	2.44	2.29		2.71	2.15	
95% CI	2.20 to 2.67	2.11 to 2.46	0.323	2.44 to 2.99	2.00 to 2.30	<0.001
Mobility %						
0	94.2	95.8		91	97.3	
1	2.9	3.2		5.8	1.8	
2	2.8	0.7		2.8	0.7	
3	0.1	0.3	0.082	0.3	0.2	<0.001
Malposition %						
No malposition	99.8	99.3		99.7	99.3	
Malposition	0.2	0.7	0.177	0.3	0.7	0.307
Root form %						
Satisfactory	99.5	99.7		99.6	99.6	
Unsatisfactory	0.5	0.3	0.397	0.4	0.4	0.830
Plaque %						
No plaque	19	13.4		17.9	14	
Plaque	81	86.6	0.034	82.1	86	0.139
Bleeding on probing %						
No bleeding	30.5	25.1		26.8	26.9	
Bleeding	69.5	74.9	0.096	73.2	73.1	0.991

* *P* values are based on GEE modeling of tooth-level data.

as furcation involvement, tooth mobility, and so forth. Hence, the impact of compliance has not been readily demonstrated to be a useful prognostic factor. Second, some of the previous studies were conducted in a controlled research setting so that their inference to the private practice setting may be limited.[7-9] Hence, results in controlled research settings may not have much general applicability because they do not account for optimal conditions that are often achieved in a private practice setting, and often are of limited value because of the short duration of follow-up. Furthermore, lack of clearly defined inclusion and exclusion criteria and an unclear definition for erratic compliers have made the evaluation of the role of compliance on tooth prognosis and eventual tooth survival difficult. The nature of the population selection potentially affects the generalizability or external validity of the comparison made between compliers and erratic compliers within the study or the study's internal validity. Moreover, it can be suggested that obtaining the information about the subject's compliance level was somehow inadequate. Therefore, subjects may be misclassified between compliers and erratic compliers, thereby introducing misclassification bias. Third, there is an inconsistency among previous studies with regard to the type of data collected and the statistical analysis used. Some data were obtained from studies that only included patient-level variables, as was the case with our previous study, whereas others conducted studies based on a combination of subject-level and tooth-level data. Such differences may create discrepancies in

Table 5.

Initial Tooth-Level Clinical Parameters by Compliance Status for Molars

	Compliance 1 (30%)			Compliance 2 (2-year)		
Clinical Variables	Complete Complier	Erratic Complier	*P**	Complete Complier	Erratic Complier	*P**
Probing depth						
Mean	4.36	4.39		4.49	4.33	
95% CI	4.07 to 4.66	4.20 to 4.58	0.881	4.18 to 4.81	4.14 to 4.51	0.373
Crown-to-root ratio						
Mean	1.72	1.71		1.73	1.71	
95% CI	1.70 to 1.75	0.69 to 0.73	0.489	1.70 to 0.75	1.69 to 1.73	0.239
Mesial bone loss						
Mean	2.58	2.28		2.84	2.16	
95% CI	2.28 to 2.88	2.08 to 2.48	0.101	2.53 to 3.15	1.97 to 2.34	<0.001
Distal bone loss						
Mean	2.67	2.38		2.93	2.25	
95% CI	2.36 to 2.99	2.17 to 2.59	0.129	2.60 to 3.26	2.06 to 2.45	0.001
Mobility %						
0	93.4	94.4		89.7	96.1	
1	4	3.8		6.6	2.7	
2	2.1	1.3		3.1	0.8	
3	0.5	0.5	0.880	0.7	0.4	0.007
Furcation %						
0	86.7	91.6		86.9	91.5	
1	12.8	7.8		12.6	7.9	
≥2	0.5	0.6	0.091	0.5	0.6	0.112
Malposition %						
No malposition	100	99		99.8	99	
Malposition	0	1	—	0.2	1	0.098
Root form %						
Satisfactory	99.4	98.7		98.7	99	
Unsatisfactory	0.6	1.3	0.192	1.3	1	0.666
Plaque %						
No plaque	7	4.6		7.1	4.6	
Plaque	93	95.4	0.198	92.9	95.4	0.172
Bleeding on probing %						
No bleeding	15.7	13.1		13.5	14.2	
Bleeding	84.3	86.9	0.376	86.5	85.8	0.815

* *P* values are based on GEE modeling of tooth-level data.

understanding the impact of compliance on tooth loss when the data are interpreted and applied to a clinical practice.

Another possible reason for lack of evidence with regard to PM and related tooth loss can be an uneven application of endpoint characteristics in existing data reviewing regular maintenance regimens.[18] Tooth loss has been referred to as the most reliable endpoint characteristic in dental longitudinal studies and is notable as a landmark of tangible patient benefit. However, the dental practitioner may exert a strong influence in the determination of tooth longevity that may create a treatment bias for this outcome. Furthermore, most of the studies that have analyzed historic data have limitations inherent to any retrospective study because the treatment procedures provided were based on clinical judgment, the patients' desires, prosthetic expediency, and financial considerations, rather than random allocation of treatment as found in a randomized controlled clinical trial.

In contrast to many previous studies, we clearly defined the categories of complete compliers and erratic

Table 6.

Hazard Ratios for the Individual Tooth Survival Based on Multivariate Survival Analysis Using the Marginal Approach With Adjustment for all Significant Confounders*

	Non-Molar		Molar	
Clinical Variables	Hazard Ratio	*P*	Hazard Ratio	*P*
Compliance 1 (30%)	0.620	0.105	0.723	0.072
Compliance 2 (2-year)	0.708	0.249	0.699	0.033

* Confounding subject-level variables included maintenance period, age, gender, smoking status, number of teeth at initial visit and reevaluation visit, percent of teeth with bleeding on probing, plaque index, and overall periodontal disease condition, whereas confounding tooth-level variables consisted of initial probing depth, initial furcation involvement for molar teeth, initial mobility, initial malposition tooth status, initial history of root canal therapy, and the level of initial alveolar bone loss.

Table 7.

Odds Ratio for the Change in Category of Alveolar Bone Loss in Shei Score Based on GEE Multiple Logistic Regression With Adjustment for all Significant Confounders*

	Non-Molar		Molar	
Clinical Variables	Odds Ratio	*P*	Odds Ratio	*P*
Compliance 1 (30%)	0.482	0.015	0.691	0.083
Compliance 2 (2-year)	0.722	0.215	0.727	0.123

* Confounding subject-level variables included maintenance period, age, gender, smoking status, number of teeth at initial visit and reevaluation visit, percent of teeth with bleeding on probing, plaque index, and overall periodontal disease condition, whereas confounding tooth-level variables consisted of initial probing depth, initial furcation involvement for molar teeth, initial mobility, initial malposition tooth status, initial history of root canal therapy, and the level of initial alveolar bone loss.

compliers. In addition, whereas previous studies only addressed the outcome of periodontal parameters, progression of periodontitis, and tooth loss in patients completely compliant with suggested PM, our data demonstrated the influence of patient compliance on measures of periodontal disease progression (bone loss) and tooth loss. Furthermore, the length of the observation period of this study surpasses that of most previous studies, and the data in this study have general applicability because the data were collected in a private practice setting. Moreover, to our knowledge our study design is the first to incorporate a tooth-level multivariate survival model and multiple logistic regression using GEE in a long-term retrospective study of the impact of patient compliance on tooth survival and alveolar bone loss, respectively. In addition, this is the first study to stratify analysis of the data into non-molars and molars with the additional confounding variables for molars of furcation involvement status. It should be noted that with a longer observation period, it is possible to observe enough tooth loss to evaluate the statistical differences in tooth loss among complete and erratic compliers.

Ideally, to better understand the effect of the interval of PM and patient compliance on tooth survival, one would conduct a prospective, multicentered, randomized clinical trial with various standardized protocols for maintenance regimens and assessment of the outcomes including both surrogate and true endpoints.[18] Unfortunately, it seems that this hypothetical design of a randomized controlled clinical trial (maintenance regimens and control, randomly allocated) would be of questionable ethics and would not be tenable to conduct. Alternatively, this study demonstrates that data based on the use of a long-term, retrospective study design that includes both tooth-level data and subject-level data, well-defined inclusion and exclusion criteria, clear definition of the categories of complete and erratic compliers, and that takes into account both surrogate and true endpoints may provide some answers to the role of the interval of PM and patient compliance in tooth prognosis and eventual tooth survival. It should be noted that the use of a tooth-level multivariate survival model is a unique feature of this study, which allows the clinician to understand the validity of regular PM.

An inherent limitation to this study is the baseline condition of the periodontium among patients because the study was conducted in the private practice of a general dentist. Therefore, the subject's periodontal condition may be somewhat better than previous studies conducted in private periodontal practices where most of the patient population has moderate to severe periodontal disease. Furthermore, some of the differences in tooth survival between this study and previous studies could be related to differences in treatment philosophies among general dentists and periodontists. It should be noted that there are no dental specialty practices available in Japan; therefore, it is impossible to collect such data in a Japanese periodontal-specialty study population. In addition, like other retrospective cohort studies in dental science, the treatment procedures provided were based on the clinical judgment of the dentists rather than random allocation of treatment. Therefore, current changes in treatment planning and improvement in the success rate of dental implants may have influenced the decision to extract or conserve a tooth over time. It is beyond the scope of this study to define the criteria for tooth extraction or the reason for tooth loss. It was also not possible in this study to investigate the effect of total non-compliance on tooth survival because of inherent difficulties in follow-up examination of non-compliant individuals.

CONCLUSIONS

This is a long-term cohort study with 20 years or more observation period conducted in a private practice by using the method of GEE to demonstrate the effectiveness and efficacy of PM. Our results revealed that molar teeth had a reduction in the risk of tooth loss for complete compliance (hazard ratio 0.723 for 30% compliance classification and 0.699 for 2-year compliance classification), with 2-year compliance classification achieving statistical significance ($P = 0.033$), and 30% compliance classification approaching statistical significance ($P = 0.072$). In contrast, neither compliance classifications resulted in a statistically significant reduction in the risk of tooth loss among non-molars, although the trend for non-molars was similar to that for molars. Furthermore, complete compliers under 30% compliance classifications were found to have >50% reduction in the risk of alveolar bone loss among non-molars. Our data suggests that complete compliance with PM can be substantially important for "tooth retention" among molars and "alveolar bone retention" among non-molars. This may also indicate the importance of furcation management during PM appointment.

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