Tooth loss in patients undergoing long-term maintenance at a private dental clinic in Japan: A retrospective study

Hiroo Kawahara, DDS*†; Miho Inoue, DDS, PhD*; Kazuo Okura, DDS, PhD*; Masamitsu Oshima, DDS, PhD*; Yoshizo Matsuka, DDS, PhD†

*Department of Stomatognathic Function and Occlusal Reconstruction, Graduate School of Biomedical Sciences, Tokushima University, Tokushima-city, Japan
†Kawahara Dental Clinic, Mima-city, Tokushima, Japan

Corresponding author:

Yoshizo Matsuka, DDS, PhD
Department of Stomatognathic Function and Occlusal Reconstruction
Graduate School of Biomedical Sciences, Tokushima University
3-18-15 Tokushima-city, 770-8504, Japan
Tel: +81-88-633-7350
Fax: +81-88-633-7391
E-mail: matsuka@tokushima-u.ac.jp
Abstract

Background: Tooth loss is generally considered the final outcome of oral disease. This retrospective study was performed to identify risk factors for tooth loss in patients undergoing long-term maintenance therapy.

Methods: We surveyed 1145 adult patients who underwent maintenance therapy for $\geq$5 years after they had undergone active treatment from January 2015 to December 2016 and established a baseline status. The study variables were patient compliance, sex, number of teeth lost, cause of tooth loss, age at start of maintenance, number of remaining teeth at start of maintenance, duration of maintenance, smoking status, use of salivary secretion inhibitors, and diabetes mellitus. Additionally, 57 patients who did not undergo maintenance therapy were surveyed to examine and compare the effects of maintenance therapy. Statistical analyses were performed to assess the correlation of each variable with tooth loss.

Results: The average number of teeth lost under maintenance therapy was 0.07/year. Significantly fewer teeth were lost in the maintenance than non-maintenance group. Most of the teeth lost were non-vital teeth, and the most common cause of tooth loss was tooth fracture. Patient age, number of remaining teeth at start of maintenance, use of salivary secretion inhibitors, and diabetes mellitus were related to tooth loss.

Conclusions: To the best of our knowledge, this is first large-scale study of tooth loss in patients undergoing long-term maintenance therapy within a general dental clinic. Our findings demonstrate that starting maintenance therapy when patients are younger and possess more teeth may prevent future tooth loss.

Key words: Compliance, maintenance, patient age, remaining teeth, tooth loss, private
dental clinic
Background

Dental studies have shown that dental caries and periodontal disease are the most common pathological conditions affecting the oral cavity. More specifically, several studies have shown that the most common cause of tooth loss (TL) is dental caries, followed by periodontal disease.\textsuperscript{1-5} Thus, control of dental caries and periodontal disease is critical for prevention of TL.

A major etiological factor underlying the pathogenesis of dental caries and periodontal disease is the formation of a biofilm on the tooth surface. Removal of dental plaque is critical in preventing dental caries and periodontal disease. Axelsson and Lindhe\textsuperscript{6} and Axelsson et al.\textsuperscript{7} found that regular maintenance therapy reduced the incidence of dental caries and periodontal disease, significantly lowering the risk of TL. Other studies have also shown decreased TL with regular maintenance therapy.\textsuperscript{8-29} Axelsson et al.\textsuperscript{7} reported that the most frequent cause of TL in patients undergoing maintenance therapy was root fractures. Other studies showed that the most frequent cause of TL, even with maintenance therapy, was periodontal disease.\textsuperscript{30,31} Various factors, such as age, smoking, diabetes mellitus (DM), and others, are also related to TL, and the risk of TL increases with the presence of additional non-vital teeth (those that have undergone root canal treatment).\textsuperscript{30,32-34} Despite reports that various factors affect TL, many of these studies were conducted under special circumstances, such as at a university hospital or within a specialist clinic, where patient demographics were limited. Additionally, few studies on the risk factors for TL have utilized large sample sizes. Furthermore, differences in patients’ immunological and genetic backgrounds, cultural factors, and socioeconomic features may affect the risk of TL.

Therefore, to verify these prior findings derived from specific or small patient
populations, we conducted a retrospective analysis in a private general clinic at a primary medical institution in Japan. More than 11,000 local residents utilize this clinic for their family dentistry needs. We investigated the effectiveness of long-term maintenance on TL as well as the various causes of TL (both with and without maintenance) to identify optimal prevention strategies. Using this approach, we aimed to determine the most convenient and effective methods for preventing TL in this population and thus improve the clinical dental care of our patients.

Methods
The present survey was conducted at a private dental clinic (Kawahara Dental Clinic) in Mima, Tokushima, Japan. The population of Mima is approximately 30,000. This dental clinic was selected because it is a general dental clinic and not a university hospital or specialist clinic. Dental examinations were performed and associated records were obtained by one of the authors (H.K., a general dentist) with the assistance of several trained dental hygienists.

Before active treatment, all patients received education regarding oral disease, dental caries, and strategies to control the risk of periodontal disease. They also underwent individual risk assessments. Cariogram computer software (D Bratthall, Malmo, Sweden) was used for caries risk assessment, and the Oral Health Information Suite (PreViser Corp., Concord, NH, USA) was used for periodontal disease risk assessment.

Following active treatment, including restorative, endodontic, and periodontal therapy, the patients underwent reevaluation of clinical parameters (probing depth, bleeding on probing, plaque index, and number of teeth present). The periodontal therapy involved oral hygiene enhancement, scaling and root planing, and/or surgical therapy according to
the individual patients' needs. The reassessment of clinical parameters was used as the baseline (BL) for each patient. The duration of maintenance was measured from the BL. All patients were required to meet the following five criteria established by Miyamoto et al. before the end of active treatment and entry into periodontal maintenance therapy: 1) <10% of sites with bleeding on probing, 2) an overall plaque score of <15%, 3) <10% of sites with a probing depth of ≥4 mm, 4) no defective restorations, and 5) no active dental caries. The maintenance period and the contents of maintenance were determined with reference to the study by Miyamoto et al. Evaluation of the maintenance interval was conducted by a dental hygienist at 3 or 6 months and was based on the patient’s periodontal tissue condition. Patients with a periodontal pocket of ≥4 mm at the time of the reevaluation visit were assigned to a 3-month maintenance regimen. The maintenance interval was not changed for any patient during the study. After reevaluation, all patients underwent maintenance, which consisted of a full-mouth clinical examination, supragingival scaling and polishing, and subgingival debridement using Gracey curettes, an ultrasonic scaler, rubber cups, and abrasive paste. Oral hygiene instructions and application of fluoride were provided according to the patients’ individual needs. When a need for treatment was determined during maintenance, the dentist (H.K.) provided the appropriate treatment (tooth extraction, restoration, prosthetic rehabilitation, and/or endodontic treatment).

The cause of any TL was determined by the dentist (H.K.) during extraction. These causes included dental caries, periodontal disease, root fracture, and others (e.g., an apical lesion, trauma, tooth transposition, or tooth extraction for convenience). The extraction of wisdom and deciduous teeth was excluded from the analysis. Tooth extraction for which the patient’s consent was not obtained before the BL was also excluded. Patient
compliance during maintenance was divided into the following two categories according to the classification established by Miyamoto et al.\textsuperscript{37} Regular: the following two requirements are met; 1) attending \( \geq 70\% \) of expected maintenance visits, 2) the interval between visits during maintenance does not exceed a maximum of 2 years. Irregular: the criteria for regular compliance have not been met, but continued maintenance visits were carried out.

\textit{Sample collection}

A total of 3907 patients visited the Kawahara Dental Clinic from 2015 to 2016; 2458 of the 3907 patients were adult patients (age of \( > 18 \) years at the end of 2016). Of the 2458 adult patients, 1943 patients (maintenance patients) visited the clinic for maintenance after establishment of their BL. In addition, 106 patients declined continuous maintenance after establishing their BL and visited the clinic only because of problems and not for maintenance (non-maintenance patients). An additional 409 patients were undergoing active treatment.

In 1145 of the maintenance patients, \( \geq 5 \) years had elapsed since their BL was established at the end of 2016 (MP5 group). Similarly, 57 non-maintenance patients were seen for \( \geq 5 \) years after establishing their BL (NMP5 group). Patients who received implant treatment were excluded.

\textit{Data collection}

Data on the following 12 characteristics were collected in the MP5 group: compliance, sex, age at BL, number of remaining teeth (RT) at BL, years from BL, number of teeth lost by various causes (dental caries, periodontal disease, root fracture, others), smoking
status (yes/no) (patients who quit smoking during maintenance were included), use of salivary secretion inhibitors (SSIs) (yes/no) (antidepressants, anxiolytics, diuretics, antihypertensives, antiarrhythmic drugs, and other drugs that inhibit salivary secretion), and DM (yes/no) (whether treatment has been done for DM). The smoking status, use of SSIs, and DM were recorded at BL. We collected data on the following four characteristics in the NMP5 group: years from BL, age at BL, number of RT at BL, and number of teeth lost since BL.

Statistical analyses

All data for the MP5 and NMP5 groups were gathered and organized into a table. We examined significant differences in the presence or absence of TL in the MP5 and NMP5 groups by a logistic regression analysis approach.

Among patients in the MP5 group, the Steel–Dwass test was performed to compare the average age at BL, years from BL, and number of RT at BL according to number of teeth lost. Next, among patients in the MP5 group, logistic regression analysis was performed to determine the relationship between the presence of TL and the following factors: compliance (regular or irregular), sex (male or female), age at BL (≤49, 50–59, or ≥60 years), number of RT at BL (28–24, 23–20, or ≤19 teeth), smoking status (yes or no), use of SSIs (yes or no), and DM (yes or no).

All statistical analyses were performed with JMP version 14 (SAS Institute, Cary, NC, USA), and P<0.05 indicated statistical significance. The statistical analysis was not verified by an independent statistician.

Results
All data of the patients in the MP5 group (n = 1145) and NMP5 group (n = 57) were selected from patient records obtained from the general dentist (H.K.) at Kawahara Dental Clinic. The average number of teeth lost per year was 0.07 in the MP5 group and 0.22 in the NMP5 group (Table 1). The average number of teeth lost per year was approximately three times as high in the NMP5 group as in the MP5 group. Logistic regression analyses revealed a significant difference in number of teeth lost since BL between the MP5 and NMP5 groups (Table 1).

Table 1. Comparison of MP5 and NMP5 groups

| Sample size | AGE (age) | YEAE (years) | RT (teeth number) | TL (teeth number) | Average number of TL/year (teeth number) | Logistic regression analyses |
|-------------|-----------|--------------|-------------------|-------------------|----------------------------------------|----------------------------|
| n           | n Mean ±SD | n Mean ±SD | n Mean ±SD | n | Odds ratio (95% CI) | P-value |
| MP5 1145   | 46.8±15.9 | 9.0±2.5 | 23.9±5.5 | 748 | 0.07 | reference |
| NMP5 57    | 46.9±21.5 | 8.4±2.5 | 21.7±7.4 | 107 | 0.22 | 2.41 (1.41–4.11) | 0.0013 |

Abbreviations: SD, standard deviation; AGE, age at baseline; RT, remaining teeth at baseline; YEAR, years from baseline; NMP5, patients not undergoing maintenance for ≥5 years from baseline; MP5, patients undergoing maintenance for ≥5 years from baseline; TL, tooth loss; CI, confidence interval.
The total number of teeth lost in the MP5 group was 748, and the most common cause was root fracture (60% of all cases of TL). Most root fractures occurred in teeth that had undergone root canal treatment and were fitted with casting posts and screw posts. In most cases of TL due to caries, the caries were below the margin of the prosthesis in root canal-treated teeth. Most cases of TL due to periodontal disease were caused by a worsening of the furcation lesion. In addition, 90% of teeth lost were non-vital teeth (Table 2).

Table 2. Tooth loss by cause and vital versus non-vital tooth status in the MP5 group

| TL Cause         | Number of vital teeth | Number of non-vital teeth | Total number of teeth (%) |
|------------------|-----------------------|---------------------------|--------------------------|
| Dental caries    | 9                     | 161                       | 170 (23%)                |
| Periodontal      | 39                    | 48                        | 87 (12%)                 |
| disease          |                        |                           |                          |
| Root fracture    | 3                     | 446                       | 449 (60%)                |
| Other            | 21                    | 21                        | 42 (5%)                  |
| Total (%)       | 72 (10%)              | 676 (90%)                 |                          |

Abbreviations: MP5, patients undergoing maintenance for ≥5 years from baseline; TL, tooth loss.

As age at BL increased in the MP5 group, the number of RT at BL decreased and TL increased. Additionally, TL due to dental caries, periodontal disease, and root fractures
increased as age at BL increased (Table 3).

**Table 3.** Characteristics of patients in the MP5 group, by age

| AGE (age) | Number of patients(n) | Average of RT number | Average of TL number | Average of TL/year (teeth number) | Average number of TL per year by cause (teeth number) |
|-----------|------------------------|----------------------|----------------------|----------------------------------|--------------------------------------------------------|
| ≤29       | 173                    | 9.32                 | 27.67                | 0.115                            | 0.001                                                  | 0 | 0.004 | 0.006 |
| 30-39     | 219                    | 8.62                 | 27.04                | 0.228                            | 0.026                                                  | 0.002 | 0.001 | 0.018 | 0.004 |
| 40-49     | 207                    | 9.34                 | 25.36                | 0.541                            | 0.057                                                  | 0.009 | 0.003 | 0.041 | 0.002 |
| 50-59     | 260                    | 8.90                 | 22.93                | 0.796                            | 0.089                                                  | 0.022 | 0.009 | 0.053 | 0.003 |
| ≥60       | 286                    | 9.31                 | 19.28                | 1.255                            | 0.134                                                  | 0.034 | 0.020 | 0.075 | 0.005 |

Abbreviations: AGE, age at baseline; RT, remaining teeth at baseline; YEAR, years from baseline; MP5, patients undergoing maintenance for ≥5 years from baseline; TL, tooth loss.

The relationships between the study variables (compliance, sex, smoking, SSI use, and DM control) and TL in the MP5 group are shown in Table 4. Compliance and smoking were not significantly related to TL; however, SSI use and DM were significantly associated with TL. All patients with DM (yes) in this study were well controlled (hemoglobin A1c <7%, National Glycohemoglobin Standardization Program). In this study, many patients used two or more drugs for SSIs. Patients using multiple SSIs had...
more TL. There was no significant difference in TL between men and women in this study (Table 4).

The results of the analysis according to number of teeth lost are shown in Table 5. Within the MP5 group, the following classification of the number of teeth lost was established: TL0 group, 0 teeth lost; TL1 group, 1 tooth lost; TL2 group, 2 teeth lost; TL3 group, 3 teeth lost; TL4 group, 4 teeth lost; and TL5 group, ≥5 teeth lost. The results of the Steel-Dwass test were as follows. Age at BL was significantly different between TL0 and TL1 (P < 0.0001). However, age at BL was not significantly different between TL1 and TL2 (P = 0.347), TL2 and TL3 (P = 1.0), TL3 and TL4 (P = 0.141), or TL4 and TL5 (P = 1.0). Similar results were obtained for the number of RT at BL (TL0 vs. TL1: P < 0.0001, TL1 vs. TL2: P = 0.405, TL2 vs. TL3: P = 0.970, TL3 vs. TL4: P = 0.266, and TL4 vs. TL5: P = 0.937). However, for years from BL, there was no significant difference between TL0 and TL1 (P = 0.142), TL1 and TL2 (P = 0.502), TL2 and TL3 (P = 0.443), TL3 and TL4 (P = 0.934), or TL4 and TL5 (P = 0.687).

The results of the logistic regression analyses for age and RT at BL according to number of teeth lost in the MP5 group are shown in Table 6. For age at BL, the presence or absence of TL was significantly different between patients who were ≤49 years old and those who were 50–59 years old, and between patients who were age ≤49 years and those age ≥60

[Table 4 here]

[Table 5 here]

[Table 6 here]
There was also a significant difference between patients age 50–59 years and those age ≥60 years (P = 0.0038, odds ratio = 1.65). As for the number of RT at BL, we observed a significant difference between patients who had 28–24 teeth and those with 23–20 teeth, and between patients who had 28–24 teeth and those with ≤19 teeth. However, there was no significant difference between patients with 23–20 teeth and those with ≤19 teeth (P = 0.99).

Table 6. Logistic regression analysis results for age and RT with TL in the MP5 group

| TL Cause       | Patients (number) | TL count (%) | Odds ratio (95% CI) | P-value |
|----------------|-------------------|--------------|---------------------|---------|
| AGE (years)    |                   |              |                     |         |
| ≤49            | 599               | 182 (24.3%)  | Reference           |         |
| 50-59          | 260               | 207 (27.6%)  | 2.62 (1.90-3.60)    | <.0001  |
| ≥60            | 286               | 359 (48.0%)  | 4.32 (3.18-5.87)    | <.0001  |
| RT (number of teeth) |     |              |                     |         |
| 28-24          | 819               | 320 (42.7%)  | Reference           |         |
| 23-20          | 125               | 159 (21.2%)  | 3.30 (2.25-4.85)    | <.0001  |
| ≤19            | 201               | 269 (35.9%)  | 3.29 (2.39-4.53)    | <.0001  |

Abbreviations: CI, confidence interval; AGE, age at baseline; RT, number of remaining teeth at baseline; MP5, patients undergoing maintenance for ≥5 years from baseline; TL, tooth loss.
Discussion

This retrospective study was performed to investigate TL in 1145 patients undergoing long-term maintenance therapy at a private dental clinic in Japan. These findings provide valuable insights into the factors that affect TL in people visiting general dental clinics. A better understanding of these factors is important to prevent TL in future.

Previous studies on tooth maintenance used small sample sizes or only included patients from specific environments, such as those in university hospitals or specialized clinics. However, the clinic in the present study was a general dental clinic visited by many local residents. The study population was large, and there was no significant bias in the sample size of each age group (maximum, n = 286; minimum, n = 173). The average number of years from BL for each age group at BL was also very similar (maximum, 9.32 years; minimum, 8.62 years). The 1145 patients who were included in this study lost 748 teeth out of a total of 27,737 teeth during maintenance therapy that lasted for an average of 9.09 years. The average number of teeth lost per year was only 0.07. Previous studies have reported an average of 0.1 to 0.2 teeth lost per year.38

In this study, the MP5 group showed significantly less TL than the NMP5 group. The average age at BL and average years from BL were very similar between the two groups, but the number of patients in the NMP5 group was small (n = 57). The average number of teeth lost per year was 0.22 in the NMP5 group (about three times the number in the MP5 group). The difference between the MP5 and NMP5 groups was statistically significant. This result closely resembles the results of the study by Costa et al.29 In their study, the average number of teeth lost per year was 0.12 in the regular compliers and 0.36 in the irregular compliers (about three times the number among regular compliers). Their study also suggested a beneficial effect of maintenance on TL. In addition, their
study was conducted in a general dental clinic, demonstrating the broad effectiveness of
maintenance for TL.

In the present study, root fractures were the most common cause of TL, followed by
caries and periodontal disease. These results are similar to those from a study in a general
dental clinic by Axelsson et al. In another study showing that the primary cause of TL
was periodontal disease, data samples were obtained from three periodontists’ private
offices. In another study, patient data were obtained after treatment by a periodontist.

In these studies, most patients were considered to be at high risk of periodontal disease.
In the present study, the status of periodontal disease at BL was as follows: healthy or
gingivitis, n = 316 (27.6%); stage I periodontitis, n = 436 (38.1%); stage II periodontitis,

n = 273 (23.8%); and stage III and IV periodontitis, n = 120 (10.5%). Most patients were
healthy or had gingivitis, stage I periodontitis, or stage II periodontitis. The fact that few
patients had stage III and IV periodontitis may explain why the rate of TL due to
periodontal disease was low and why TL during maintenance decreased. Therefore, it is
difficult to compare our results with those of other studies reporting periodontal treatment
and maintenance in patients with severe periodontal disease.

In our study, 90% of teeth lost were non-vital teeth. This may be explained by a previous
study in which root canal treatment had a significant effect on TL. Root canal treatment
may also reportedly affect the deterioration of furcation lesions in molars. One study
showed that as the number of non-vital teeth increased, TL due to root fractures and caries
increased. Therefore, a decrease in the number of non-vital teeth may reduce TL due to
caries, periodontal disease, and root fractures.

Interestingly, we found no significant differences in the effect of smoking on TL under
maintenance. Smoking is, however, a clear risk factor for periodontal disease. In one
study by Costa et al.,\textsuperscript{29} smokers exhibited significantly more TL than nonsmokers (P < 0.05, odds ratio = 4.22). While the average age of smokers in our study was 45.3 years, most smokers in the study by Costa et al.\textsuperscript{29} were >55 years of age. Although the number of RT at BL was very similar between the two groups in our study, age might have increased the risk of TL in the study by Costa et al.\textsuperscript{29}. Notably, smoking is a risk factor for periodontal disease but not a direct pathogenic factor. Despite our findings, we will continue to educate patients on the risk of TL and periodontal disease caused by smoking and offer them smoking cessation guidance.

The relationship between DM and periodontal disease is well known.\textsuperscript{39} Patients with DM lose significantly more teeth than those without DM. In the present study, the odds ratio was 2.78 with regard to DM. It was 2.73 in the above-mentioned study by Costa et al.\textsuperscript{29} and 2.64 in a study by Al-Shammari et al.\textsuperscript{40}; these results are very similar to ours. Previous studies have also shown significant associations between TL and systemic diseases such as hypertension, heart disease, cerebrovascular disease, rheumatoid arthritis, and asthma.\textsuperscript{4,30} Although the relationship between the etiology of the disease and TL is clear with regard to DM, this relationship remains unclear for many other diseases. The adverse effect of thirst is reportedly associated with the therapeutic drugs used for many diseases.\textsuperscript{41} However, no reports have described the relationship between SSI use and TL. The present study showed a significant association between SSI use and TL. Based on this finding, the significant relationship between various systemic diseases and TL is not due to the disease etiology and may be increased by the use of SSIs.

In this study, 1145 patients lost 748 teeth during an average of 9.09 years of maintenance. However, 766 patients lost no teeth. TL was biased in some patients. In total, 179 (15.6\%) patients in the TL2, TL3, TL4, and TL5 groups lost 548 teeth (73.2\%). Table 5 shows the
Age at BL, years from BL, and number of RT at BL in each TL group. Age at BL was significantly different between TL0 and TL1. There were no significant differences between TL1 and TL2, between TL2 and TL3, between TL3 and TL4, or between TL4 and TL5. However, age at BL was very similar between TL2 and TL3 and between TL4 and TL5 (P = 1). Therefore, age at BL may have been divided into the TL0 group, TL1 group, TL2/TL3 group, and TL4/TL5 group. Similar results were obtained for the number of RT at BL. However, the number of years from BL was not significantly different between the consecutive groups (TL0, TL1, TL2, TL3, TL4, and TL5). The number of years from BL may not be associated with TL.

For age and RT at BL, logistic analysis was performed by classifying the patients based on the average value in each TL group and the results of the Steel–Dwass test (Table 6). Age at BL was significantly different between ages ≤49 and 50–59 years, between ≤49 and ≥60 years, and between ages 50–59 years and ≥60 years (P = 0.0038, odds ratio = 1.65). TL reportedly increases with age, and our results were similar.\(^{42,43}\) The number of RT at BL was also significantly different between 28–24 and 23–20 RT and between 28–24 and ≤19 RT, but not between 23–20 and ≤19 RT (P = 0.99). These findings suggest that TL was less likely to occur if the number of RT at BL was ≥24 than ≤23. Interestingly, the number of RT around the age of 50 years was about 24. Perhaps the increase in TL with age may be due to a decrease in the number of RT. These results suggest that if the number of RT is ≥24, there is a high possibility that TL can be prevented during maintenance. One explanation for the increase in TL as the number of RT decreases may be the use of fixed or removable dentures. We excluded patients treated with implants from this study. Within the MP5 group, the use of dentures increased as the number of RT decreased. Few patients with ≥24 RT used removable dentures. Several studies have
revealed significant loss of denture abutments. Another explanation may be that patients with a low number of RT have received more restorative prosthetic treatment in the past and have more non-vital teeth. Some reports have also described significant loss of non-vital teeth.

**Conclusion**

We found that significantly fewer teeth were lost per year in patients who underwent maintenance than in those who did not. Most lost teeth were non-vital teeth, and tooth fracture was the most common cause of TL. We also found that statistically significant risk factors for TL were patient age at the start of maintenance, number of remaining teeth at the start of maintenance, use of SSIs, and DM. Our results will be of great interest to dentists involved in long-term maintenance care of patients in a general practice. This study suggests that maintenance from a younger age in patients with fewer non-vital teeth and more remaining teeth can help to reduce TL. Additionally, DM and the use of SSIs can affect TL.

**Abbreviations**

TL: Tooth loss  
DM: Diabetes mellitus  
BL: Baseline  
MP5: Maintenance patients for ≥5 years from baseline  
NMP5: Non-maintenance patients for ≥5 years from baseline  
RT: Remaining teeth  
SSIs: Salivary secretion inhibitors
Declarations

Ethics approval and consent to participate
This study was approved by the Clinical Research Ethics Review Committee of Tokushima University Hospital (Approval number: 2674). In this study, the patients’ right to privacy protection was respected; additionally, written informed consent was obtained from all patients. This research was conducted in full accordance with the Declaration of Helsinki established by the World Medical Association.

Consent for publication
Not applicable.

Availability of data and materials
The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests
All authors declare that they have no competing interests.

Funding
The authors declare that they have received no funding for the work.

Acknowledgments
The authors gratefully acknowledge the staff at Kawahara Dental Clinic, Tokushima, Japan. The authors also thank Angela Morben, DVM, ELS, from Edanz Group (https://en-
author-services.edanzgroup.com/), for editing a draft of this manuscript.

Authors’ contributions: H.K. and Y.M. were responsible for the study design and protocol. H.K. collected and analyzed the data and wrote the manuscript. M.I., K.O., and M.O. provided assistance with the study design, data analysis, and critical revision of the manuscript. All authors discussed the results and approved the final version of the manuscript.
1. Morita M, Kimura T, Kanegae M, Ishikawa A, Watanabe T. Reasons for extraction of permanent teeth in Japan. Community Dent Oral Epidemiol. 1994;22:303-6.

2. Stabholz A, Babayof I, Mersel A, Mann J. The reasons for tooth loss in geriatric patients attending two surgical clinics in Jerusalem, Israel. Gerodontology. 1997;14:83-8.

3. Sayegh A, Hilow H, Bedi R. Pattern of tooth loss in recipients of free dental treatment at the University Hospital of Amman, Jordan. J Oral Rehabil. 2004;31:124-30.

4. Al-Shammari KF, Al-Ansari JM, Al-Melh MA, Al-Khabbaz AK. Reasons for tooth extraction in Kuwait. Med Princ Pract. 2006;15:417-22.

5. Montandon AAB, Zuza EP, Toledo BEC. Prevalence and reasons for tooth loss in a sample from a dental clinic in Brazil. Int J Dent. 2012;2012:719750.

6. Axelsson P, Lindhe J. Effect of controlled oral hygiene procedures on caries and periodontal disease in adults. Results after 6 years. J Clin Periodontol. 1981;8:239-48.

7. Axelsson P, Nystrom B, Lindhe J. The long-term effect of a plaque control program on tooth mortality, caries and periodontal disease in adults. Results after
30 years of maintenance. J Clin Periodontol. 2004;31:749-57.

8. Hirschfeld L, Wasserman B. A long-term survey of tooth loss in 600 treated periodontal patients. J Periodontol. 1978;49:225-37.

9. McFall WT, Jr. Tooth loss in 100 treated patients with periodontal disease. A long-term study. J Periodontol. 1982;53:539-49.

10. Lindhe J, Nyman S. Long-term maintenance of patients treated for advanced periodontal disease. J Clin Periodontol. 1984;11:504-14.

11. Goldman MJ, Ross IF, Goteiner D. Effect of periodontal therapy on patients maintained for 15 years or longer. A retrospective study. J Periodontol. 1986;57:347-53.

12. Nabers CL, Stalker WH, Esparza D, Naylor B, Canales S. Tooth loss in 1535 treated periodontal patients. J Periodontol. 1988;59:297-300.

13. Wood WR, Greco GW, McFall WT, Jr. Tooth loss in patients with moderate periodontitis after treatment and long-term maintenance care. J Periodontol. 1989;60:516-20.

14. McLeod DE, Lainson PA, Spivey JD. The predictability of periodontal treatment as measured by tooth loss: a retrospective study. Quintessence Int. 1998;29:631-5.
15. Tonetti MS, Muller-Campanile V, Lang NP. Changes in the prevalence of residual pockets and tooth loss in treated periodontal patients during a supportive maintenance care program. J Clin Periodontol. 1998;25:1008-16.

16. Matthews DC, Smith CG, Hanscom SL. Tooth loss in periodontal patients. J Can Dent Assoc. 2001;67:207-10.

17. Checchi L, Montevecchi M, Gatto MR, Trombelli L. Retrospective study of tooth loss in 92 treated periodontal patients. J Clin Periodontol. 2002;29:651-6.

18. Fardal O, Johannessen AC, Linden GJ. Tooth loss during maintenance following periodontal treatment in a periodontal practice in Norway. J Clin Periodontol. 2004;31:550-5.

19. Papantonopoulos GH. Effect of periodontal therapy in smokers and non-smokers with advanced periodontal disease: results after maintenance therapy for a minimum of 5 years. J Periodontol. 2004;75:839-43.

20. Chambrone LA, Chambrone L. Tooth loss in well-maintained patients with chronic periodontitis during long-term supportive therapy in Brazil. J Clin Periodontol. 2006;33:759-64.

21. Eickholz P, Kaltschmitt J, Berbig J, Reitmeir P, Pretzl B. Tooth loss after active periodontal therapy. 1: patient-related factors for risk, prognosis, and quality of
22. Jansson L, Lagervall M. Periodontitis progression in patients subjected to supportive maintenance care. Swed Dent J. 2008;32:105-14.

23. Tsami A, Pepelassi E, Kodovazenitis G, Komboli M. Parameters affecting tooth loss during periodontal maintenance in a Greek population. J Am Dent Assoc. 2009;140:1100-7.

24. Miyamoto T, Kumagai T, Lang MS, Nunn ME. Compliance as a prognostic indicator. II. Impact of patient's compliance to the individual tooth survival. J Periodontol. 2010;81:1280-8.

25. Matuliene G, Studer R, Lang NP, Schmidlin K, Pjetursson BE, Salvi GE, et al. Significance of periodontal risk assessment in the recurrence of periodontitis and tooth loss. J Clin Periodontol. 2010;37:191-9.

26. Ng MC, Ong MM, Lim LP, Koh CG, Chan YH. Tooth loss in compliant and non-compliant periodontally treated patients: 7 years after active periodontal therapy. J Clin Periodontol. 2011;38:499-508.

27. Kim SY, Lee JK, Chang BS, Um HS. Effect of supportive periodontal therapy on the prevention of tooth loss in Korean adults. J Periodontal Implant Sci. 2014;44:65-70.
28. Seirafi AH, Ebrahimi R, Golkari A, Khosropanah H, Soolari A. Tooth loss assessment during periodontal maintenance in erratic versus complete compliance in a periodontal private practice in Shiraz, Iran: a 10-year retrospective study. J Int Acad Periodontol. 2014;16:43-9.

29. Costa FO, Lages EJ, Cota LO, Lorentz TC, Soares RV, Cortelli JR. Tooth loss in individuals under periodontal maintenance therapy: 5-year prospective study. J Periodontal Res. 2014;49:121-8.

30. Stadler AF, Mendez M, Oppermann RV, Gomes SC. Tooth loss in patients under periodontal maintenance in a private practice: a retrospective study. Braz Dent J. 2017;28:440-6.

31. Ravald N, Johansson CS. Tooth loss in periodontally treated patients: a long-term study of periodontal disease and root caries. J Clin Periodontol. 2012;39:73-9.

32. Costa FO, Santuchi CC, Lages EJ, et al. Prospective study in periodontal maintenance therapy: comparative analysis between academic and private practices. J Periodontol. 2012;83:301-11.

33. Pretzl B, Eickholz P, Saure D, Pfefferle T, Zeidler A, Dannewitz B. Endodontic status and retention of molars in periodontally treated patients: results after 10 or more years of supportive periodontal therapy. J Clin Periodontol. 2016;43:1116-
Suzuki S, Yoshino K, Takayanagi A, et al. Number of non-vital teeth as indicator of tooth loss during 10-year maintenance: a retrospective study. Bull Tokyo Dent Coll. 2017;58:223-30.

Bratthall D, Hansel Petersson G. Cariogram--a multifactorial risk assessment model for a multifactorial disease. Community Dent Oral Epidemiol. 2005;33:256-64.

Page RC, Martin JA, Loeb CF. The Oral Health Information Suite (OHIS): its use in the management of periodontal disease. J Dent Educ. 2005;69:509-20.

Miyamoto T, Kumagai T, Jones JA, Van Dyke TE, Nunn ME. Compliance as a prognostic indicator: retrospective study of 505 patients treated and maintained for 15 years. J Periodontol. 2006;77:223-32.

Lee CT, Huang HY, Sun TC, Karimbux N. Impact of patient compliance on tooth loss during supportive periodontal therapy: A systematic review and meta-analysis. J Dent Res. 2015;94:777-86.

Tonetti MS, Greenwell H, Kornman KS. Staging and grading of periodontitis: Framework and proposal of a new classification and case definition. J Periodontol. 2018;89 Suppl 1:S159-S172.
40. Al-Shammari KF, Al-Khabbaz AK, Al-Ansari JM, Neiva R, Wang HL. Risk indicators for tooth loss due to periodontal disease. J Periodontol. 2005;76:1910-8.

41. Miranda-Rius J, Brunet-Llobet L, Lahor-Soler E, Farre M. Salivary secretory disorders, inducing drugs, and clinical management. Int J Med Sci. 2015;12:811-24.

42. Pretzl B, Kaltschmitt J, Kim TS, Reitmeir P, Eickholz P. Tooth loss after active periodontal therapy. 2: tooth-related factors. J Clin Periodontol. 2008;35:175-82.

43. Saito M, Shimazaki Y, Fukai K, et al. Risk factors for tooth loss in adult Japanese dental patients: 8020 Promotion Foundation Study. J Investig Clin Dent. 2019;10:e12392.

44. Muller S, Eickholz P, Reitmeir P, Eger T. Long-term tooth loss in periodontally compromised but treated patients according to the type of prosthodontic treatment. A retrospective study. J Oral Rehabil. 2013;40:358-67.