Association Between Tooth Loss, Body Mass Index, and All-Cause Mortality Among Elderly Patients in Taiwan

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Abstract: To date, the effect of tooth loss on all-cause mortality among elderly patients with a different weight group has not been assessed. This retrospective cohort study evaluated the data obtained from a government-sponsored, annual physical examination program for elderly citizens residing in Taipei City during 2005 to 2007, and follow-up to December 31, 2010. We recruited 55,651 eligible citizens of Taipei City aged ≥65 years, including 29,572 men and 26,079 women, in our study. Their mortality data were ascertainment based on the national death files. The number of missing teeth was used as a representative of oral health status. We used multivariate Cox proportional hazards regression analysis to determine the association between tooth loss and all-cause mortality. After adjustment for all confounders, the hazard ratios (HRs) of all-cause mortality in participants with no teeth, 1 to 9 teeth, and 10 to 19 teeth were 1.36 (95% confidence interval (CI): 1.15–1.61), 1.24 (95% CI: 1.08–1.42), and 1.19 (95% CI: 1.09–1.31), respectively, compared with participants with 20 or more teeth. A significant positive correlation of body mass index (BMI) with all-cause mortality was found in overweight and overweight elderly patients and was represented as a U-shaped curve. Subgroup analysis revealed a significant positive correlation in overweight (no teeth: HR = 1.49, 95% CI: 1.21–1.83; 1–9 teeth: HR = 1.23, 95% CI: 1.03–1.47; 10–19 teeth: HR = 1.20, 95% CI: 1.06–1.36) and overweight participants (no teeth: HR = 1.37, 95% CI: 1.05–1.79; 1–9 teeth: HR = 1.27, 95% CI: 1.07–1.52). The number of teeth lost is associated with an increased risk of all-cause mortality, particularly for participants with underweight and overweight.

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Abbreviations: BMI = body mass index, CI = confidence interval, HR = hazard ratio, ICD = International Classification of Diseases, OBSERVATIONAL STUDY

INTRODUCTION

The global prevalence of periodontal disease (PD) is 20% to 50% of the overall population.1–3 This disease is caused by the accumulation of a specific bacterial biofilm around the teeth. The initial presentation is in the form of reversible gingivitis, which can be treated after biofilm removal.4,5 Subsequently, PD progresses with the destruction of the periodontal connective tissue and alveolar bone, which eventually results in tooth loss.6 Dental caries is also a common chronic disease that causes pain and disability across all age groups. If left untreated, dental caries can lead to pain and infection, tooth loss, and edentulism.7–9 The loss of teeth consequently influences the mastication and nutritional status of patients.

Tooth loss is a crucial oral health problem in the elderly population and correcting this problem may reduce the elevated risk of associated mortality. Several studies have indicated a positive association between tooth loss and mortality among the elderly population. Most of these studies were conducted in countries outside Asia.1–14 In Japan, Ando et al15 conducted a 5.6-year cohort study of 7779 men aged 40 to 79 years, showing that men aged 40 to 64 years with no teeth had significantly higher mortality than that of men with ≥20 teeth; however, no associations were observed between the number of teeth and all-cause mortality among those aged 65 to 79 years. Ansai et al16 conducted a 5.5-year cohort study of 1282 subjects aged 80 years, indicating that tooth loss is a significant predictor of mortality in women, but not men. Another 10-year cohort study of 118 subjects aged 80 years or older by Morita et al17 showed that men with ≥20 teeth had an increased survival rate; however, this was not observed among women. Because of the inconsistent results of previous studies, a large-scale cohort study is required to further investigate the association of the number of teeth with mortality.

Several studies have focused on the association between tooth loss, body mass index (BMI), and mortality worldwide.18 Substantial evidence has suggested a direct association between tooth loss and diseases known to affect mortality,11,19–21 and numerous studies have begun to investigate the role of obesity in periodontitis.22,23 This association is being assessed because both tooth loss and obesity are associated directly with life-threatening diseases, such as cardiovascular diseases and stroke, and other diseases that have been shown to affect health and mortality. Therefore, it is crucial to comprehend the interrelationships between tooth loss, BMI, and mortality, and to discover additional supporting evidence to explain this association scientifically and epidemiologically. Several studies have explained the link between tooth loss and diseases such as cardiovascular disease, stroke, and dementia.11,19,26 Moreover, numerous study groups have evaluated population samples to
collect statistical data regarding the relationship between tooth loss and obesity.\(^2\) The collection of statistical information from various populations facilitates contemplating the association between tooth loss and obesity accurately. One study attempted to biologically explain the similarities between them, and reported that they are similar in their responses to inflammation in the body and in disease conditions, and that they are associated.\(^3\) The optimal BMI and the effects of tooth loss on the risk of mortality among elderly people remain unclear.

In this retrospective cohort study, we examined whether elderly participants with tooth loss had an increased mortality risk over a follow-up period of 6 years. Given that masticatory function mediates the link among oral health, body weight, and mortality, we expected a positive association between mortality and increased tooth loss. Tooth loss can affect both the dietary intake and nutritional status of elderly people,\(^4\) thereby influencing body weight and increasing the mortality risk. Therefore, we hypothesized that tooth loss is associated with all-cause mortality among elderly participants with varying BMIs.

**MATERIALS AND METHODS**

**Study Population**

In this retrospective cohort study, the cohort comprised 74,223 participants aged ≥55 years from a standard, annul physical examination program for the elderly population, conducted by the Taipei City government during 2005 to 2007. All citizens participated voluntarily, and were encouraged to visit annually, but the present study was conducted using only the results from the initial visits. The demographic and lifestyle data (eg, marital status, education level, smoking status, and alcohol consumption) were collected through self-administered questionnaires. During the medical checkup, blood pressure measurement, blood sample collection, and laboratory analyses were performed for each participant. We excluded 343 participants aged <65 years from the 74,223 participants, and further excluded 18,229 participants with missing survey data regarding BMI (n = 1062), marital status (n = 1427), education level (n = 9441), smoking status (n = 522), alcohol consumption (n = 533), the number of teeth present (n = 36), laboratory data (n = 2460), and details of the dental and prosthetic status (n = 2748). The final analytical sample comprised 55,651 participants, with 29,572 men, and 26,079 women. The data regarding participant identification were removed to ensure participant anonymity throughout the study period. The data acquisition and processing protocol were approved by the Institutional Review Board of Taipei City Hospital (IRB No.: TCHIRB-1030321-W).

**Definition of the Number of Teeth**

In this program, an oral examination was performed by dentists, which including the details of the dental and prosthetic status of each participant. The number of teeth was used to represent the oral health status and was arbitrarily categorized as follows: no teeth, 1 to 9 teeth, 10 to 19 teeth, and ≥20 teeth. A sensitivity analysis was also performed with the number of teeth as a continuous variable.\(^14\) In this study, missing teeth are defined by sites with nonrepairable roots and missing roots area with no fixed prosthesis present.

**Definition of BMI**

Both height and weight were measured during the examination by using standardized procedures. BMI was calculated as weight in kilograms divided by height in meters squared.
have no missing teeth for the sensitivity analysis). Stratified Cox proportional hazard regression analysis was used to estimate the effect of the number of teeth on all-cause mortality. We conducted all analyses by using SAS (version 9.3; SAS Institute, Inc., Cary, NC) and STATA (version 13.0; STATA Corp, College Station, TX) statistical software packages.

**RESULTS**

**Participant Characteristics**

Table 1 summarizes the proportions of patients with the number of teeth and their baseline characteristics as well as the follow-up duration or mortality rate. The mean age of the participants was 73.34 [standard deviation (SD): 6.28] years. During the 6-year study period, 177,601 person-years of follow-up were recorded, with an average follow-up period of 3.04 (SD: 1.81) years. At the baseline, 81.76% of the elderly patients had 20 teeth or more, 12.07% had 10 to 19 teeth, 4.04% had 1 to 9 teeth, and 2.12% had no teeth. Overall, 3530 (6.34% of all participants) deaths occurred during the 6-year follow-up period. Participants with no teeth exhibited a higher mortality rate (12.53%) than did those with 10 to 19 teeth (8.01%) and those with 20 teeth or more (5.74%). A high prevalence of tooth loss was observed among participants who were men, older, underweight, single, and smokers and those who had lower education levels, diabetes mellitus, hypertension, hyperlipidemia, and nonregular dental prophylaxis.

### TABLE 1. Baseline Characteristic of Participants

| Variable                        | Total (n = 55,651) | 0 | 1–9  | 10–19 | ≥20 | P-Value |
|---------------------------------|-------------------|---|------|-------|-----|---------|
|                                | n = 1181 | n = 2250 | n = 6717 | n = 45,503 |
| **Gender**                      |          |          |          |          |
| Male                            | 29,572   | 648      | 1263     | 3719     | 23,942 | 52.62   |
| Female                          | 26,079   | 533      | 987      | 2998     | 21,561 | 47.38   |
| **Age**                         |          |          |          |          |
| 65–69                           | 18,688   | 161      | 427      | 1883     | 16,217 | 35.64   |
| 70–74                           | 14,326   | 251      | 567      | 1728     | 11,780 | 25.89   |
| 75–79                           | 12,900   | 330      | 621      | 1774     | 10,175 | 22.36   |
| 80–84                           | 6949     | 286      | 425      | 956      | 5282   | 11.61   |
| ≥85                             | 2788     | 153      | 210      | 376      | 2049   | 4.50    |
| **Marital status**              |          |          |          |          |
| Married                         | 41,149   | 759      | 1505     | 4809     | 34,076 | 74.89   |
| Single                          | 14,502   | 422      | 745      | 1908     | 11,427 | 25.11   |
| **Education level**             |          |          |          |          |
| None                            | 3493     | 139      | 203      | 478      | 2673   | 5.87    |
| 1–6                             | 2734     | 70       | 117      | 357      | 2190   | 4.81    |
| 7–12                            | 22,653   | 520      | 982      | 2753     | 18,398 | 40.43   |
| >12                             | 26,771   | 452      | 948      | 3129     | 22,242 | 48.88   |
| **Smoking**                     |          |          |          |          |
| No                              | 50,707   | 1027     | 1951     | 5937     | 41,792 | 91.84   |
| Yes                             | 4944     | 154      | 139      | 780      | 3711   | 8.16    |
| **Alcohol consumption**         |          |          |          |          |
| No                              | 45,199   | 1000     | 1874     | 5429     | 36,896 | 81.08   |
| Yes                             | 10,452   | 181      | 153      | 788      | 8607   | 18.92   |
| **BMI**                         |          |          |          |          |
| Underweight                     | 2041     | 67       | 127      | 256      | 1591   | 3.50    |
| Normal weight                   | 32,381   | 706      | 1263     | 3802     | 26,610 | 58.48   |
| Overweight                      | 18,397   | 354      | 739      | 2265     | 15,039 | 33.05   |
| Obesity                         | 2832     | 54       | 121      | 394      | 2263   | 4.97    |
| **Diabetes mellitus**           |          |          |          |          |
| No                              | 9147     | 260      | 490      | 726      | 7121   | 15.65   |
| Yes                             | 32,381   | 722      | 1368     | 4074     | 26,217 | 57.62   |
| **Hypertension**                |          |          |          |          |
| No                              | 28,973   | 608      | 1153     | 3554     | 24,558 | 53.97   |
| Yes                             | 26,678   | 1033     | 874      | 4289     | 21,642 | 49.26   |
| **Hyperlipidemia**              |          |          |          |          |
| No                              | 41,856   | 1001     | 1807     | 5131     | 33,917 | 74.54   |
| Yes                             | 13,795   | 180      | 152      | 1586     | 11,586 | 25.46   |
| **Regular dental prophylaxis**  |          |          |          |          |
| No                              | 52,121   | 1033     | 874      | 6179     | 42,889 | 94.26   |
| Yes                             | 3530     | 148      | 125      | 538      | 2614   | 5.74    |

BMI = body mass index.
Association Between the Number of Teeth and Mortality

We observed a positive association between the number of teeth lost and all-cause mortality (Figure 1). After control for other covariates, participants with a high number of teeth lost exhibited significantly higher hazard ratios (HRs) for all-cause mortality (no teeth: HR = 1.36, 95% confidence interval (CI): 1.15–1.61; 1–9 teeth: HR = 1.24, 95% CI: 1.08–1.42; 10–19 teeth: HR = 1.19, 95% CI: 1.09–1.31) (Table 2). Multivariate Cox proportional hazard analysis identified the male sex (HR = 1.80, 95% CI: 1.66–1.96), an older age, a lower education level, a single status (HR = 1.18, 95% CI: 1.09–1.27), smoking (HR = 1.70, 95% CI: 1.54–1.88), diabetes mellitus (HR = 1.64, 95% CI: 1.51–1.78), and hypertension (HR = 1.16, 95% CI: 1.08–1.24) as independent risk factors for mortality. Participants with regular dental prophylaxis had lower mortality (HR = 0.54, 95% CI: 0.50–0.58) than did participants with nonregular dental prophylaxis. Among the BMI-based categories, underweight participants exhibited a significantly higher mortality risk compared with that of normal weight participants (HR = 2.05, 95% CI: 1.82–2.31).

Sensitivity Analysis of Associations Between the Number of Teeth and Mortality

The results of the sensitivity analysis of the associations between the number of teeth and mortality are shown in Table 3. Propensity score-based approaches for investigating the causal effects of the number of teeth on mortality revealed a significant association between the number of teeth and all-cause mortality (no teeth: HR = 2.28, 95% CI: 2.07–2.51; 1–9 teeth: HR = 1.73, 95% CI: 1.60–1.87; and 10–19 teeth: HR = 1.37, 95% CI: 1.30–1.44). When the number of teeth was considered a continuous variable, participants with all numbers of teeth had a significantly decreased all-cause mortality risk (HR = 0.99, 95% CI: 0.99–0.99). In our study, 32.8% of participants wore partial or complete removable dentures. We also used different definitions of the number of teeth (eg, participants with partial or complete removable dentures were considered to have no missing teeth for the sensitivity analysis), and the results remained robust (no teeth: HR = 1.50, 95% CI: 1.23–1.84; 1–9 teeth: HR = 1.30, 95% CI: 1.11–1.53; 10–19 teeth: HR = 1.19, 95% CI: 1.08–1.31).

Subgroup Analysis of Associations Between the Number of Teeth and Mortality

The results of the subgroup analyses are shown in Figure 2. The HRs exhibited similar trends for each subgroup. Among the male participants, those with <20 teeth where significantly associated with increased all-cause mortality (no teeth: HR = 1.38, 95% CI: 1.13–1.68; 1–9 teeth: HR = 1.38, 95% CI: 1.18–1.62; 10–19 teeth: HR = 1.24, 95% CI: 1.11–1.38). Among the underweight participants, a significant association was observed between the number of teeth lost and all-cause mortality (no teeth: HR = 1.49, 95% CI: 1.21–1.83; 1–9 teeth: HR = 1.73, 95% CI: 1.03–1.47; 10–19 teeth: HR = 1.20, 95% CI: 1.06–1.36). Among the overweight participants, those with <10 teeth exhibited a significantly high mortality risk (no teeth: HR = 1.37, 95% CI: 1.05–1.79; 1–9 teeth: HR = 1.27, 95% CI: 0.69–2.33).

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**TABLE 2. Multivariate Cox Proportional Model of Factors Associated With All-Cause Mortality**

| Variable                  | HR   | 95% CI          | P-Value |
|---------------------------|------|-----------------|---------|
| Gender                    |      |                 |         |
| Male                      | 1.80 | 1.66–1.96       | <0.001  |
| Female                    | 1.00 |                 |         |
| Age                       |      |                 |         |
| 65–69                     | 1.00 |                 |         |
| 70–74                     | 1.52 | 1.34–1.73       | <0.001  |
| 75–79                     | 2.42 | 2.15–2.73       | <0.001  |
| 80–84                     | 4.45 | 3.93–5.02       | <0.001  |
| ≥85                       | 8.34 | 7.31–9.51       | <0.001  |
| Marital status            |      |                 |         |
| Married                   | 1.00 |                 |         |
| Single                    | 1.18 | 1.09–1.27       | <0.001  |
| Education level           |      |                 |         |
| None                      | 1.00 |                 |         |
| 1–6                       | 0.78 | 0.65–0.94       | 0.007   |
| 7–12                      | 0.77 | 0.68–0.87       | <0.001  |
| >12                       | 0.59 | 0.52–0.67       | <0.001  |
| Smoking                   |      |                 |         |
| No                        | 1.00 |                 |         |
| Yes                       | 1.70 | 1.54–1.88       | <0.001  |
| Alcohol consumption       |      |                 |         |
| No                        | 1.00 |                 |         |
| Yes                       | 0.68 | 0.62–0.75       | <0.001  |
| BMI                       |      |                 |         |
| Underweight               | 2.05 | 1.82–2.31       | <0.001  |
| Normal weight             | 1.00 |                 |         |
| Overweight                | 0.82 | 0.76–0.89       | <0.001  |
| Obesity                   | 0.91 | 0.76–1.08       | 0.281   |
| Diabetes mellitus         | 1.64 | 1.51–1.78       | <0.001  |
| Hypertension              | 1.16 | 1.08–1.24       | <0.001  |
| Hyperlipidemia            | 1.11 | 1.00–1.24       | 0.055   |
| Regular dental prophylaxis|      |                 |         |
| No                        | 1.00 |                 |         |
| Yes                       | 0.54 | 0.50–0.58       | <0.001  |
| Number of teeth           |      |                 |         |
| 0                         | 1.36 | 1.15–1.61       | <0.001  |
| 1–9                       | 1.24 | 1.08–1.42       | 0.002   |
| 10–19                     | 1.19 | 1.09–1.31       | <0.001  |
| ≥20                       | 1.00 |                 |         |

BMI = body mass index, CI = confidence interval, HR = hazard ratio.
TABLE 3. Sensitivity Analysis of the Associations Between the Number of Teeth and Mortality

| Variable | HR     | 95% CI      | P-Value |
|----------|--------|-------------|---------|
| Model 1: Number of teeth: propensity-score-based |        |             |         |
| 0        | 2.28   | 2.07–2.51   | <0.001  |
| 1–9      | 1.73   | 1.60–1.87   | <0.001  |
| 10–19    | 1.37   | 1.30–1.44   | <0.001  |
| ≥20      | 1.00   |             |         |
| Model 2: Number of teeth (modeled continuously) | 0.99   | 0.99–0.99   | <0.001  |
| Model 3: Number of teeth | 1.50   | 1.23–1.84   | <0.001  |
| 1–9      | 1.30   | 1.11–1.53   | <0.001  |
| 10–19    | 1.19   | 1.08–1.31   | <0.001  |
| ≥20      | 1.00   |             |         |

CI = confidence interval, HR = hazard ratio. Variables included in the multivariates model: age, sex, marital status, education level, regular dental prophylaxis, smoking status, alcohol consumption, diabetes mellitus, hypertension, and hyperlipidemia.

* Participants with partial or complete removable dentures were considered to have no missing teeth.

FIGURE 2. Subgroup analysis of all-cause mortality.
Among the normal weight and obese participants, no significant association was observed between the number of teeth and all-cause mortality.

### DISCUSSION

In this study, we demonstrated an association between the number of teeth lost and an increased risk of all-cause mortality. The patients who had lost 11 to 20 and >20 teeth, particularly underweight participants, exhibited a significantly higher risk of all-cause mortality compared with those who had lost 0 to 10 teeth. Although previous studies have investigated the relationship between tooth loss and all-cause mortality, they have not included the category of BMI. In addition, despite the inclusion of BMI as a covariate, no subgroup analysis has been conducted by categorizing overweight and underweight participants, despite such associations being able to be determined, because both stroke and dementia have been associated with being overweight. Tooth loss influences mastication and nutritional status. Poor nutrition may be related to being underweight. Moreover, tooth loss can be associated with being overweight based on the overlapping diseases that occur under both these conditions. Thus, it is crucial to understand the relationship between these diseases and tooth loss, and their effects on mortality through statistical analyses.

Our findings demonstrated an association between the number of teeth lost and an increased risk of all-cause mortality. Most previous studies in countries other than Asian have evaluated the relationship between tooth loss and a single cause of mortality. Tooth loss is a risk indicator for various diseases such as cardiovascular disease, stroke, and dementia. Several recent studies have proposed that oral diseases may lead to systemic inflammation, as indicated by increased C-reactive protein levels. Inflammation, possibly within the central nervous system, is believed to play a pivotal role in the pathogenesis of dementia and stroke.

Our study found that male participants aged 65 years or older with less than 20 teeth were significantly associated with increased all-cause mortality, which is consistent with the findings of the previous study by Morita et al., but inconsistent with those of other Asian cohort studies by Ando et al. and Ansai et al. The prevalence of participants with less than 20 teeth in these 2 studies was higher than 50%, which is much higher than that in our study (6.17% had lost >20 teeth). These participants might represent a group of elder people, which may explain the different observation in our study.

In our study, the loss of 11 to 20 and >20 teeth was associated with an increased risk of all-cause mortality among underweight patients. Previous studies have found an association between being overweight and increased mortality. Tooth loss influences dietary choices; older people with many missing teeth consume less meat, fruit, beans, and oils, and primarily obtain their required energy from solid fats, alcohol, and added sugar. Therefore, tooth loss can affect both the dietary intake and nutritional status of such people, thereby increasing the risk of mortality. Although we did not find a dose-effect relationship between tooth loss and mortality among the underweight participants, we obtained a significant HR when tooth loss was treated as a continuous variable.

Socioeconomic status (SES) may be a crucial confounder for not only prosthetic replacement but also mortality. A meta-analysis by Polzer et al. indicated that if published results are not adjusted for SES, the effect of missing prosthetic replacement on mortality is likely to be overestimated. Although dental services are covered by the National Health Insurance program in Taiwan, prosthetic replacement is not included. In this study, we adjusted only for the education level, which was used as a proxy of SES. We cannot rule out the possibility that SES had a residual confounding effect.

By contrast, subgroup analysis showed that overweight participants with severe tooth loss had an increase of 27% to 37% in mortality, with overweight participants having a lower risk of mortality (18% reduction in mortality). The impact of severe tooth loss on mortality cannot be ignored. Therefore, not only overweight participants but also overweight participants should pay attention to oral hygiene to reduce the risk of tooth loss. In addition, the obese participants exhibited an association between tooth loss and mortality, but this association was statistically nonsignificant. Based on our results, we recommend that public health efforts include population-wide strategies and resources to ensure that oral health programs are available from early life onward, with the aim of reducing the prevalence of tooth loss and mortality.

Our study has several limitations. First, information on other confounding factors that might affect tooth loss and mortality, such as dementia, cerebrovascular disease, stroke, and cancer, was not available. Although our analyses were adjusted for common chronic health conditions and baseline patient characteristics, it is possible that subclinical diseases or other diseases were not measured or contributed to increased survival. Additional studies are required to evaluate the impact of this confounder on the association between tooth loss and mortality. Second, information bias in subject characteristics and comorbidities cannot be avoided in studies using self-report questionnaires. However, the comorbidities in this study were combined with data on laboratory parameters, reducing the possibility of recall bias. Third, we used the baseline examination data to represent all of the participants in the cohort. These data may have changed with time, thus conferring complex effects on the respective mortality rates. However, our results demonstrate the value of a single determination of tooth loss in predicting the risk of mortality. Fourth, the participants in our study may not be representative of the general population. However, because the risk comparison was based on internal comparisons, the calculated relative risks are a reasonable estimate of those in the general population. Finally, a total of 20% of the people who had missing survey data and laboratory data. Underweight people and those with tooth loss >20 were more likely to have missing data. Because mortality was more prevalent among these groups than among those with complete information, our findings underestimate the true differences and are conservative.

In conclusion, the number of teeth lost is associated with an increased risk of all-cause mortality. All-cause mortality includes causes such as cardiovascular disease, stroke, and dementia, and these diseases are strongly associated with tooth loss and being overweight. Tooth loss could lead directly to influence dietary choices or poor digestion, thus resulting in becoming overweight. This might explain the association between the increased risk of all-cause mortality and tooth loss, particularly in underweight people. Our results indicated a bidirectional relationship between all-cause mortality and tooth loss, and further research must be conducted to explore the mechanisms underlying the empirical associations observed in our study.

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