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Dental status and compression of life expectancy with disability in Japan

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Keywords:	Gerontology, Epidemiology, Edentulous/edentulism
Abstract:	Background: This study examined whether number of teeth contributes to the compression of morbidity, measured as a shortening of the life expectancy with disability, an extension of healthy life expectancy, and overall life expectancy. Methods: A prospective cohort study was conducted. A self-reported baseline survey was conducted to 126,438 community-dwelling older people aged ≥65 years in Japan in 2010, and 85,161 (67.4%) responded. The onset of functional disability and all-cause mortality were followed-up for 1,374 days (follow-up rate = 96.1%). A sex-stratified illness-death model was applied to estimate the adjusted hazard ratios (aHRs) for three health transitions (healthy to dead, healthy to disabled, and disabled to dead). Absolute differences in life expectancy, healthy life expectancy, and life expectancy with disability according to the number of teeth were also estimated. Age, denture use, socioeconomic status, health status, and health behavior were adjusted. Results: Compared with the edentulous participants, participants with ≥20 teeth had lower risks of moving from healthy to dead [aHR (95% CI); men: 0.58 (0.50, 0.68); women: 0.70 (0.57, 0.85)] and from healthy to disabled transitions [men: 0.52 (0.44, 0.61); women: 0.58 (0.49, 0.68)].

	They moved from a disabled to dead earlier [men: 1.26 (0.99, 1.60); women: 2.42 (1.72, 3.38)]. Among the participants aged ≥85 years, those with ≥20 teeth had longer life expectancy (men: +57 days; women: +15 days) and healthy life expectancy (men: +92 days; women: +70 days) and shorter life expectancy with disability (men: -35 days; women: -55 days) compared with the edentulous participants. Similar associations were observed among the younger participants and those with 1-9 or 10-19 teeth. Conclusions: The presence of remaining teeth was associated with significant compression of morbidity: older Japanese adults' life expectancy with disability was compressed by 35–55 days within the follow-up for 1,374 days.

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Original Research Report

Dental status and compression of life expectancy with disability in Japan

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Abstract

Background: This study examined whether number of teeth contributes to the compression of morbidity, measured as a shortening of the life expectancy with disability, an extension of healthy life expectancy, and overall life expectancy.

Methods: A prospective cohort study was conducted. A self-reported baseline survey was conducted to 126,438 community-dwelling older people aged ≥65 years in Japan in 2010, and 85,161 (67.4%) responded. The onset of functional disability and all-cause mortality were followed-up for 1,374 days (follow-up rate = 96.1%). A sex-stratified illness-death model was applied to estimate the adjusted hazard ratios (aHRs) for three health transitions (healthy to dead, healthy to disabled, and disabled to dead). Absolute differences in life expectancy, healthy life expectancy, and life expectancy with disability according to the number of teeth were also estimated. Age, denture use, socioeconomic status, health status, and health behavior were adjusted.

Results: Compared with the edentulous participants, participants with ≥20 teeth had lower risks of moving from healthy to dead [aHR (95% CI); men: 0.58 (0.50, 0.68); women: 0.70 (0.57, 0.85)] and from healthy to disabled transitions [men: 0.52 (0.44, 0.61); women: 0.58 (0.49, 0.68)]. They moved from a disabled to dead earlier [men: 1.26 (0.99, 1.60); women: 2.42 (1.72, 3.38)]. Among the participants aged ≥85 years,

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those with ≥20 teeth had longer life expectancy (men: +57 days; women: +15 days) and healthy life expectancy (men: +92 days; women: +70 days) and shorter life expectancy with disability (men: -35 days; women: -55 days) compared with the edentulous participants. Similar associations were observed among the younger participants and those with 1-9 or 10-19 teeth.

Conclusions: The presence of remaining teeth was associated with significant compression of morbidity: older Japanese adults' life expectancy with disability was compressed by 35–55 days within the follow-up for 1,374 days.

Keywords: Life Expectancy, Longevity, Oral health, Dentition, Epidemiology, Survival Analysis

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Introduction

Compression of morbidity, namely extending healthy life expectancy and overall life expectancy, as well as shortening life expectancy with disabilities or diseases (the difference between life expectancy and healthy life expectancy), is becoming a global concern in the current aging society (Fries 1980; Vos et al. 2016; Kassebaum et al. 2016). Both life expectancy and healthy life expectancy have extended in recent decades; however, life expectancy with disability has also extended (Kassebaum et al. 2016). The recent Global Burden of Disease Study reported that life expectancy with disability has increased from 7.7 years to 8.1 years for men and from 9.4 years to 10.0 years for women between 2005 and 2015 (Kassebaum et al. 2016). For a healthy aging society, public health should not only focus in increasing life expectancy alone, but also in extending healthy life expectancy and decreasing life expectancy with disability.

Oral diseases are suggested risk factors of various kinds of disability and death (Polzer et al. 2012; Wu et al. 2016). For example, periodontal diseases are associated with chronic systemic inflammation and infection, which contribute to atherosclerotic plaque development (Kebschull et al. 2010) It is also suggested that these factors contribute to future incidence of cardiovascular diseases (Kebschull et al. 2010; Polzer et al. 2012). Poor diet and nutrition due to lack of teeth is another potential mechanism

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(Ritchie et al. 2002) because poor nutritional status is a risk factor for cognitive/functional decline (Sanders et al. 2016) and death (Flegal et al. 2007). In fact, edentulous people were more likely to have a cognitive/physical function decline (Tsakos et al. 2015; Wu et al. 2016), and premature death was predicted by clinically examined number of teeth (Hu et al. 2015). Therefore, healthy life expectancy and life expectancy may be influenced by oral diseases. In that case, the extent of the contribution of oral health at the population level would be major because of their high prevalence; untreated dental caries in the permanent dentition and severe periodontitis are the first and the sixth most prevalent chronic diseases worldwide, respectively (Marcenes et al. 2013).

However, it is unclear whether maintaining good oral health in later life contributes to the compression of morbidity because previous studies have separately evaluated the association between oral health and either disability *or* mortality, thus they were not able to evaluate life expectancy with disability. To overcome this gap in the literature, we aimed to simultaneously investigate the association between the number of teeth and onset of functional disability, mortality without functional disability, and mortality after functional disability among older people in Japan.

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Method

Ethical consideration

Ethical approval of this study was obtained from the ethics committee of Nihon Fukushi University. We considered that the people who responded to our survey agreed to participate in the study. We followed the STROBE guidelines.

Study design and setting

We conducted a prospective cohort study using the data of Japan Gerontological Evaluation Study (JAGES) project, a large-scale prospective panel study targeting community-dwelling older people in Japan. The baseline survey was conducted in 2010, and self-reported questionnaires were mailed to 126,438 people aged ≥65 years without a certification from the Long-term Care Insurance (Ministry of Health Labour and Welfare 2002) in 24 municipalities. Random sampling from the small administrative regions was employed in 13 large municipalities, while all eligible residents in 11 small municipalities were included. Participants' survival and functional disability status were followed-up for up to 1,374 days using the database of the national and municipal government registry. The follow-up duration varied between municipalities. The median (interquartile range) of the follow-up period was 1,027 (313) days for disability onset

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and 1,100 (281) days for mortality.

In the baseline survey, 85,161 responded (response rate = 67.4%). We excluded 9 individuals missing information on age or sex and 4,574 who were classified as not being independent regarding basic activities of daily living (bADL). This resulted in 80,578 respondents who were eligible to be followed-up. Among them, 77,397 (36,074 men [mean age, 73.3 years] and 41,323 women [mean age, 73.8 years]) were successfully linked to their mortality/functional disability data (follow-up rate = 96.1%) (Appendix 1). The total follow-up person-years were 226,134.6 years.

Outcomes

Outcomes of the present study were onset of functional disability and all-cause mortality obtained from the municipal and the national database. Onset of functional disability was determined when a person was newly qualified for the Long-term Care Insurance level 2 or higher (Ministry of Health Labour and Welfare 2002), which is based on a multistep assessment of functional and cognitive impairments by physicians and the Certification Committee of Needed Long-Term Care. This definition was used in previous epidemiological studies (Aida et al. 2012; Hikichi et al. 2015). Information on mortality in this study would be reliable since we obtained the data from the national

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long-term care insurance database.

Predictor variable

Our main predictor was the number of remaining teeth at baseline, which was determined by the following single question: "*How many remaining teeth do you have?*" Their answer was chosen from *"≥20 teeth," "10–19 teeth," "1–9 teeth,"* and *"No teeth."* The self-reported number of teeth in this project was validated using the clinical data of the subsample (Yamamoto et al. 2012) and was used in previous studies (Sato et al. 2016).

Covariates

We used the following variables as covariates: age (65-69, 70-74, 75-79, 80-84, or ≥85 years), denture use (using a denture/not using a denture), years of education (<6, 6-9, 10-12, or ≥13 years), self-reported comorbidity (receiving treatments for any of the following diseases: heart disease, stroke, hypertension, or diabetes mellitus), self-rated health (very poor, poor, good, or very good), falling experience in the previous year (yes/no), smoking status (current smoker, former smoker, or never smoker), alcohol drinking status (daily drinker, occasional drinker, former drinker, or never drinker), walking time (<0.5, 0.5–0.9, 1.0-1.4, or ≥1.5 hours per day), body mass index (underweight: <18.5 kg/m^2, normal weight: 18.5-24.9 kg/m^2, overweight: 25.0-29.9

kg/m^2, or obesity: ≥30 kg/m^2), and depression assessed by the Geriatric Depression Scale (Sheikh and Yesavage 1986) (<5, 5-9, or ≥10).

Statistical analyses

Illness-death model

To consider the three categories of health status, the illness-death model, one of the multistate survival models was applied (Hinchliffe et al. 2013). To determine the health status transition (alive and healthy, alive with a disability, and dead), the illness-death model was applied (Hinchliffe et al. 2013). Figure 1 shows the conceptual framework of the model. There are four states: State 1 (alive and healthy), State 2 (alive with a disability), State 3 (dead without a disability), and State 4 (dead after being disabled); the three transitions between these states are: Transition 1 (State 1 to State 3), Transition 2 (State 1 to State 2), and Transition 3 (State 2 to State 4). Hazards of each transition — $\alpha_{13}(t)$, $\alpha_{12}(t)$, and $\alpha_{24}(t)$ in Figure 1, respectively — were simultaneously estimated (Hinchliffe et al. 2013). In the present study, all participants started from State 1 because we restricted them to participants independently performing their basic ADL at the baseline survey (Appendix 1). We assumed that once the participants moved to State 2, they would not return to State 1 because the recovery from a functional disability (the

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Long-term Care Insurance level 2 or higher) was rare in Japan (Kijima 2007).

Model construction

All analyses were stratified by sex to consider its differences in life expectancy (Luy and Minagawa 2014). Two models were constructed: a model adjusted for age (Model 1) and another model adjusted for all covariates (Model 2). In addition, survival curve of the probability for staying in each state was estimated (Hinchliffe et al. 2013). Life expectancy, healthy life expectancy, and life expectancy with disability from the baseline survey and proportion of healthy life expectancy in life expectancy were estimated by calculating the area under the curve (van den Hout et al. 2014).

Main analyses were conducted applying the multiple imputation procedure on the explanatory variables. In this procedure, the multivariate normal imputation method under an assumption of missing at random was applied, and five multiply imputed datasets were created. Estimated parameters were then combined using the Rubin's combination methods (Rubin 1987; Carpenter and Kenward 2012). Probability for staying in each state after the multiple imputation was calculated by the mean of the estimated probabilities in each of the five datasets. In addition, two types of sensitivity analyses were conducted: (1) an analysis including dummy categories indicating

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missing information on each explanatory variable and (2) another analysis in which participants who had died or become disabled in the first 6 months were excluded. All analyses were conducted using the Stata 14.1 software (Stata Corp LP, College Station, Texas, US), especially the programs of *illdprep*, *stpm2*, and *stpm2illd*.

Results

Table 1 shows the demographic characteristics of the participants. The characteristics of the participants with more teeth were: younger, not using a denture, with a higher education, higher income, good self-rated health, and no experience of falling, never smoker, walking longer, normal or overweight, and not depressed.

At the end of the follow-up, the prevalence of the participants in the alive and healthy state, alive with a disability, dead without a disability, and dead after being disabled were 91.2%, 2.5%, 4.6%, and 1.7% among men, respectively and 94.1%, 2.9%, 2.1%, and 0.8% among women, respectively (Appendix 2).

Table 2 presents the results of the illness-death model showing the hazard ratios (HRs) and 95% confidence intervals (CIs) for each transition. After adjusting for all covariates, among both men and women, having a higher number of teeth was significantly associated with lower risks of dying without being disabled (i.e., Transition

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1) and onset of disability (i.e., Transition 2). On the other hand, the number of remaining teeth was associated with an early death after being disabled (i.e., Transition 3) among both men and women although it was not statistically significant among men. These results were confirmed by the sensitivity analyses: the analysis with missing information as dummy categories and that without participants who had died or become disabled in the first 6 months showed similar results (results are available on request).

Appendixes 3 and 4 show the probability of the participants being in each state with a conditional age of 65–69, 75–79, and ≥85 years among men and women, respectively. Participants with fewer teeth were likely to move from the alive and healthy state (blue area) to dead (black area) or alive with a disability state (orange area) in the early time period since the baseline, especially among older people. In addition, these participants were likely to remain longer in the alive with a disability state (orange area).

Figure 2 shows the estimated healthy life expectancy and life expectancy with disability with the conditional age of 65–69, 75–79, and ≥85 years. Among all of the estimated population, participants with fewer teeth had shorter healthy life expectancy (blue) and life expectancy (blue + orange) and longer life expectancy with disability (orange) (Figure 2). Details of the estimated values of healthy life expectancy and life

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expectancy are shown in Table 3. Life expectancy with disability was decreased, and the proportion of healthy life expectancy in total life expectancy increased with an increasing number of teeth (Table 3).

Discussion

This large-scale prospective cohort study showed that having more remaining teeth was associated with the compression of morbidity; community-dwelling older people with more teeth had lower mortality, lower incidence of functional disability, and higher mortality after onset of disability. In addition, they had longer healthy life expectancy and life expectancy and shorter life expectancy with disability.

Strengths and limitations of this study

This is the first study simultaneously evaluating the independent association between number of teeth and mortality, functional disability, and duration of life with disability. We estimated the absolute days of healthy life expectancy, life expectancy, and life expectancy with disability with a follow-up period of 1,374 days. Healthy life expectancy is a useful summary measure reflecting both the length and quality of life (Stiefel et al. 2010; Kassebaum et al. 2016). The estimated effect size between the

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remaining teeth and healthy life expectancy and life expectancy would be clinically significant because it is comparable with the estimated effect size of statin use on extending life expectancy, which is 58 days (Pandya et al. 2015). Furthermore, we used the relative and absolute scales to evaluate the association between the number of teeth and disability and mortality. Most previous studies have only used the relative scale (Wu et al. 2016; Polzer et al. 2012). The absolute scale is easy to interpret, which can be useful for policymakers and the general public (Gigerenzer 2009). Additionally, we used a large-scale prospective cohort data including multiple cities from all over Japan. We followed-up for 226,134.6 person-years, which would be comparable with or larger than that of other studies; for example, the median of the number of participants and follow-up duration of each study reviewed in a large systematic review were 8,876 and 12 years, respectively (Aune et al. 2016).

This study has important limitations. First, the follow-up period was relatively short at 1,374 days. However, we believe that reverse causation does not seriously violate this study's results because the sensitivity analysis without participants who had died or become disabled in the first 6 months showed similar results. Such a limitation might cause small absolute differences estimated in this study. Larger absolute differences would be obtained if the follow-up period was longer because more events

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would occur. In fact, the result of the present study showed larger absolute differences among older people, whose mortality rate was high. Second, cause of death was unknown because we do not have information on it. Our outcome, all-cause mortality, could include death not related to dental status. Future studies should add information on cause-specific mortality. Third, the number of remaining teeth was self-reported. However, the question used to determine the number of remaining teeth was validated using the clinical examination of the subsample of this cohort (Yamamoto et al. 2012). Fourth, generalizability of the present results to the whole Japanese population was limited because the 24 municipalities in this study were not randomly selected and the sampling method of residents differed according to the population of the municipality. However, demographic characteristics of study participants were similar to the general Japanese population. Fifth, generalizability of this study's results for other countries is unknown because all municipalities included in this study were in Japan.

Comparison with other studies

The association between number of remaining teeth and all-cause/cause-specific mortality has been reported in previous studies (Aida et al. 2011; Hu et al. 2015). A systematic review also suggested the relationship between tooth loss and

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all-cause/circulatory mortality (Polzer et al. 2012). The association between the number of teeth and functional decline has also been reported in previous cohort studies (Tsakos et al. 2015; Aida et al. 2012; Sato et al. 2016). It is suggested that having more teeth contributes to improving life expectancy and healthy life expectancy; however, no study has investigated the association between remaining teeth and life expectancy with disability. Thus, the present study fills this gap in the literature.

Possible mechanisms to explain study findings

Diet, nutrition, and systemic inflammation/infection are suggested as the underlying mechanisms of the relationship between remaining teeth and functional/cognitive disability and mortality (Ritchie et al. 2002; Kebschull et al. 2010). People with fewer remaining teeth have poorer nutritional status (Ritchie et al. 2002). Poor nutritional status is a risk factor of functional decline (Sanders et al. 2016) and death (Flegal et al. 2007). Systemic infection and inflammation due to periodontal pathogens contribute to atherosclerotic plaque development and raise the risk of cardiovascular diseases (Kebschull et al. 2010), which are major causes of functional disability in Japan (Ministry of Health Labour and Welfare 2013). A study using the biomarkers of inflammation supports this association (de Oliveira et al. 2010).

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Another possible mechanism is the social interaction pathway. Poor oral health affects the social aspects of quality of life, such as avoiding conversation, laughing, and/or eating with other people because of chewing difficulties and embarrassment (Kressin et al. 1996). In fact, poor oral condition among community-dwelling older adults is associated with lower ability to get out of one's neighborhood independently (Makhija et al. 2011). Fewer remaining teeth predicts the future onset of being homebound among older people in Japan (Koyama et al. 2016). Therefore, this could reduce future social interactions, which is a large risk factor for mortality (Holt-lunstad et al. 2010).

Shorter life expectancy with disability among people with teeth can be explained by the delayed onset of disability, rather than having remaining teeth was associated with premature death among those with disability because both life expectancy and healthy life expectancy were longer among those with larger numbers of teeth (Figure 2). This is supported by a previous study showing that having ≥20 remaining teeth was associated with lower risks of mortality among older institutionalized people (Shimazaki et al. 2001). The lower point estimates among men than women would depend on the fact that the difference between life expectancy and healthy life expectancy is generally longer in women than in men; the differences are

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9.1 years and 12.3 years in men and women in Japan, respectively (Ministry of Health Labour and Welfare 2012). The association between higher numbers of teeth and shorter life expectancy with disability was not statistically significant among men. Shorter life expectancy among men compared to women (Ministry of Health Labour and Welfare 2012), and other limitations of the study, may have adversely affected our ability to detect the relationship between life expectancy with disability and number of teeth among men.

Future research

Studies with longer follow-up periods are needed because the duration of the follow-up might influence the estimated absolute differences in life expectancy, healthy life expectancy, and life expectancy with disability according to the number of teeth. We could only estimate the days of life expectancy, healthy life expectancy, and life expectancy with disability during the 3-year follow-up. It is expected that larger differences in life expectancy, healthy life expectancy, and life expectancy with disability by the number of teeth would be obtained with longer followed-up data. In addition, studies investigating the precise mechanisms of such associations are needed.

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Policy implications

This study suggested that maintaining good dental status in older age could contribute to compression of morbidity. The extent of the contribution would be clinically significant: life expectancy with disability of the participants aged ≥85 years was compressed by 35–55 days within the follow-up period of 1,374 days, as well as extending their healthy life expectancy and life expectancy. The results of this study highlight the public health importance of providing appropriate high quality treatment and prevention services to older people to enable them to maintain a healthy dentition, and in particular the retention of functioning teeth in later life.

Conclusions

Having more remaining teeth was independently associated with lower risks of mortality and functional disability, and shorter life expectancy with disability in a population of older people in Japan.

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Table 1. Characteristics of the participants

	Men (n = 36,074)					Women (n = 41,323)				
	No. of teeth					No. of teeth				
	≥20	10-19	1-9	0	Missing	≥20	10-19	1-9	0	Missing
n	12,367	9,233	8,662	4,951	861	13,362	10,266	10,544	5,723	1,428
	%	%	%	%	%	%	%	%	%	%
Age (years)										
65-69	43.0	37.3	25.3	15.9	24.3	42.4	36.5	23.2	9.6	19.7
70-74	31.7	30.0	27.6	21.7	27.4	31.4	30.1	28.0	19.9	25.9
75-79	17.2	20.8	24.9	26.5	24.5	17.0	20.3	26.5	27.2	27.8
80-84	6.6	9.2	15.6	22.7	16.4	7.1	9.9	15.4	25.1	18.3
≥85	1.5	2.7	6.6	13.2	7.4	2.0	3.3	6.9	18.2	8.3
Denture use										
Not using a denture	66.5	33.7	24.3	30.4	8.9	68.2	34.6	23.1	26.3	12.3
Using a denture	27.3	61.0	69.8	58.6	20.1	21.0	55.4	67.5	58.3	30.4
Missing	6.2	5.3	5.9	10.9	71.0	10.8	10.0	9.4	15.4	57.3
Education (years)										
<6	0.5	1.1	2.0	3.0	3.1	1.1	1.9	3.6	8.4	4.6
6-9	34.0	41.5	48.0	52.9	35.5	41.5	47.2	52.3	56.2	41.2
10-12	34.9	32.7	27.9	23.8	27.3	38.0	34.0	29.1	21.3	23.8
≥13	26.9	20.2	16.8	13.0	20.9	15.3	12.1	9.1	5.6	12.0
Missing	3.6	4.4	5.2	7.4	13.1	4.0	4.8	6.0	8.5	18.3
Income										
Low	23.4	29.6	33.5	36.7	27.5	25.5	29.5	33.3	34.6	25.1
Middle	32.7	31.0	27.5	22.9	23.2	28.2	25.3	20.6	16.1	16.2
High	33.5	25.9	22.2	19.5	22.1	27.2	22.2	18.2	14.6	13.7
Missing	10.4	13.5	16.8	20.9	27.2	19.2	22.9	27.9	34.7	45.0
Comorbidity										
With comorbidity	51.7	53.2	52.8	53.7	51.9	46.4	49.1	52.6	55.5	49.9
No comorbidity	44.9	43.2	42.5	41.5	39.8	48.7	45.5	41.2	38.6	38.9
Missing	3.3	3.6	4.6	4.8	8.2	4.9	5.4	6.2	5.9	11.3
SRH										
Very poor	2.1	2.5	3.9	4.6	3.3	1.6	1.9	2.6	3.2	2.7
Poor	12.2	16.3	20.8	22.4	19.3	12.5	14.7	18.9	21.5	19.3
Good	68.9	68.8	64.9	61.5	64.7	71.2	71.7	67.8	65.0	64.1
Very good	16.1	11.6	9.5	10.1	11.5	13.4	10.5	9.1	8.9	10.9
Missing	0.7	0.8	1.0	1.3	1.3	1.3	1.2	1.6	1.5	3.0
Falling experience										
Yes	19.5	25.3	29.1	32.7	26.0	27.2	31.4	36.0	39.5	30.8
No	76.4	70.1	65.8	61.7	62.3	69.0	64.6	59.5	54.6	56.1

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Missing	4.1	4.6	5.1	5.6	11.7	3.8	4.0	4.6	5.9	13.1
Smoking status										
Current smoker	13.1	19.3	23.3	23.7	9.1	1.9	3.2	3.7	3.9	1.6
Former smoker	51.5	50.5	49.1	49.8	20.3	4.0	5.1	4.7	4.4	3.3
Never smoker	29.6	23.8	20.6	17.8	12.0	84.9	81.3	77.8	75.3	47.7
Missing	5.8	6.4	7.0	8.7	58.7	9.2	10.4	13.8	16.4	47.4
Alcohol drinking										
Daily drinker	34.3	32.0	29.2	24.8	11.0	4.2	4.0	3.4	2.4	1.5
Occasional drinker	27.1	23.9	20.7	16.3	9.2	12.8	12.1	9.3	6.3	5.0
Former drinker	4.7	6.0	7.3	7.0	2.4	1.0	1.0	1.0	0.9	0.5
Never drinker	29.2	33.2	37.6	45.0	21.1	77.3	78.1	80.4	83.6	54.4
Missing	4.7	4.9	5.3	6.9	56.2	4.7	4.8	5.9	6.8	38.5
Walking time (hours per day)										
<0.5	24.6	29.3	34.0	36.8	30.1	28.3	31.2	35.5	38.9	30.5
0.5-0.9	34.7	32.8	31.0	27.9	30.4	34.4	33.6	30.9	26.9	27.0
1.0-1.4	17.6	16.4	14.4	13.5	12.7	15.2	13.3	12.8	11.9	12.3
≥1.5	18.5	15.9	14.8	14.7	12.8	15.9	14.9	12.6	11.8	11.3
Missing	4.7	5.6	5.8	7.1	14.1	6.2	7.0	8.2	10.4	18.8
BMI										
Underweight	3.6	4.3	6.8	7.8	5.8	7.7	7.3	8.1	9.2	10.3
Normal weight	64.4	61.2	60.8	58.6	54.9	64.9	61.3	57.2	52.4	51.8
Overweight	26.3	27.0	23.4	21.9	22.8	19.8	21.9	22.0	20.9	16.7
Obesity	1.6	2.0	1.8	1.9	2.0	2.7	2.9	3.6	3.4	2.2
Missing	4.2	5.6	7.2	9.8	14.5	4.9	6.6	9.1	14.0	19.0
GDS										
<5	69.6	62.0	55.7	54.0	54.6	62.3	58.8	53.7	49.8	44.5
5-9	14.4	18.2	21.2	20.0	16.8	14.6	16.3	18.0	19.2	13.8
≥10	3.7	5.8	8.0	7.9	5.9	3.9	4.9	6.6	7.1	4.5
Missing	12.3	14.1	15.2	18.1	22.6	19.2	20.0	21.7	23.9	37.3

All P-values were <0.001.

Abbreviations: SRH: self-rated health, BMI: Body-Mass Index, GDS: Geriatric Depression Scale

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Table 2. Results of the illness-death model with multiple imputations: association between the number of remaining teeth and each transition

	Men (n = 36,074)						Women (n = 41,323)					
	Model 1			Model 2			Model 1			Model 2		
	HR	95% CI		HR	95% CI		HR	95% CI		HR	95% CI	
No. of teeth (ref. 0 teeth)												
Transition 1: healthy to dead												
≥20 teeth	0.48	0.41, 0.55	*	0.58	0.50, 0.68	*	0.62	0.51, 0.76	*	0.70	0.57, 0.85	*
10-19 teeth	0.63	0.55, 0.73	*	0.71	0.62, 0.82	*	0.76	0.63, 0.92	*	0.81	0.67, 0.98	*
1-9 teeth	0.76	0.67, 0.87	*	0.80	0.70, 0.91	*	0.76	0.64, 0.91	*	0.77	0.64, 0.92	*
Transition 2: healthy to disabled												
≥20 teeth	0.42	0.36, 0.49	*	0.52	0.44, 0.61	*	0.52	0.44, 0.61	*	0.58	0.49, 0.68	*
10-19 teeth	0.58	0.50, 0.67	*	0.65	0.56, 0.76	*	0.70	0.60, 0.81	*	0.75	0.65, 0.86	*
1-9 teeth	0.74	0.65, 0.84	*	0.77	0.67, 0.88	*	0.72	0.63, 0.82	*	0.73	0.64, 0.83	*
Transition 3: disabled to dead												
≥20 teeth	1.00	0.79, 1.27		1.26	0.99, 1.60		2.11	1.52, 2.94	*	2.42	1.72, 3.38	*
10-19 teeth	1.03	0.81, 1.29		1.20	0.94, 1.53		2.32	1.69, 3.19	*	2.42	1.76, 3.34	*
1-9 teeth	1.05	0.86, 1.28		1.14	0.93, 1.40		1.41	1.05, 1.90	*	1.41	1.04, 1.90	*

* P<0.05

Abbreviations: HR: hazard ratio, CI: confidence interval

Transition 1: transition from the alive and healthy state to the dead without a disability state

Transition 2: transition from the alive and healthy state to the alive with a disability state

Transition 3: transition from the alive with a disability state to the dead after being disabled state

Model 1: Age was adjusted.

Model 2: Model 1 + denture use, education, income, comorbidity, self-rated health, falling experience, smoking status, alcohol drinking, walking time, body mass index, and Geriatric Depression Scale score were adjusted.

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Table 3. Expected healthy life expectancy and life expectancy with disability with follow-up of 3 years

	Men				Women			
	HALE (days)	LE (days)	LED (days)	HALE/LE (%)	HALE (days)	LE (days)	LED (days)	HALE/LE (%)
Aged 65–69 years								
Number of teeth								
≥20	1343.5	1355.9	12.4	99.1	1358.8	1367.7	8.9	99.3
10-19	1336.3	1352.0	15.7	98.8	1355.2	1366.6	11.4	99.2
1-9	1330.9	1349.5	18.6	98.6	1355.8	1367.2	11.4	99.2
0	1319.5	1343.7	24.2	98.2	1349.6	1365.2	15.7	98.9
Aged 75–79 years								
Number of teeth								
≥20	1306.9	1330.6	23.7	98.2	1334.2	1356.1	21.9	98.4
10-19	1291.5	1321.4	29.9	97.7	1324.9	1352.9	28.0	97.9
1-9	1279.9	1315.3	35.4	97.3	1326.5	1355.1	28.6	97.9
0	1256.1	1302.6	46.5	96.4	1310.6	1350.2	39.5	97.1
Aged ≥85 years								
Number of teeth								
≥20	1243.8	1280.1	36.3	97.2	1245.8	1302.1	56.3	95.7
10-19	1215.3	1261.0	45.7	96.4	1218.0	1288.9	70.9	94.5
1-9	1194.3	1248.4	54.1	95.7	1222.5	1301.9	79.3	93.9
0	1151.7	1223.1	71.4	94.2	1176.3	1287.5	111.2	91.4

Abbreviations: HALE: healthy life expectancy, LE: life expectancy, LED: life expectancy with disability

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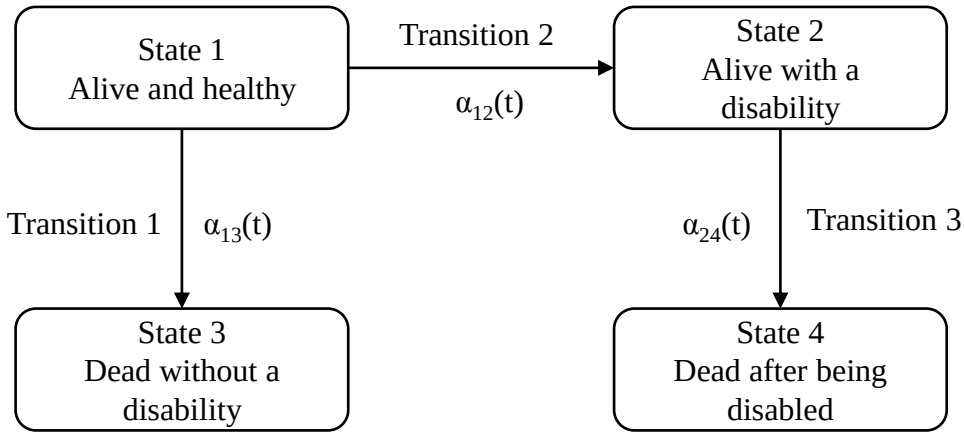


Figure 1. Illness-death model

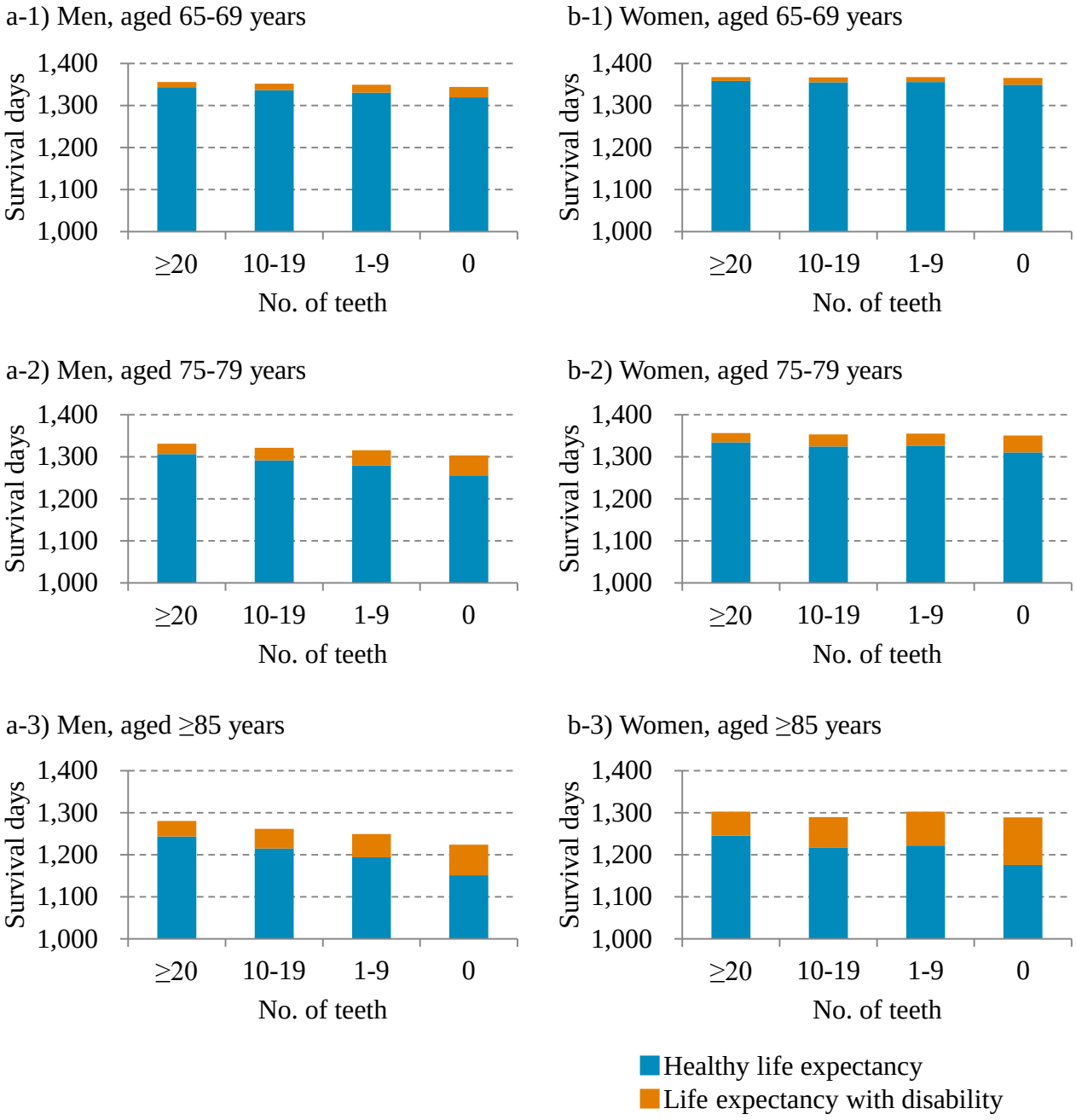


Figure 2. Estimated healthy life expectancy and life expectancy with disability; each covariate except age was conditioned at as follows: using a denture, education of 6-9 years, low income, with comorbidity, good self-rated health, no falling experience, not a smoker, not a drinker, walking <0.5 hours, normal weight, and no depression.

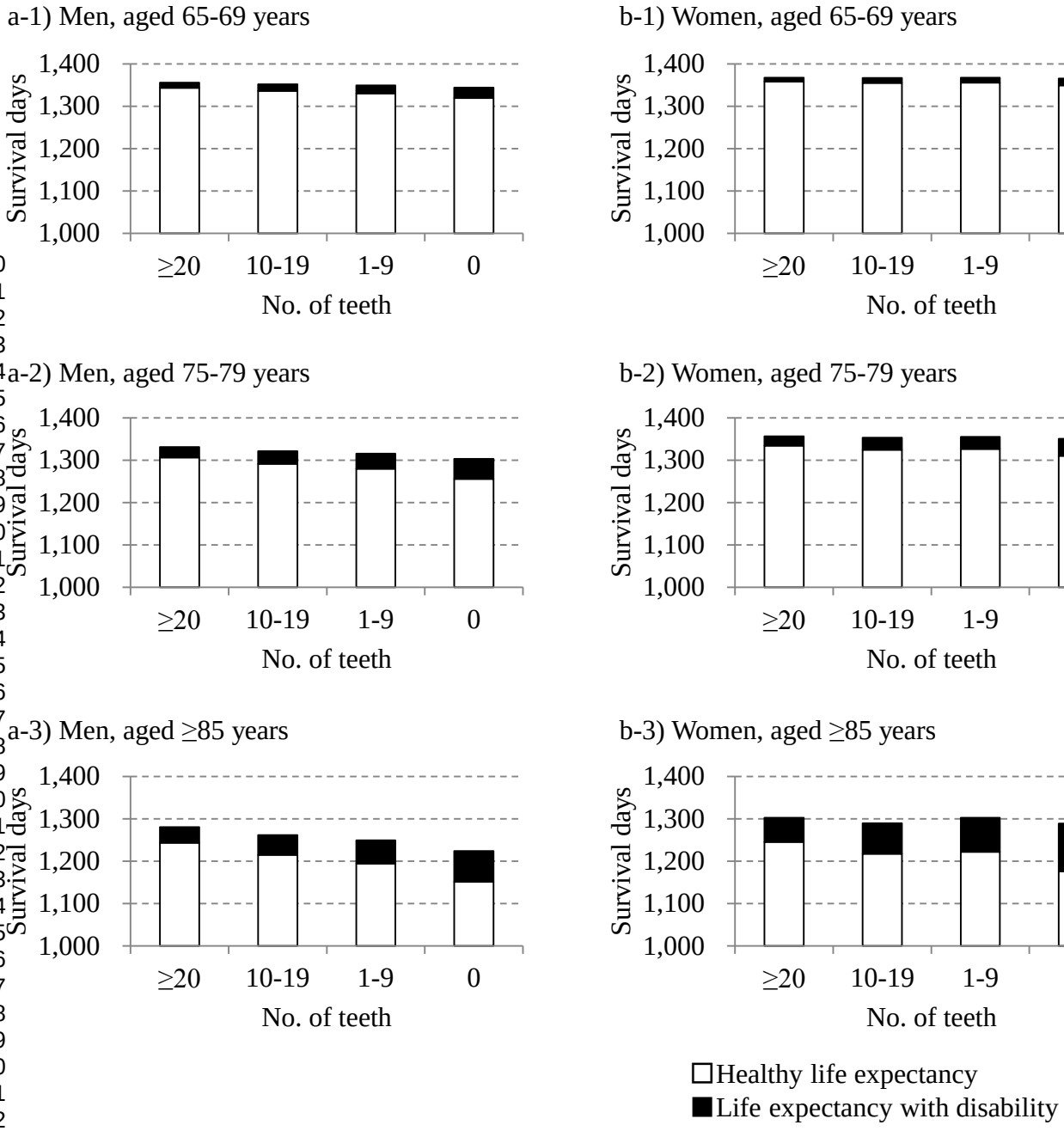
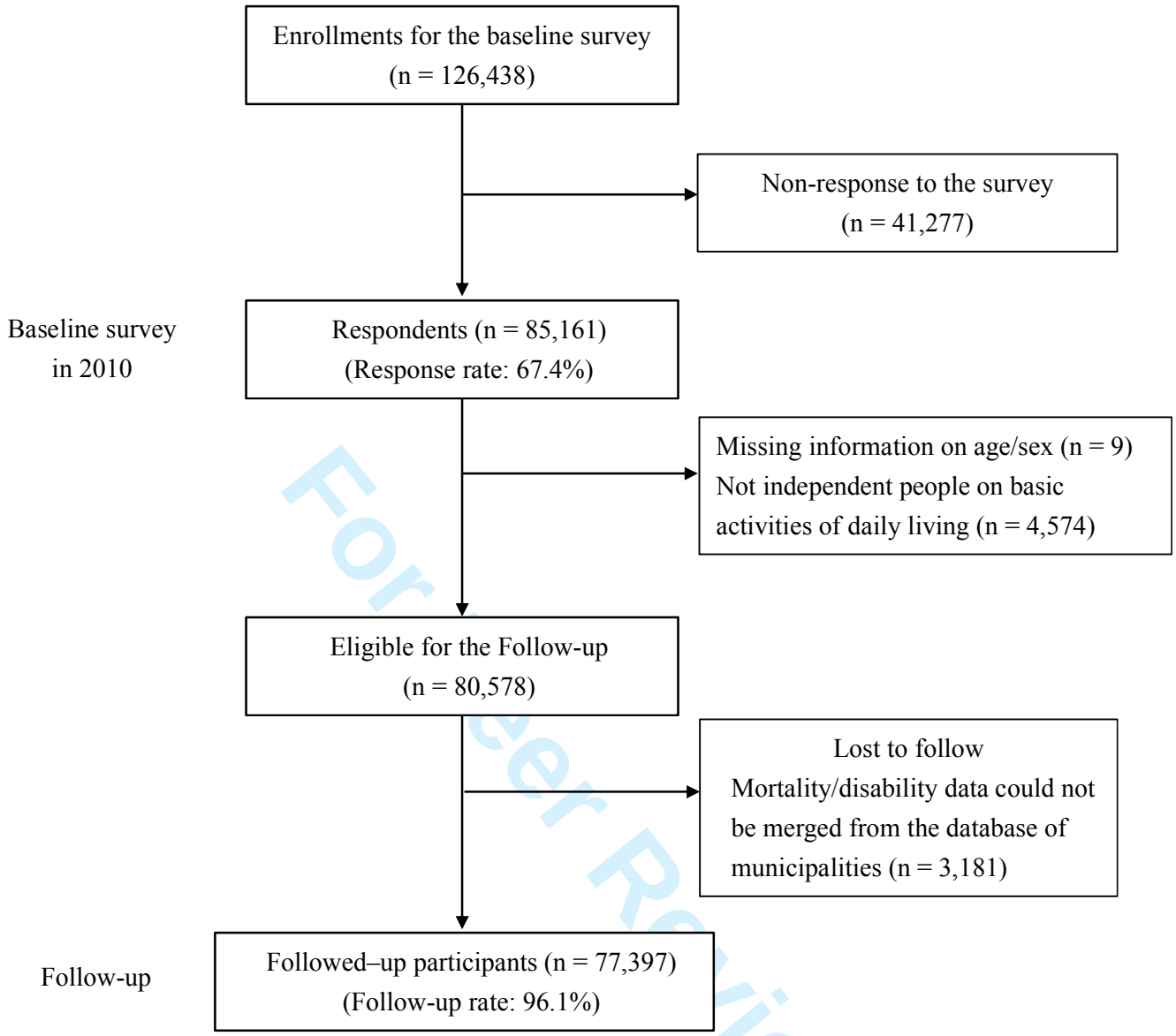


Figure 2. Estimated healthy life expectancy and life expectancy with disability; each covariate except age was conditioned at as follows: using a denture, education of 6-9 years, low income, with comorbidity, good self-rated health, no falling experience, not a smoker, not a drinker, walking <0.5 hours, normal weight, and no depression.



Appendix 1. Flowchart of the study participants; the basic activities of daily living was measured using a single question: *"Can you walk, take a bath or use a toilet independently?"* with the choice of *"I can do them without assistance," "I can do them with partial assistance by hand, etc.,"* and *"I need full assistance in doing them."* People who answered *"I can do them without assistance"* were followed.

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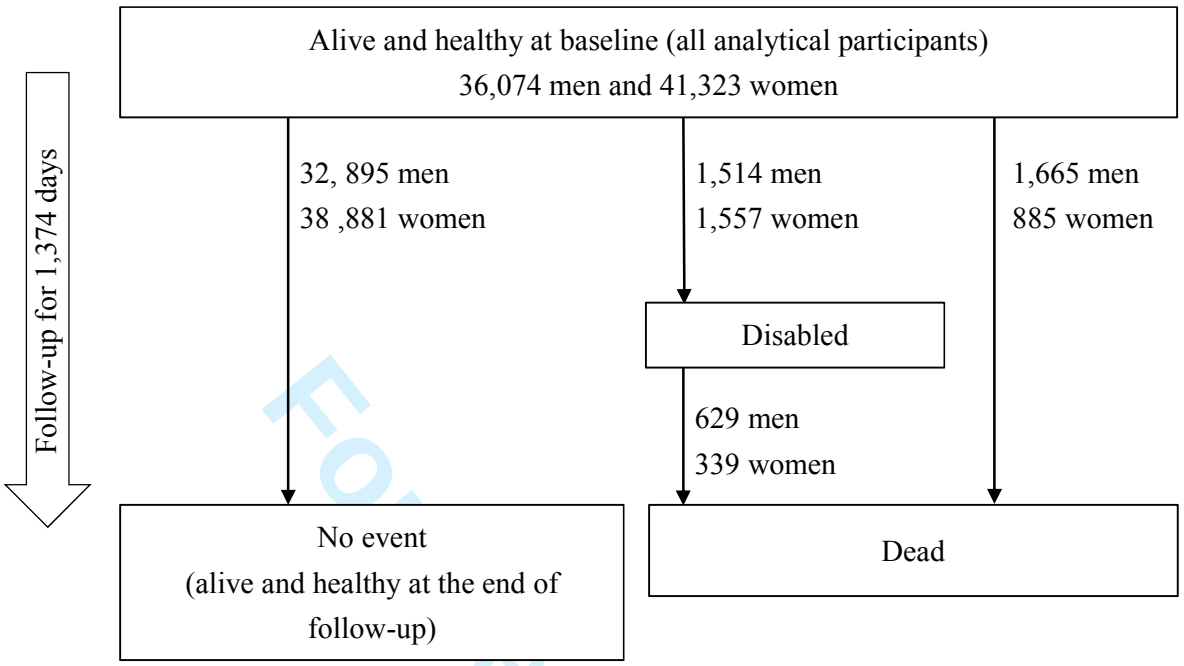

Appendix 2. Health status trajectory of the analytical participants

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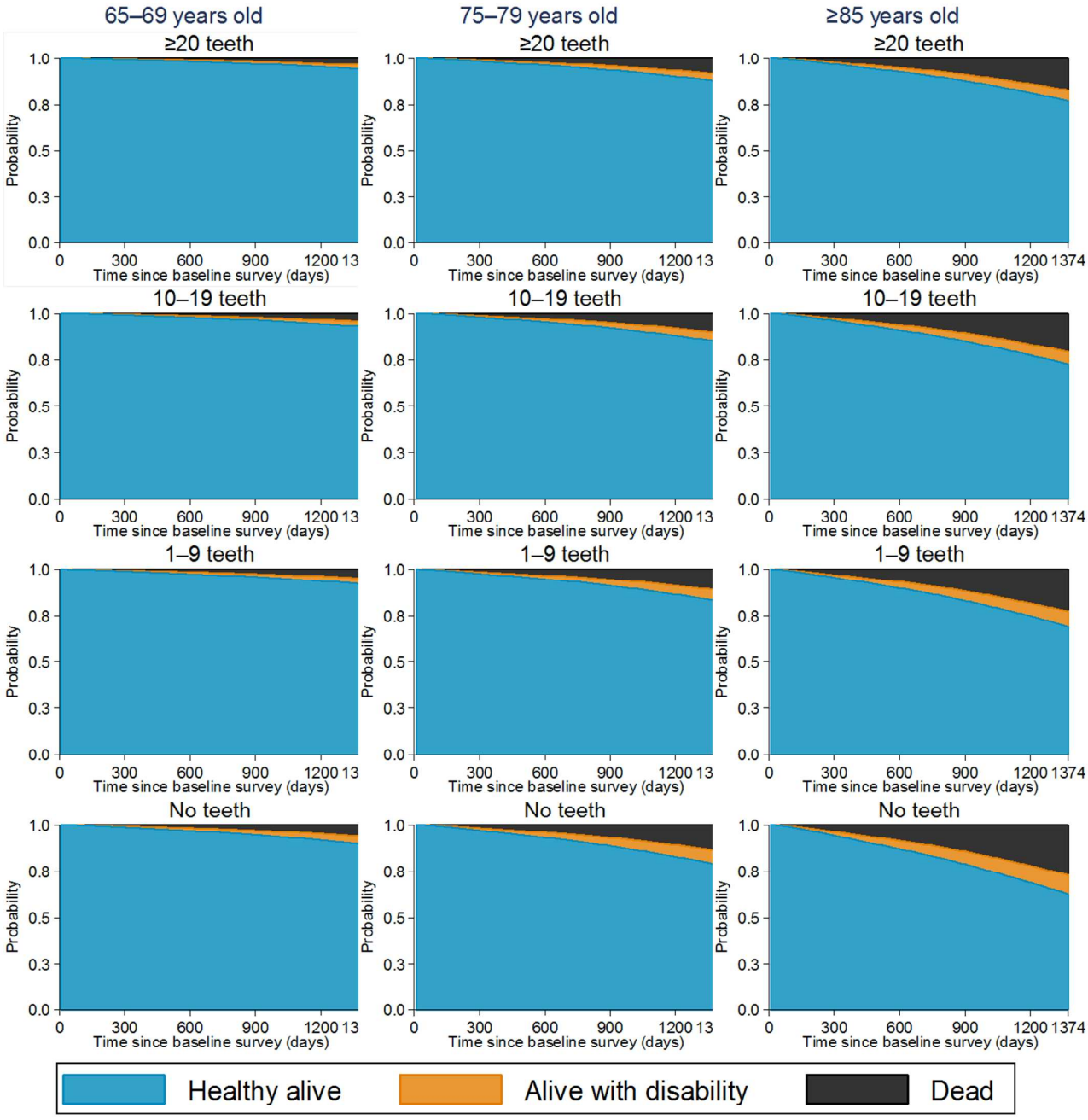
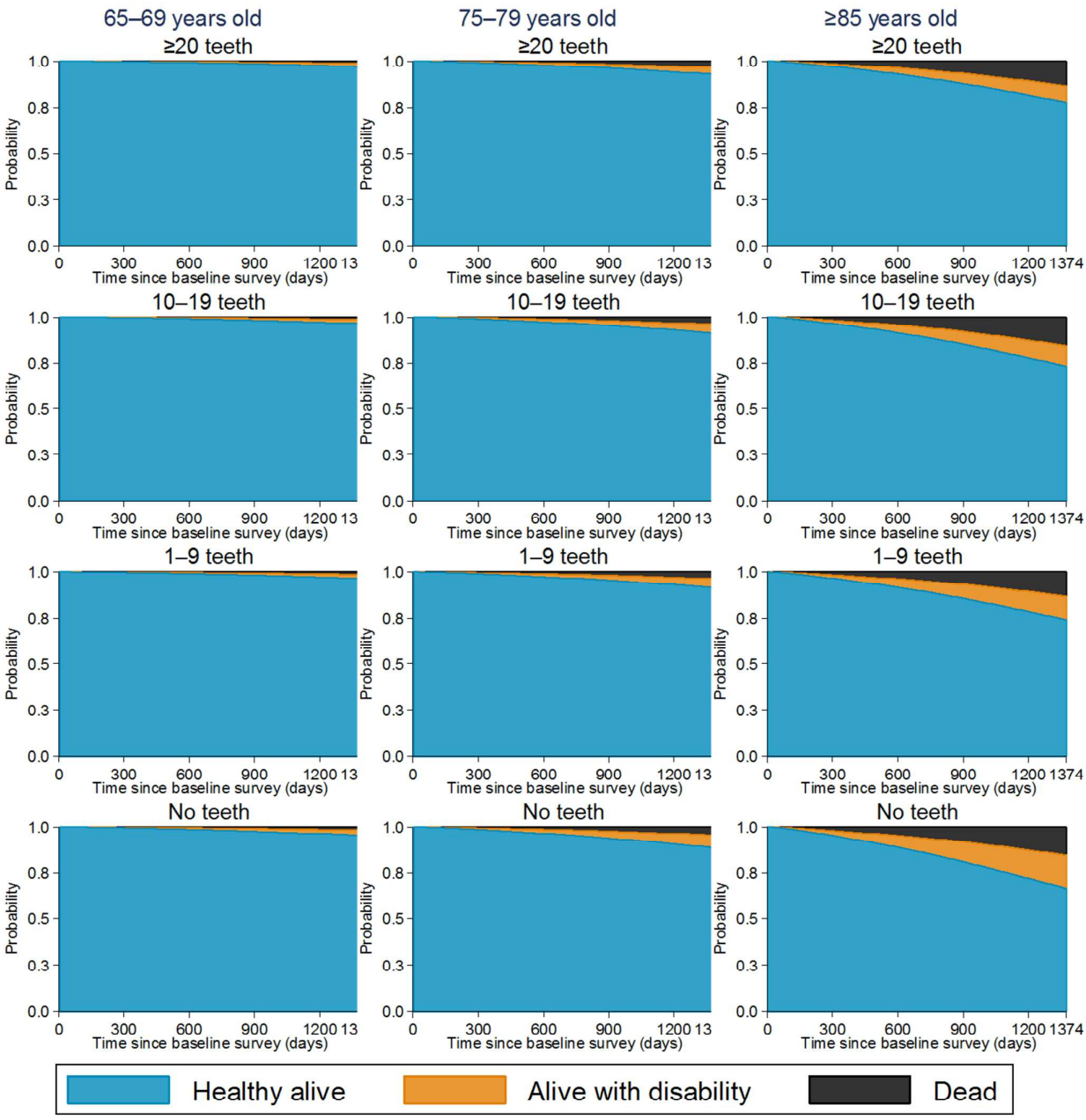


Appendix 3. Probability for stacking in each state among MEN (alive without a disability, alive with a disability, or dead); age, denture use, education, income, comorbidity, self-rated health, falling experience, smoking status, alcohol drinking, walking time, body mass index, and depression were adjusted.



Appendix 4. Probability for stacking in each state among WOMEN (alive without a disability, alive with a disability, or dead); age, denture use, education, income, comorbidity, self-rated health, falling experience, smoking status, alcohol drinking, walking time, body mass index, and depression were adjusted.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No.	Recommendation	Page No.	Relevant text from manuscript
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1	Title
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2	Abstract
Introduction				
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5	Introduction
Objectives	3	State specific objectives, including any prespecified hypotheses	5	Therefore, we aimed to simultaneously investigate the association between the number of teeth and onset of functional disability, mortality without functional disability, and mortality after functional disability among Japanese older people.
Methods				
Study design	4	Present key elements of study design early in the paper	6	We conducted a prospective cohort study using the data of Japan Gerontological Evaluation Study (JAGES) project, a large-scale prospective panel study targeting community-dwelling older Japanese people.
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6	Study design and setting
Participants	6	(a) Cohort study—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up Case-control study—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls Cross-sectional study—Give the eligibility criteria, and the sources and methods of selection of participants	6	Study design and setting
		(b) Cohort study—For matched studies, give matching criteria and number of exposed and unexposed Case-control study—For matched studies, give matching criteria and the number of controls per case	NA	NA

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Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-9	Outcomes; Predictor variable; Covariates
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7-9	Outcomes; Predictor variable; Covariates
Bias	9	Describe any efforts to address potential sources of bias	10	Model construction
Study size	10	Explain how the study size was arrived at	6	Study design and setting

Continued on next page

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Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-9	Outcomes; Predictor variable; Covariates
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	10	Statistical analyses
		(b) Describe any methods used to examine subgroups and interactions	10	Statistical analyses
		(c) Explain how missing data were addressed	10	Model construction
		(d) Cohort study—If applicable, explain how loss to follow-up was addressed Case-control study—If applicable, explain how matching of cases and controls was addressed Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	NA	NA
		(e) Describe any sensitivity analyses	10	Model construction
Results				
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	6-7	Figure 1
		(b) Give reasons for non-participation at each stage	6-7	Figure 1
		(c) Consider use of a flow diagram	6-7	Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11	Table 1
		(b) Indicate number of participants with missing data for each variable of interest	11	Table 1
		(c) Cohort study—Summarise follow-up time (eg, average and total amount)	6	Study design and setting
Outcome data	15*	Cohort study—Report numbers of outcome events or summary measures over time	11	Appendix 1
		Case-control study—Report numbers in each exposure category, or summary measures of exposure		
		Cross-sectional study—Report numbers of outcome events or summary measures		
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	12	Table 2
		(b) Report category boundaries when continuous variables were categorized	12	Table 2
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	13	Figure 3

Continued on next page

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Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	13	Appendixes 2 and 3
Discussion				
Key results	18	Summarise key results with reference to study objectives	13-14	This large-scale prospective cohort study showed that having more remaining teeth was associated with the compression of morbidity; community-dwelling older people with more teeth had lower mortality, lower incidence of functional disability, and higher mortality after onset of disability. In addition, they had longer HALE and LE and shorter LED.
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14	Strengths and limitations of this study
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	16	Discussion
Generalisability	21	Discuss the generalisability (external validity) of the study results	15	Third, generalizability of this study's results for other countries is unknown because all municipalities included in this study were in Japan.
Other information				
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	19-20	Acknowledgements

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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