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Number of natural teeth, denture use and mortality in Chinese elderly: a population-based prospective cohort study

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Abstract

Background: The associations between the number of natural teeth/denture use and all-cause mortality remain unclear due to lack of investigation for the potential interaction between tooth loss and denture use and for the potential changes in these exposures over time in older adults. We undertake this study to evaluate the associations of the number of natural teeth and/or denture use with mortality in Chinese elderly.

Methods: This is a prospective cohort study of 36,283 older adults (median age: 90). The number of natural teeth and denture use were collected with structured questionnaire. We evaluated hazard ratios (HRs) and confidence intervals (CIs) using a Cox proportional hazards model adjusting for demographic factors, education, income, lifestyle factors, and comorbidities.

Results: We documented 25,857 deaths during 145,947 person-years of observation. Compared to those with 20+ teeth, tooth loss was associated with a gradual increase in mortality, with an adjusted HR of 1.14 (95% CI, 1.06 to 1.23) for those with 10–19 teeth, 1.23 (95% CI, 1.15 to 1.31) for those with 1–9 teeth, and 1.35 (95% CI, 1.26 to 1.44) for those without natural teeth. Denture use was associated with lower risk of mortality (adjusted HR 0.81; 95% CI, 0.77 to 0.84). Subgroup analyses indicated that the benefit of denture use was greater in men than in women ($P = 0.02$) and tended to decrease with age ($P < 0.001$). The effects of denture use did not differ among various degrees of tooth loss ($P = 0.17$).

Conclusions: Tooth loss was associated with an increased risk of mortality in older adults. Denture use provided a protective effect against death for all degrees of tooth loss however, this effect appeared to be modified by sex and age.

Keywords: Cohort study, Denture, Mortality, Tooth loss

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Background

Teeth play an important physiological role in human, which affect chewing, swallowing, speaking, facial aesthetics, and social interactions [1]. Tooth loss represents a major health problem, particularly for elderly [1]. The prevalence of edentulism increases with age and varies among countries [2, 3]. The global age-standardized prevalence of edentulism in 2010 was 2.4% [2]. Although a decline in tooth loss and edentulism has been observed in the past decade [2], the World Health Organization goal of retaining at least 20 teeth at the age of 80 years has not yet been met in most countries [4].

A number of prospective studies have found an association between tooth loss and all-cause mortality, cardiovascular and cancer mortality [5–11]. Wearing dentures may reduce the mortality in older adults [7, 12, 13]. Tooth loss and denture use may affect mortality through inflammation, nutrition, masticatory function, facial appearance, and social engagement [14–18]. Despite a fair amount of previous research, many questions remain unclear. First, the shape of the association between teeth number and mortality, and the minimum teeth number that have no additional mortality risk were still unclear. Second, the associations with potential interactions, such as age and sex, were controversial in previous studies [19, 20]. Third, tooth loss and denture use are closely related, but the potential interaction between tooth loss and denture use, in relation to mortality, have not been comprehensively evaluated. Fourth, many important confounders, like economic status, were not adjusted in most previous studies [5–13]. Fifth, previous studies evaluating denture use and mortality showed inconsistent results [13, 21]. Lastly, tooth loss and the denture use may change over time, but no previous studies have considered the variability over time in evaluating the effect. We carried out this study was to prospectively evaluate the associations of the number of natural teeth and/or denture use with mortality using the Chinese Longitudinal Healthy Longevity Survey (CLHLS) datasets.

Methods

Study design and participants

CLHLS is an ongoing longitudinal interview survey of over 40,000 old adults in 22 of 31 Chinese provinces. The included participants represent 985 million persons, about 85% of the national population [22]. The investigation began in 1998 and follow-up surveys were undertaken in 2000, 2002, 2005, 2008, 2011, and 2014, with approximately a 90% response rate in each wave. To maintain a large enough sample size, the CLHLS replaced the deceased respondents with new participants in the follow-up waves. To avoid the problem of small sub-sample sizes at the more advanced ages, the CLHLS interviewed nearly all centenarians [22]. Details of the

CLHLS have been described elsewhere [22]. The study was approved by the Ethics Committee of Peking University and Duke University. Informed consents were obtained from all participants during the face-to-face interview.

Our inclusion criteria for participants were: aged 65 years or above; had data on the number of natural teeth and/or denture use; and data about the death time was available for at least one follow-up survey. We included all participants from the 1998 survey as all participants were newly recruited. For the follow-up surveys, the participants included the survivals from the previous waves and the new recruits. Only the new recruits needed to be included as the survivals from the previous waves had already been included. This strategy enabled us to analyze based on the largest sample size. In the end, we included 36,283 participants from the CLHLS, with 36,153 participants for the analysis of number of natural teeth and 36,230 for denture use (Figure 1 in the Additional file). There was a small difference in the participant numbers for the two analyses because some participants only reported one of the two exposure data.

Assessment of the exposures

Self-reported number of natural teeth and the use of dentures were collected with the following questions: 1) How many natural teeth (teeth that are naturally grown) do you still have? 2) Do you have false teeth? (False teeth referred to any type of non-natural teeth, including partial or complete, removable or implant-retained fixed dentures). Data were repeatedly collected in each wave. We grouped the number of remaining teeth into four categories (0, 1–9, 10–19, and ≥ 20). We evaluated the combined effects by grouping the participants into 8 categories according to teeth number and denture use. Though the education level of included participants were low and one third of the subjects were cognitively impaired, the validity of self-reported number of natural teeth and denture use may not be influenced as the interviewers could help older adults to confirm their responses to these questions.

Assessment of deaths

We ascertained the survival status through a face-to-face interview with a close family member for those interviewees who had died before the next wave [22]. The survival time was defined as the period from the date of the baseline visit to the date of death. The data for the participants who survived until the 2014 survey were censored at the time of the 2014 survey, and those who were lost to follow-up were censored at the time of the last survey.

Assessment of covariates

We selected covariates that may confound the relationship based on a review of literature [23, 24]. The selected covariates should have an impact on the overall mortality and been collected in the CLHLS. For example, we included fresh fruit intake and vegetable consumption because they may be influenced by teeth health and have an impact on mortality [25]. Because the sample size of this study is large and statistical power is strong, we included as many covariates as possible to minimize the potential confounding effect. We obtained covariate information from the structured questionnaire [26]. The covariates for our analyses included sociodemographic characteristics, routine physical checkup (weight, height, and blood pressure), lifestyle behaviors (smoking, alcohol drinking, physical activity, fresh fruit intake, and vegetable consumption), self-reported medical history, activities of daily living (ADL), cognitive function (evaluated by the Mini-Mental State Examination, MMSE) [27], and depressive symptoms.

Statistical analysis

We evaluated all-cause mortality according to the number of natural teeth and denture use with Kaplan-Meier survival plots. To explore the shape of the relationship, we used additive Cox regression, taking number of natural teeth as a smoothed term. Penalized splines were used for smoothing. The degrees of freedom were determined according to Akaike Information Criterion and residual deviance. For better interpretation of effect, we also evaluated the hazard ratios (HRs) and 95% confidence intervals (CIs) with time-dependent Cox regression. We divided the subject's time of observation into several intervals based on the time of follow-up surveys and date of death. The exposure values at the beginning of each interval were used for this interval.

Multivariable models were applied to adjust for confounding factors. We adjusted for age at baseline, sex, and residence (urban or rural, defined according to the official registration record for Chinese citizen) in the basic analysis model. Additionally, we adjusted for education, living arrangement, sufficient income for daily needs, smoking, alcohol drinking, frequent vegetable consumption, frequent fruit consumption, frequent physical activity, ADL, cognitive impairment (defined as MMSE < 24), body mass index, hypertension, self-reported diabetes mellitus, self-reported heart disease, self-reported cerebrovascular disease, self-reported respiratory disease in the fully-adjusted model. We coded the participants with missing covariate data to the reference group or median group when the missing rate was low (< 5%). When the rate of missing data was $\geq 5\%$, a separate missing response category was created. Based

on the HRs and mortality rate, we calculated the age- and sex-specific number needed to treat (NNT) [28], which is conceptually easier to understand.

We conducted subgroup analyses by age, sex, residence, years of education, BMI, smoking status, and drinking status, in order to investigate potential effect-modifying effect. We also evaluated the association of teeth number with all-cause mortality by denture use and vice versa.

We conducted a number of sensitivity analyses: 1) additionally adjusting for depressive symptom, current marital status, time of recruitment; 2) using the baseline number of natural teeth and denture use as covariates; 3) excluding patients with a history of diabetes mellitus, heart disease, cerebrovascular disease, or respiratory diseases; 4) excluding participants with an observation time of < 3 years, > 12 years, or without tooth loss; 5) additionally adjusting for living location; and 6) considering the participants with unknown survival status censored at the median of follow-up (3 years) as previous study [29]; 6) excluding the participants who reported more number of natural teeth than the teeth number in the previous wave of survey. Analyses were completed using Stata version 12.0 (StataCorp LP, College Station, TX, USA) and R software version 3.4.1 (R Development Core Team, 2017).

Results

Baseline characteristics

Table 1 presents the baseline characteristics. The median age of participants was 90 years (interquartile range [IQR] 81 to 99) and 41.1% were men. Most of the participants (98.1%) had lost one or more teeth and 37.3% had lost all teeth. The overall denture use rate was 23.6% and increased with tooth loss.

Number of natural teeth and all-cause mortality

The median follow-up time was 3 years (maximum: 16.5 years, IQR 1.6 to 5.7 years). During a total of 145,947 person-years of observation, we documented 25,857 deaths (71.3%). Figure 1-A suggested that the mortality among various teeth groups were significantly different (log-rank test: $P < 0.001$).

Figure 2 presented the nonlinear association between the number of natural teeth and mortality. We considered the participants with 28 teeth as reference as they had the lowest risk. Twenty-eight is also the number of usable teeth in human. The association was hockey stick-shaped (Test for nonlinear: $P = 0.009$). The HRs first decreased with the number of natural teeth (approximately between 0 to 25 teeth) and then kept stable (approximately between 26 to 32 teeth). The minimum number of natural teeth showing no significantly increased mortality was 25 teeth (HR for 25 teeth: 1.03,

Table 1 Characteristics of participants by the number of natural teeth and denture use

	Number of natural teeth (n = 36,153)				Denture use (n = 36,230)		P-value ^a
	20+	10–19	1–9	0	Yes	No	
No. of participants	5504	5024	12,146	13,479	8423	27,807	
Median (IQR) age, years	74(67–84)	84(77–91)	91(84–100)	95(87–100)	86(79–94)	91(82–100)	< 0.001
Male, n(%)	3126(56.8)	2489(49.5)	4965(40.9)	4251(31.5)	4053(48.1)	10,840(39.0)	< 0.001
Residence, n(%)							
Urban	2349(42.7)	2054(40.9)	4444(36.6)	5368(39.8)	4361(51.8)	9919(35.7)	< 0.001
Rural	3155(57.3)	2970(59.1)	7702(63.4)	8111(60.2)	4062(48.2)	17,888(64.3)	
Education time, years							
0	2474(45.1)	2913(58.2)	8447(70.0)	9986(74.5)	4451(53.1)	19,374(70.1)	< 0.001
> =1	3009(54.9)	2090(41.8)	3624(30.0)	3414(25.5)	3935(46.9)	8269(29.9)	
Living arrangement							
Living alone	4870(88.6)	4260(84.8)	10,473(86.3)	11,927(88.5)	7335(87.1)	24,268(87.3)	0.60
With others	628(11.4)	762(15.2)	1668(13.7)	1546(11.5)	1086(12.9)	3523(12.7)	
Sufficient income for daily needs							
Yes, n(%)	3979(80.8)	3149(77.4)	6528(74.7)	7882(77.6)	5608(81.9)	15,974(75.7)	< 0.001
No, n(%)	948(19.2)	918(22.6)	2209(25.3)	2280(22.4)	1238(18.1)	5130(24.3)	
Median (IQR) BMI, kg/m ²	20.5(18.2–23.6)	19.5(17.2–22.4)	18.5(16.3–21.1)	18.4(16.2–21.0)	19.8(17.7–22.7)	18.6(16.5–21.3)	< 0.001
Smoking, n(%)							
Non-smoker	3285(59.8)	3232(64.4)	8311(68.5)	9663(71.8)	5285(62.8)	19,240(69.3)	< 0.001
Current smoker	1406(25.6)	1025(20.4)	2180(18.0)	1998(14.8)	1692(20.1)	4938(17.8)	
Former smoker	804(14.6)	764(15.2)	1642(13.5)	1803(13.4)	1440(17.1)	3594(12.9)	
Alcohol consumption, n(%)							
Non-drinker	3455(62.9)	3383(67.4)	8264(68.1)	9806(72.9)	5770(68.6)	19,191(69.1)	0.272
Current drinker	1459(26.6)	1080(21.5)	2575(21.2)	2413(17.9)	1745(20.7)	5790(20.8)	
Former drinker	581(10.6)	558(11.1)	1290(10.6)	1241(9.2)	896(10.7)	2789(10.0)	
Frequent vegetable intake, n(%)	1859(33.8)	1829(36.4)	4765(39.2)	5546(41.2)	3030(36.0)	10,989(39.5)	< 0.001
Frequent fruit intake, n(%)	811(14.8)	563(11.2)	1262(10.4)	1841(13.7)	1679(19.9)	2821(10.2)	< 0.001
Frequent physical activity, n(%)	2242(40.8)	2033(40.5)	4899(40.4)	4889(36.3)	3713(44.1)	10,393(37.4)	< 0.001
Impaired cognitive function, n(%)	724(13.7)	1183(25.3)	4633(42.6)	5740(51.1)	1912(24.9)	10,387(42.5)	< 0.001
Restricted ADL, n(%)	605(11.0)	869(17.3)	3483(28.8)	5494(40.9)	2068(24.6)	8401(30.3)	< 0.001
Hypertension, n(%)	2548(47.9)	2133(43.9)	5051(43.3)	5598(43.9)	3457(42.7)	11,900(44.8)	0.001
Diabetes, n(%)	163(1.2)	153(1.3)	110(2.2)	155(2.8)	212(2.5)	371(1.3)	< 0.001
Heart disease, n(%)	982(7.3)	788(6.5)	417(8.3)	495(9.1)	935(11.2)	1758(6.4)	< 0.001

Table 1 Characteristics of participants by the number of natural teeth and denture use (Continued)

	Number of natural teeth (n = 36,153)				Denture use (n = 36,230)		P-value ^a
	20+	10–19	1–9	0	Yes	No	
Cerebrovascular disease, n(%)	565(4.2)	478(4.0)	230(4.6)	304(5.6)	494(5.9)	1082(3.9)	< 0.001
Respiratory disease ^a , n(%)	1540(11.5)	1364(11.3)	584(11.7)	587(10.7)	1078(12.9)	3009(10.9)	< 0.001
Denture use, n(%)							
Yes	652(11.9)	856(17.1)	1952(16.1)	4958(36.8)	NA	NA	NA
No	4845(88.1)	4161(82.9)	10,170(83.9)	8506(63.2)	NA	NA	NA
Number of natural teeth, n(%)							
20+	NA	NA	NA	NA	652(7.7)	4845(17.5)	< 0.001
10–19	NA	NA	NA	NA	856(10.2)	4161(15.0)	
1–9	NA	NA	NA	NA	1952(23.2)	10,170(36.7)	
0	NA	NA	NA	NA	4958(58.9)	8506(30.7)	

IQR Interquartile range, ADL Activity of daily living, BMI Body mass index, NA Not available

The differences were tested by Kruskal-Wallis test or χ^2 test

^a Including bronchitis, emphysema, asthma, pneumonia

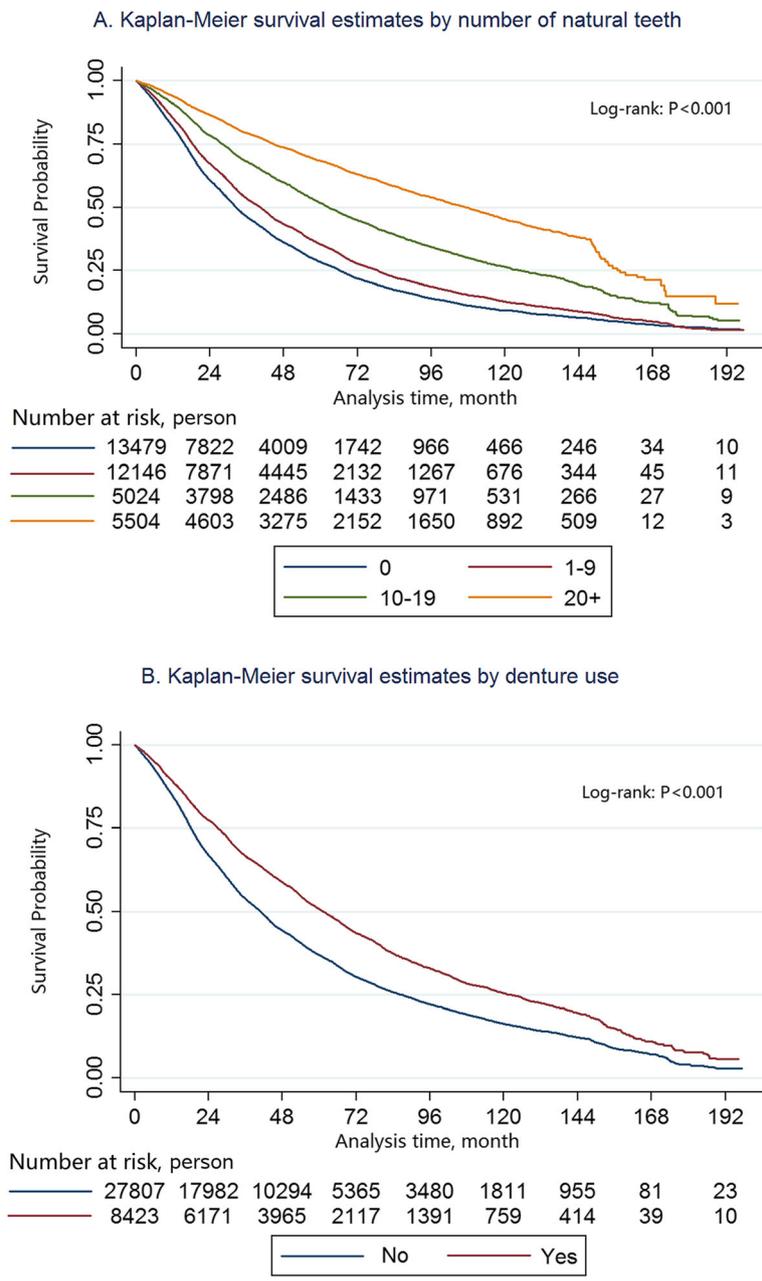


Fig. 1 Kaplan–Meier plot showing the mortality by the number of natural teeth and denture use

95% CI 0.99 to 1.08, $P = 0.18$; HR for 24 teeth: 1.05, 95% CI 1.00 to 1.10, $P = 0.05$).

Table 2 presents the HRs categorized by teeth number. Tooth loss was associated with a gradual increase in the risk of mortality (P -trend < 0.001), with an adjusted HR of 1.14 (95% CI, 1.06 to 1.23) for those with 10–19 teeth, 1.23 (95% CI, 1.15 to 1.31) for those with 1–9 teeth, and 1.35 (95% CI, 1.26 to 1.44) for those lacking natural teeth, as compared to those with 20+ teeth.

Denture use and all-cause mortality

Figure 1-B suggested that the mortality in denture users was lower than non-users (log-rank test $P < 0.001$). The individuals with dentures had lower risk of mortality as compared with those who did not (adjusted HR 0.81; 95% CI 0.77 to 0.84) (Table 2). Overall, 17.3 and 34.8 older adults need to wear dentures to prevent one death in 5 and 10 years, respectively. The NNTs increased with age and were larger in women than in men (Table 3).

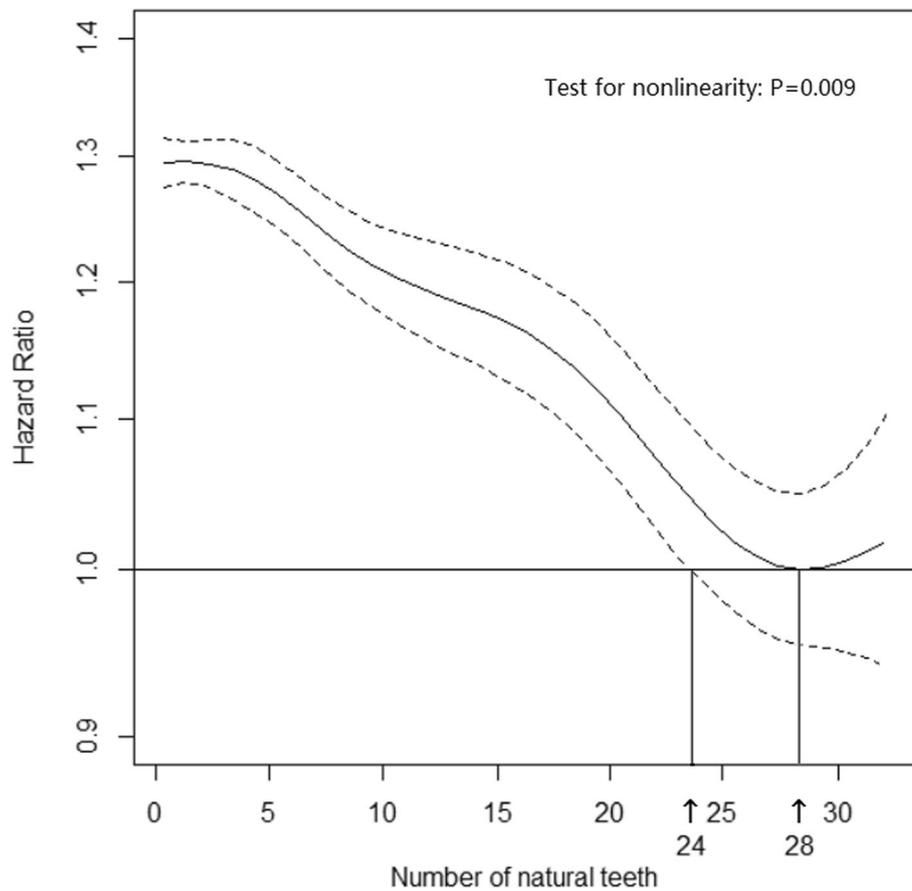


Fig. 2 Association between the number of natural teeth and mortality. The results were based on additive cox regression taking number of natural teeth as a smoothing term in the model. The inflection point with lowest hazard (28 teeth) was considered the reference. The additive cox regression model has adjusted for age, sex, residence, denture use, education, sufficient income for daily needs, living arrangement, BMI, smoking, alcohol drinking, frequent vegetable consumption, frequent fruit consumption, impaired activity of daily living, cognitive impairment, hypertension, self-reported history of diabetes mellitus, self-reported history of heart disease, self-reported history of cerebrovascular disease, and self-reported history of respiratory diseases. The minimum number of natural teeth showing no significantly increased risk was 25 (HR for 24 teeth: 1.05, 95%CI 1.00 to 1.10, $P = 0.05$; HR for 25 teeth: 1.03, 95%CI 0.99 to 1.08, $P = 0.18$)

Combined effects of tooth loss and denture use

Among those who did not use dentures, the adjusted HRs as compared with the elderly without natural teeth were 0.91 (95%CI 0.87 to 0.96), 0.87 (95%CI 0.82 to 0.93), and 0.75 (95%CI 0.70 to 0.80) for those with 1–9, 10–19, and 20+ teeth, respectively (Table 1 in the Additional file). The estimated HRs tended to be larger for denture users than non-users in each category of teeth.

Subgroup analyses

For the number of natural teeth, the comparisons of the 0 tooth group ($P = 0.001$) or 1–9 teeth group ($P < 0.001$) versus the reference group (20+ teeth) were different by age group; the risks tended to be higher in the younger elderly (65–79 years) than in the older age group of 80+ (Table 2 in the Additional file). Subgroup analyses for number of natural teeth by sex, residence status, BMI,

smoking status, alcohol drinking, and denture use did not show any interaction effects.

Subgroup analyses for denture use showed interaction effects with age ($P < 0.001$) and sex ($P = 0.02$). The benefit of denture use tended to decrease with age, with a fully-adjusted HR of 0.65 for those aged 65–79 years, 0.73 for those aged 80–89 years, and 0.84 for those aged 90 and over. Denture use was associated with a greater reduction in mortality in men (HR 0.76; 95% CI 0.71 to 0.82) than in women (HR 0.84; 95% CI 0.79 to 0.89).

Sensitivity analysis

Our sensitivity analyses, additionally adjusting for depressive symptom, marital status, time of recruitment, and living location yielded results largely similar to the primary results (Table 3 in the Additional file). The effect size by Cox regression analyses, evaluating the baseline number of natural teeth and denture use, was

Table 2 Associations of the number of natural teeth or denture use with mortality

	Hazard Ratio[95% Confidence Interval]		
	Unadjusted model	Basic model ^a	Fully adjusted model ^b
Number of natural teeth			
No. of participants	36,153	36,100	20,816
No. of deaths	25,737	25,713	12,757
20+	1.00	1.00	1.00
10–19	1.59[1.51, 1.69]	1.13[1.07, 1.20]	1.14[1.06, 1.23]
1–9	2.60[2.48, 2.72]	1.29[1.23, 1.36]	1.23[1.15, 1.31]
0	3.18[3.03, 3.33]	1.46[1.38, 1.53]	1.35[1.26, 1.44]
P-trend	< 0.001	< 0.001	< 0.001
Denture use			
No. of participants	36,230	36,100	20,816
No. of deaths	25,824	25,713	12,757
No	1.00	1.00	1.00
Yes	0.66[0.64, 0.68]	0.76[0.74, 0.79]	0.81[0.77, 0.84]

HR Hazard ratio, CI Confidence interval;

^aBasic model: adjusted for age (years), sex (men or women), and residence (urban or rural), teeth number (0, 1–9, 10–19, ≥20, for analysis of denture use), denture use (yes or no, for analysis of teeth number);

^bFully adjusted model: additionally adjusted for education (yes or no), sufficient income for daily needs (yes or no), living arrangement (living alone or with others), BMI (< 18.5, ≥ 18.5 and < 24, or ≥ 24), smoking (current smoker, former smoker, or never smoker), alcohol drinking (current drinker, former drinker, or non-drinker), frequent vegetable consumption (yes or no), frequent fruit consumption (yes or no), impaired activity of daily living (yes or no), cognitive impairment (yes or no), hypertension (yes or no), self-reported history of diabetes mellitus (yes or no), self-reported history of heart disease (yes or no), self-reported history of cerebrovascular disease (yes or no), and self-reported history of respiratory diseases (yes or no)

slightly smaller than the primary results, but the conclusion was unchanged. Sensitivity analyses by excluding participants with an observation time of < 3 years, > 12 years, without loss of teeth, with increased number of natural teeth between two waves of surveys, and considering the older adults with unknown survival status censored at the median of follow-up (3 years) showed no major difference.

Discussion

This cohort study of 36,283 Chinese older adults suggested there was likely to be a hockey stick-shaped association between the number of natural teeth and all-cause mortality. The mortality risk decreased with increment of number of natural teeth, and those who had 24 teeth or less were associated with significantly increased

risk of mortality. This finding suggested that 25 teeth is the minimum number of natural teeth to avoid extra risk of death. Denture use was associated with a decreased risk of all-cause mortality that tended to wane with age. The absolute benefit of wearing dentures was large and varied with age. In order to prevent one death in 5 years, approximately 6 to 7 older people aged 56–79 need to wear dentures, compared with 37 to 42 people for those aged 95 and over. The benefit of wearing dentures was similar among different degrees of tooth loss. The primary results were robust as shown in a series of sensitivity analyses.

Our findings are consistent with previous analyses in older populations [7–9, 12]. In a cohort study of 21,730 individuals, the number of natural teeth was inversely associated with mortality [7]. A retrospective cohort study

Table 3 Age- and sex-specific number needed to treat to prevent one death in 5 and 10 years

	5-year mortality rate in non-denture users	10-year mortality rate in non-denture users	HR[95% CI] of denture users versus non-denture users	NNT[95% CI] to prevent one death in 5 years	NNT[95% CI] to prevent one death in 10 years
65–79 years & men	19.8%	44.7%	0.64[0.55, 0.74]	6.4[4.7, 9.7]	6.6[5.1, 9.6]
80–89 years & men	56.1%	85.7%	0.69[0.62, 0.78]	9.1[7.2, 12.9]	24.0[19.1, 33.4]
> = 90 years & men	82.4%	97.9%	0.83[0.75, 0.92]	36.7[24.6, 79.6]	287.3[193.7, 617.8]
65–79 years & women	16.7%	36.7%	0.66[0.56, 0.78]	7.3[5, 12.6]	6.8[5.0, 11.2]
80–89 years & women	48.9%	81.5%	0.79[0.70, 0.90]	12.8[8.5, 27.2]	28.3[19.4, 58.5]
> = 90 years & women	82.1%	97.7%	0.85[0.79, 0.93]	41.5[28.3, 82.9]	300[205.7, 595.5]

HR Hazard ratio, CI Confidence interval, NNT Number needed to treat
HRs were based on fully-adjusted cox regression models

of 55,651 old adults suggested that the HRs of all-cause mortality in the participants with no teeth, 1–9 teeth, and 10–19 teeth were 1.36, 1.24, and 1.19, respectively, which were similar to our estimates [8]. In the Golestan Cohort Study, wearing dentures reduced all-cause mortality by 10% [12]. The effect was smaller than our estimate (19%), possibly due to the difference in ethnicity and age.

Previous studies yielded mixed results about the interaction of age and sex on the association between teeth number and mortality. A cohort study suggested that number of natural teeth was inversely associated with all-cause mortality among the individuals aged 40–64 years but not among those aged 65–79 years [5]; However, an association was shown among adults aged 65 and older in another cohort study [7]. In a cohort study of 1282 subjects aged 80 years, tooth loss was a predictor of mortality in women but not in men [9]; However, in a 10-year cohort study of 118 subjects aged 80 years or over, an association between number of natural teeth and survival rate was shown in men but not in women [10]. A possible explanation is that the sample sizes in subgroups in these studies were too small. Our subgroup analyses by age did show between-group differences, but the association persisted in most subgroups.

Our subgroup analysis suggested that the protective effect of denture use decreased with age. The younger elders (65–79 years) had the highest risk of death due to tooth loss in our study; This more severely affected group may therefore have been more readily able to demonstrate a protective effect of wearing dentures. Our subgroup analysis by sex suggested that the effect of wearing dentures tended to be greater in men than in women. A possible explanation is that men tend to have a poorer nutritional status than women [30], while wearing dentures could effectively improve nutritional intake [31]; Therefore men are likely to have more benefits from denture use. Additionally, previous studies have shown that men are less active in social participation than women [32], while wearing dentures can encourage social participation [33]; Thus, it is expected that men will benefit more from denture placement. Only one prior study investigated denture use and mortality by sex. In this study, denture use was associated with lower mortality in women but not in men in individuals with less than 10 teeth; there were no major differences of mortality rates between subjects with 10 or more teeth with and without dentures or based on sex [34]. The sample size in this subgroup might be too small to test the difference.

Based on additive cox regression, we found that the risk of mortality decreased with increment of numbers of natural teeth. The risk was parallel to the severity of tooth loss and a statistically significant increased risk

was observed at 24 or less teeth. This may be because more tooth loss could have a more severe influence on the masticatory function and nutritional status, which in turn, be linked to overall mortality. The elderly with 24 or less teeth had $\geq 5\%$ increased risk. For the elderly with 25 or more teeth, there was no sufficient evidence of increased risk, and if any, the risk would be less than 3%.

In addition to the burden of inflammation, another possible mechanism underlying the association of tooth loss and mortality could be nutrition. Fewer teeth are associated with impaired masticatory function and nutritional status [14, 15], which in turn, increases the risk of mortality [35, 36]. This was consistent with our analysis of baseline characteristics, which suggested that the individuals with fewer teeth had lower BMI. Denture may reduce mortality by improving masticatory function, bite force, and nutritional state [16]. Use of dentures may also benefit older adults through preventing foreign body asphyxiation, enhancing phonetics, improving facial appearance, and facilitating social engagement [17, 18].

The use of dentures in older adults could be influenced by the cost. Cost for dentures varies greatly depending on type of dentures, type of materials used, additional necessary equipment, and region. For example, the cost for one replacement tooth in China ranged from approximately 60 USD to 1500 USD [37]. In China, a variety of dentures are available for older adults, adapted to their income. The overall denture use rate, particularly in those with no or few remaining teeth, was relatively low in this study as compared with the older adults from Western Europe or Japan. This is because denture use rate is closely related to economic status, while China is a developing country and 60.6% of the included participants were from rural area with low income.

The strengths of this study included the large sample size, the prospective cohort study design, investigation of the optimal teeth number and the shape of association, and evaluation of the interaction between teeth number and denture use. In addition, we used a time-dependent Cox proportional model which could not only control the baseline number of natural teeth/denture use, but also control the change in these exposures during follow-up. Furthermore, our sensitivity analyses were robust, which could reduce potential bias from additional confounders (such as marital status), participants with extreme short or long survival, and different methods for handling censored data. Lastly, this study also found solid evidence that the protective effect of denture use was modified by age and sex.

Our study has several limitations. First, residual confounding by other unmeasured or unknown factors remains possible. Second, we cannot investigate the type of dentures, cause of death, time of tooth loss and

denture use, dental symptoms, and dental care/ utilization, as these data were not collected. Third, our study included a sample with very old age (median age: 90 years). The participants are older than the general elder population in China. The main study findings, including the evaluation for the optimal number of natural teeth, may not be applicable to other population. Fourth, the primary results may be influenced by the exclusion of 6642 participants whose survival status was unknown as they might have different characteristics. However, our subgroup analyses suggested that the primary effects were not modified by most baseline characteristics. The sensitivity analysis by considering the older adults with unknown survival status censored at the median of follow-up (3 years) suggested that the primary results were robust. Fifth, According to the 4th National Oral Health Survey, the mean remaining teeth was 22.5 ± 8.7 and denture use rate was 34.0% in the 65 to 74 age group in 2015–2016 in China (data for the elderly aged 75 and over was not collected) [38]. The mean remaining teeth (17.6 ± 10.6) and denture use rate (29.9%) in this age group were relatively lower in our study. This was because our data was collected much earlier than this national survey and there was a continuous improvement in oral health of Chinese elderly in the past decades. This may influence the generalizability of our conclusion. Sixth, there is a threat that some older adults whom died soon after recruitment may not be due to tooth loss or denture use. We undertook sensitivity analysis by excluding participants with an observation time of < 3 years and the result showed no major differences as compared to the primary results. Therefore, we did not include an induction period in the primary results as most previous studies. Last, the quality of evidence is low due to the observational study design.

Conclusion

In conclusion, our results indicate that tooth loss was associated with an increased risk of all-cause mortality. The optimal number of natural teeth in older adults was ≥ 25 . Wearing dentures might have a protective effect against death, and the effect tended to decrease with age and be greater in men than in women. Preventing tooth loss and using dentures would have substantial public health benefits in view of the high prevalence of tooth loss and low denture use rate in this rapidly growing population.

Supplementary information

Supplementary information accompanies this paper at <https://doi.org/10.1186/s12903-020-01084-9>.

Additional file 1: Figure S1. Flowchart of participant enrollment

Additional file 2: Table S1. Combined effects of tooth loss and denture use on mortality

Additional file 3: Table S2. Subgroup analysis for the associations between the number of natural teeth or denture use with mortality

Additional file 4: Table S3. Sensitivity analysis for the association of the number of natural teeth or denture use with mortality

Abbreviations

CLHLS: Chinese longitudinal healthy longevity survey; BMI: Body mass index; HR: Hazard ratios; CI: Confidence interval; ADL: Activities of daily living; MMSE: Mini-mental state examination; NNT: Number needed to treat; IQR: Interquartile range

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Authors' contributions

XMS and CM designed research; JQY, YBL, CM, and XMS conducted research; JQY, CM, and YBL wrote paper; CM, YZ, and XMS provided administrative, technical, or material support; YZ, XG, ZXY, VBK, HSC, JSL critically revised the manuscript for important intellectual content; XMS had primary responsibility for final content. The authors read and approved this manuscript.

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Availability of data and materials

This study was based on the datasets from the Chinese Longitudinal Healthy Longevity Survey (CLHLS) in longevity areas. The CLHLS data can be publicly obtained through the National Archive of Computerized Data on Aging (NACDA) (<https://www.icpsr.umich.edu/icpsrweb/NACDA/series/487>).

Ethics approval and consent to participate

The study was approved by the Ethics Committee of Peking University and Duke University. Written informed consents were obtained from all participants during the face-to-face interview.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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