Effect of oral health on functional disability and mortality in older adults in Japan: a cohort study

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Summary

Background Oral health has previously shown associations with functional disability and mortality. We aimed to explore the associations of various aspects of oral health status with functional disability and mortality using survival analysis, as well as the relative magnitudes of the impact of these aspects on outcomes.

Methods We obtained data for individuals aged 75 years and older in Shimane, Japan, who had at least one oral health check-up between April 1, 2016, and March 31, 2022 under Japan's long-life medical care system insurance system. Those with missing data or with functional disability at baseline were excluded. 13 aspects of oral health status were assessed by dentists or dental hygienists as part of the check-up (using protocols provided by the Japan Dental Association and the Japanese Ministry of Health, Labour and Welfare): number of remaining teeth, subjective masticatory performance, objective masticatory performance, periodontal tissue status, functional dysphagia, tongue mobility, articulation, oral hygiene, number of decayed teeth, inadaptation of dentures of the upper jaw and lower jaw (considered separately), oral mucosal disease, and dry mouth. Multivariate Cox proportional hazards models were used to analyse the associations between each aspect of oral health and functional disability and mortality, with fully adjusted models adjusting for sex, age, BMI, medical history, or a propensity score derived from these covariates. Population-attributable fractions (PAFs) were calculated to assess the differential impacts of these oral health status aspects on outcome occurrence.

Findings Of the 24 619 individuals who had an oral health check-up during the study period, 21 881 individuals were included in the analysis of functional disability (9175 [41·93%] men, 12 706 [58·07%] women, mean age 78·31 years [SD 2·88], mean follow-up 41·43 months [20·80]), and 22 747 individuals in the analysis of mortality (9722 [42·74%] men, 13 025 [57·26%] women, mean age 78·34 years [2·89], mean follow-up 42·63 months [20·58]). All 13 aspects of oral health status showed significant associations with the occurrence of mortality, while functional disability was associated with 11 aspects (excluding oral mucosal disease and dry mouth) in the fully adjusted model. Based on PAFs, of all oral health aspects assessed, objective masticatory performance had the greatest impact on both functional disability (PAF 23·10% [95% CI 20·42–25·69] for the lowest and 10·62% [8·18–12·99] for the second-lowest quartile of performance) and mortality (16·47% [13·44–19·40] and 8·90% [5·87–11·82]).

Interpretation Various aspects of oral health are associated with mortality and functional disability. Maintaining good oral health in older adults might help to reduce these outcomes.

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For the Japanese translation of the abstract see Online for appendix 1

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See Online for appendix 1

Introduction

Despite the widespread prevalence of oral diseases, which affect more than 3·5 billion people worldwide,[1] oral health has been neglected in clinical practice.[2] Therefore, WHO has set a target of achieving universal health coverage for oral health across its member states by 2030.[3] Japanese health care is bolstered by the country's universal health insurance system.[4] The 8020 Campaign, championed by the Japan Dental Association and the Japanese Ministry of Health, Labor and Welfare, aims to encourage individuals to maintain 20 or more teeth until at least 80 years of age.[5] Consequently, the oral health status of older Japanese adults has substantially improved,[6] albeit with regional disparities.[7] Oral care promotion through universal health coverage is challenging due to inequalities in oral health, both in Japan and worldwide.[8]

In the context of global ageing, ensuring oral health in old age is crucial for maintaining health and longevity.[9] In Japan, a country with a rapidly ageing population, poor oral health was reported to increase health-care costs and the risks of aspiration pneumonia and Alzheimer's disease.[10] Moreover, oral health problems are associated with poorer physical function and a greater decline in physical function in older adults.[11] The concept of oral frailty—recognised as an aggregated representation of oral health issues—is associated with severe physical conditions that increase

Research in context

Evidence before this study

A systematic review conducted by Dibello and colleagues in 2023 elucidated the relationship between oral frailty indicators in older adults and major adverse health outcomes. Using the search strategy from this systematic review, including the terms "(oral health* OR oral environment* OR oral care*) AND (disabilities* OR mortality* OR neurodegenerat* or survival*)", restricted to the English language, we searched titles and abstracts via PubMed from the time of the systematic review's publication until March 8, 2024. We specifically examined studies that evaluated the association between various aspects of oral health status and the occurrence of functional disability and mortality, and the population-attributable fraction (PAF). Among the studies included in our additional search results, we found one that simultaneously evaluated the effect of various aspects of oral health status on functional disability and mortality. However, the study used a subjective assessment of oral health status. Notably, one study examined the differential influence of various aspects of oral health status on mortality using the PAF. Dibello and colleagues highlighted that the evidence regarding oral health status is moderate for some aspects (eg, number of teeth, self-rated oral health, periodontal disease, masticatory function, and occlusal force) and low to very low for other aspects (eg, oral diadochokinesis, tongue pressure, dry mouth, difficulties in swallowing or chewing, and tooth or mouth pain), emphasising the need for high-quality studies.

Added value of this study

This study examined whether various subjective and objective aspects of oral health status affect functional disability and mortality. We compared the differential impacts of each aspect of oral health status on outcome occurrence using the PAF. Our results suggest that older adults with poor oral health status across most aspects assessed during check-ups are at an increased risk of functional disability and mortality. Objective masticatory performance was found to have the greatest impact on outcome occurrence.

Implications of all the available evidence

Our findings underscore the importance of early assessment of the oral health of older adults and timely interventions to prevent functional disability and mortality. Based on the substantial PAF of objective masticatory performance, it is essential not to overlook the functional aspects related to chewing. However, considering that various oral health-related aspects contribute to these adverse health outcomes, it is important to address each individual aspect of oral health status while also considering their additive effects.

mortality.[12] Various aspects of oral health status, which deteriorate interdependently, make multicompositional concepts such as oral frailty crucial for adverse health-related outcomes. A 2021 systematic review identified 12 indicators of poor oral health status related to frailty across four categories that contribute to a decline in cognitive and motor function, including number of teeth and periodontal disease.[13] A systematic review by Dibello and colleagues reported associations between various aspects of poor oral health status and major adverse health-related outcomes, such as mortality and functional disability.[14] Accordingly, the relevance of some aspects of oral health status, such as the number of remaining teeth, self-rated oral health, periodontal disease, and oral motor skills, was supported by a moderate quality of evidence according to the GRADE system, whereas other aspects (such as difficulties in chewing and dry mouth) were supported by low or very low quality of evidence. The limitations of these studies included a small sample, lack of standardised measurement methods, and reliance on subjective evaluation. Research simultaneously examining the subjective and objective aspects of oral health status in relation to both functional disability and mortality is scarce. In addition, only one study has estimated the population-attributable fraction (PAF) of oral health status with regard to mortality,[15] and there are few studies examining functional disability, necessitating further investigation.

See Online for appendix 2

Since 2016, the Japanese Ministry of Health, Labor and Welfare has promoted annual oral health check-ups for all individuals aged 75 years and older as part of a policy to increase healthy life expectancy. Using data from oral health check-ups, we aimed to explore the associations between each aspect of oral health status and functional disability and mortality.

Methods

Study design and participants

In Japan, all individuals aged 75 years and older are enrolled in the long-life medical care system insurance (LMCSI)[16] and can undergo a free annual oral health check-up. Data used in this study were obtained from the Shimane Extended Union of Medical Care System for Latter-Stage Elderly People; data related to oral health check-ups, care certification, and death were processed to ensure anonymity. For this cohort study, included participants were aged 75 years and older, residing in the Shimane prefecture, Japan, and had at least one oral health check-up between April 1, 2016, and March 31, 2022 (appendix 2 p 6). Individuals with functional disabilities (requiring care through the LMCSI because of physical or cognitive impairment) at baseline or with missing data on oral health status were excluded. For the functional disability analysis, participants were further excluded if they died before certification for care and support services was offered. No data on the race or ethnicity of the participants were available.

This study was approved by the Medical Research Ethics Committee of Shimane University Faculty of Medicine

(20220723-1). All data used in the study were anonymised; thus, this study was exempt from requiring informed consent per ethical guidelines for medical and health research involving human individuals in Japan.

Oral health status

For oral check-ups for older adults, manuals with relevant protocols are provided by the Japan Dental Association and the Japanese Ministry of Health, Labour and Welfare.[17,18] For this study, 13 aspects of oral health status were used. Oral health status was assessed by dentists or dental hygienists, and the number of remaining teeth was categorised into five groups (0, 1–9, 10–19, 20–27, or ≥28 teeth). Subgingival remnants that could be used for chewing were considered as remaining teeth. Numbers of decayed teeth were categorised as high (≥3 teeth) or low (<3 teeth). Fixed prosthetic teeth (bridges), removable prosthetic teeth (dentures), and missing teeth were assessed visually and on palpation. An objective masticatory performance test was done using Sugarless Fine gummy jellies (FINE, Tokyo, Japan), which participants chewed for 15 s without swallowing. The comminuted gummy jelly pieces were then collected from the mouth and counted. Objective masticatory performance was categorised into quartiles, with quartile 1 being the lowest performance (fewest pieces) and quartile 4 the highest performance (most pieces). Appendix 2 (p 3) provides details on objective masticatory performance validity. Subjective masticatory performance was assessed using a questionnaire on the participants' chewing capabilities (ability or inability to masticate).[18] For periodontal tissue status, dentists assessed tooth mobility (four levels: M0–M3) and overall condition after inspecting for redness, swelling, bleeding, suppuration, and tartar deposition.[17,18] The status of periodontal tissue was evaluated by considering all subgingival remnants in addition to remaining teeth. Periodontal tissue status was categorised into four grades (normal, mild status, moderate status, and severe status) based on teeth movability, regardless of tooth count, or no remaining teeth (edentulous). To assess functional dysphagia, the repetitive saliva swallowing test was used:[17–19] participants consumed water and consecutively performed three dry swallows, with the cumulative time taken categorised into good performance (<30 s; considered as absence of functional dysphagia) or poor performance (≥30 s; presence of functional dysphagia).[20] Tongue mobility was evaluated using an oral health check-up manual.[18] Tongue mobility was verified based on a participant's ability to protrude the tongue in various directions. The ability or inability to protrude beyond the lips was defined as good or poor tongue mobility, respectively. Articulation was assessed using a single-syllable sound articulation hearing test, in which participants read aloud the sentence "panda-no-takara-mono". If any of the monosyllables pa, ta, ka, and ra could not be clearly heard, the patient was recorded as having poor articulation (ie, presence of articulation disorder).[17,18,21] Oral hygiene status (categorised as good or poor) was assessed by examining for dental plaque adhesion (clean, moderate, abundant, or no remaining teeth), tongue coating (clean, moderate, or abundant), breath odour (not noticeable, mild, or strong), and denture cleaning and cleanliness (clean, moderate, dirty, or no dentures). If any of the categories were classified as abundant, strong, or dirty, the oral hygiene status was judged as poor.[17,18] The inadaptation of dentures of the upper or lower jaw was used as an indicator of occlusal status.[18] Dentists determined denture fit by visual and tactile examination. Individuals requiring adjustment, repair, or fabrication of dentures were determined to have denture maladaptation (recorded as a binary variable). Oral mucosal disease status was examined visually and on palpation by dentists to determine the need for follow-up (yes or no).[17,18] Dry mouth status (as a binary variable) was assessed via a questionnaire and was ascertained if participants responded affirmatively to two or more of the statements "mouth feels dry", "tongue hurts", and "taste has decreased". Additionally, if only one of the three questions was answered affirmatively, the individual was also considered to have oral dryness if they met any of the following criteria: reported taking five or more types of oral medication per day; had poor nutritional status; or oral dryness was suspected during the dentist's visual inspection and palpation.

Functional disability and mortality

We investigated the occurrence of mortality and functional disabilities in the cohort between April 1, 2016, and March 31, 2022. The verification of all-cause mortality involved cross-referencing local registries with the Japanese National Vital Statistics. Functional disability was defined as requiring care through the LMCSI owing to physical or cognitive impairment. This system offers formal care and support services to eligible older adults with disabilities. Care needs are stratified into seven levels (appendix 2 p 4).[22] For the purposes of this study, onset of functional disability was defined as the issuance of a level 4 or higher certification by the LMCSI service (based on a previous study),[23] with the date of the LMCSI application serving as the incident date. Individuals with level 4 care needs struggle to lead independent lives because of physical and cognitive functional decline, and require more than 50 min per day of care to complete basic activities of daily living. Follow-up time (in person-months) was measured from the date of oral health check-ups to the date of functional disability onset or death, or until censoring on March 31, 2022.

Covariates

Sex (male or female), age (years), height, and weight were assessed during an oral health check-up. BMI was categorised as less than 18·5 to <25·0 kg/m^2 and ≥25·0 kg/m^2. For medical history, physician diagnoses of Alzheimer's disease, Parkinson's disease, fracture, osteoporosis, arthropathy, cerebrovascular disease, infectious pneumonia, aspiration pneumonia, depressive disorder, hypertension, or periodontal disease were extracted based on data from medical claims under the health insurance system.

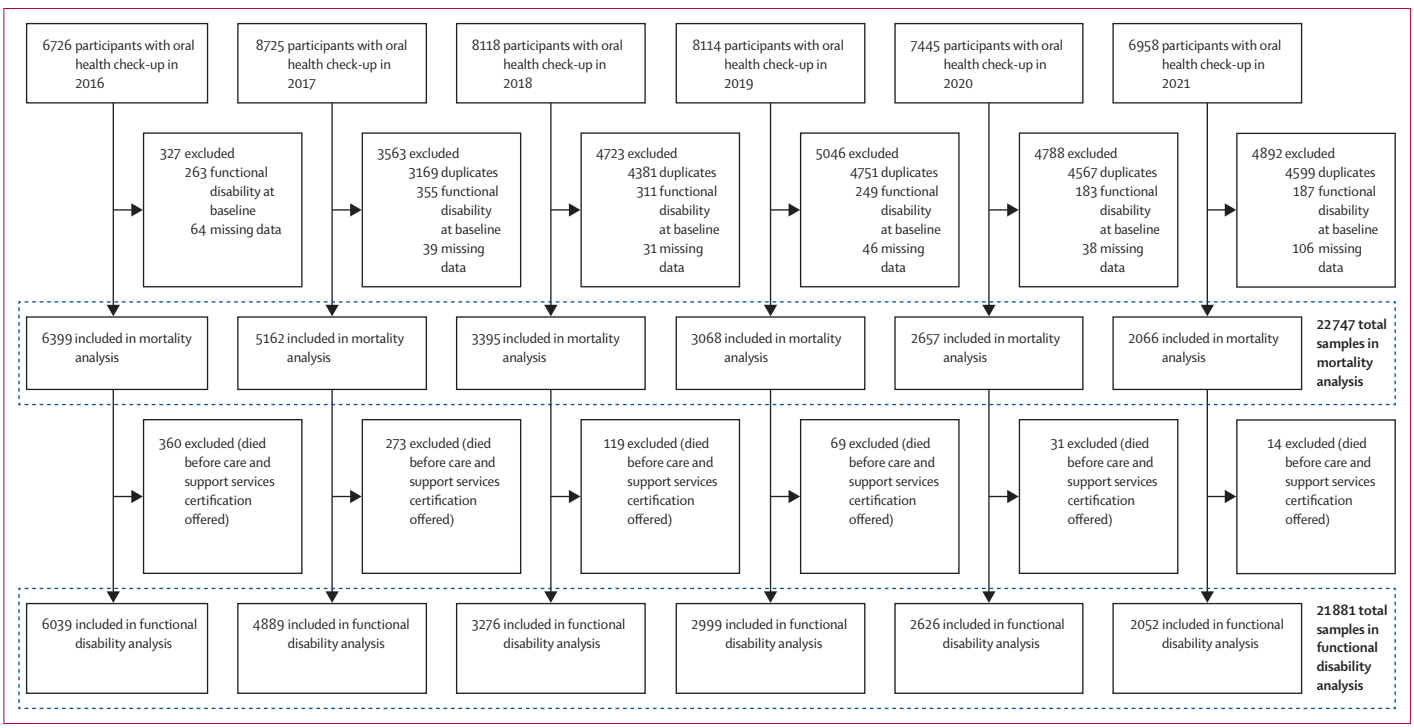

Figure: **Study profile**

The presence or absence of a history of these conditions was then included in the analyses as binary covariates (present or absent). Confounding variables for adjustment were chosen in accordance with clinical knowledge and prior literature.

Statistical analysis

Descriptive statistics were used to present continuous variables as means and SDs, whereas categorical variables were presented as frequencies and percentages.

Kaplan–Meier analyses with log-rank tests were used to estimate survival probabilities and generate survival curves. Survival probabilities were estimated as a function of time from the baseline survey when participants were first assessed. Survival curves were generated for each of the 13 aspects of oral health status. The assumption of proportional hazards was evaluated by visual inspection and no violation was found. We used Cox proportional hazards models to calculate hazard ratios and 95% CIs for the associations between oral health status and the occurrence of functional disability or mortality. Considering the intercorrelations among the aspects of oral health status, each analysis assessed a single indicator. The multivariate analysis model included model 1, which was adjusted for sex, age, and BMI category; model 2, which further adjusted for medical history; and model 3, which incorporated a propensity score derived from all covariates. Subsequently, we calculated the 95% CI of the PAF as the impact of each aspect of oral health status on functional disability and mortality, after adjusting for propensity scores. Information on propensity score calculations and validity assessment of the main analysis model is available in appendix 2 (p 5). Considering the potential reverse causation of the obtained results, sensitivity analyses were conducted in which participants with outcomes occurring within 1 year after baseline were excluded from the analysis.

Statistical analyses were done using Stata version 18.0. Statistical significance was set at $p<0·05$.

Role of the funding source

There was no funding source for this study.

Results

24 619 individuals underwent an oral health check-up at least once between April 1, 2016, and March 31, 2022, of whom 1872 with functional disabilities at baseline or missing data were excluded (figure). The remaining 22 747 individuals were included in the analysis of mortality, comprising 9722 (42·74%) men and 13 025 (57·26%) women, with a mean age of 78·34 years (SD 2·89). A further 866 participants were excluded from the functional disability analysis because they died before care and support services certification was offered. The final analysis of functional disability included 21 881 individuals (9175 [41·93%] men, 12 706 [58·07%] women, mean age 78·31 years [SD 2·88]). Participant baseline characteristics are summarised in table 1. The mean follow-up periods were 42·63 months (20·58) for mortality and 41·43 months (SD 20·80) for functional disability.

Kaplan–Meier survival estimates for each aspect of oral health status showed that poorer oral health status

	Analysis sample for functional disability (n=21 881)	Analysis sample for mortality (n=22 747)
Sex		
Male	9175 (41·93%)	9722 (42·74%)
Female	12 706 (58·07%)	13 025 (57·26%)
Age, years	78·31 (2·88)	78·34 (2·89)
BMI, kg/m^2		
Mean (SD)	22·63 (3·09)	22·62 (3·10)
<18·5	1776 (8·12%)	1879 (8·26%)
18·5 to <25·0	15 512 (70·89%)	16 116 (70·85%)
≥25·0	4593 (20·99%)	4752 (20·89%)
Medical history		
Alzheimer's disease	813 (3·72%)	862 (3·79%)
Parkinson's disease	429 (1·96%)	462 (2·03%)
Fracture	3725 (17·02%)	3903 (17·16%)
Osteoporosis	7230 (33·04%)	7497 (32·96%)
Arthropathy	9815 (44·86%)	10 216 (44·91%)
Cerebrovascular disease	5745 (26·26%)	6036 (26·54%)
Infectious pneumonia	6422 (29·35%)	6673 (29·34%)
Aspiration pneumonia	60 (0·27%)	62 (0·27%)
Depressive disorder	2133 (9·75%)	2255 (9·91%)
Hypertension	14 775 (67·52%)	15 405 (67·72%)
Periodontal disease	11 322 (51·74%)	11 672 (51·31%)
Follow-up period, months	41·43 (20·80)	42·63 (20·58)
Number of remaining teeth		
Mean (SD)	17·36 (9·28)	17·30 (9·31)
≥28	2412 (11·02%)	2489 (10·94%)
20–27	8841 (40·40%)	9146 (40·21%)
10–19	5363 (24·51%)	5584 (24·55%)
1–9	3492 (15·96%)	3653 (16·06%)
0	1773 (8·10%)	1875 (8·24%)
Objective masticatory performance*		
Mean (SD)	14·91 (12·19)	14·84 (12·17)
Quartile 4 (highest)	5438 (24·85%)	5614 (24·68%)
Quartile 3	5207 (23·80%)	5393 (23·71%)
Quartile 2	5595 (25·57%)	5822 (25·59%)
Quartile 1 (lowest)	5641 (25·78%)	5918 (26·02%)
Periodontal tissue status		
Edentulous	1661 (7·59%)	1754 (7·71%)
Normal	4569 (20·88%)	4726 (20·78%)
Mild status	8570 (39·17%)	8878 (39·03%)
Moderate status	6362 (29·08%)	6625 (29·12%)
Severe status	719 (3·29%)	764 (3·36%)
Subjective masticatory performance		
Able to masticate	14 841 (67·83%)	15 383 (67·63%)
Unable to masticate	7040 (32·17%)	7364 (32·37%)
Functional dysphagia: RSST time, s		
Mean (SD)	16·80 (11·89)	16·81 (11·87)
<30 (good)	19 831 (90·63%)	20 614 (90·62%)
≥30 (poor)	2050 (9·37%)	2133 (9·38%)
Tongue mobility		
Good	21 579 (98·62%)	22 421 (98·57%)
Poor	302 (1·38%)	326 (1·43%)
(Table 1 continues in next column)		

	Analysis sample for functional disability (n=21 881)	Analysis sample for mortality (n=22 747)
(Continued from previous column)		
Articulation		
Good	21 410 (97·85%)	22 236 (97·75%)
Poor	471 (2·15%)	511 (2·25%)
Oral hygiene		
Good	19 987 (91·34%)	20 744 (91·19%)
Poor	1894 (8·66%)	2003 (8·81%)
Number of decayed teeth		
Mean (SD)	0·77 (1·85)	0·78 (1·85)
<3 (low)	19 732 (90·18%)	20 499 (90·12%)
≥3 (high)	2149 (9·82%)	2248 (9·88%)
Inadaptation of denture of upper jaw		
No	18 197 (83·16%)	18 888 (83·04%)
Yes	3684 (16·84%)	3859 (16·96%)
Inadaptation of denture of lower jaw		
No	17 747 (81·11%)	18 419 (80·97%)
Yes	4134 (18·89%)	4328 (19·03%)
Oral mucosal disease		
No	21 124 (96·54%)	21 946 (96·48%)
Yes	757 (3·46%)	801 (3·52%)
Dry mouth		
No	17 651 (80·67%)	18 311 (80·50%)
Yes	4230 (19·33%)	4436 (19·50%)

Data are n (%) or mean (SD). RSST=repetitive saliva swallowing test. *Measured as the number of gummy jelly pieces counted after 15 s mastication, where fewer pieces indicates lower performance.

Table 1: **Participant characteristics**

was associated with a higher risk of functional disability and mortality for all aspects of oral health status (appendix 2 pp 13–20).

Table 2 shows the associations between various aspects of oral health status and incidence of functional disability. In model 1, all 13 aspects of oral health status (number of remaining teeth, objective and subjective masticatory performance, periodontal tissue status, functional dysphagia, tongue mobility, articulation, oral hygiene, number of decayed teeth, inadaptation of dentures in either the upper or lower jaw, oral mucosal disease, and dry mouth) were associated with the incidence of functional disability. Model 2, in which all medical history variables were added, yielded similar results for all oral health aspects except dry mouth, which no longer showed a significant association with disability. Model 3, which adjusted for the propensity score of all covariates, revealed significant associations between 11 aspects of oral health status (excluding oral mucosal disease and dry mouth) and functional disability. Sensitivity analyses excluding participants with functional disability occurring from baseline to 1 year of follow-up (n=20 357) yielded findings consistent with the primary results (appendix 2 p 10).

Associations between various aspects of oral health status and mortality are shown in table 3. In model 1,

	Participants, n	Incident functional disability per person-month (95% CI)	Hazard ratio (95% CI)		
			Model 1	Model 2	Model 3
Number of remaining teeth					
≥28	2412	1·34 (1·13–1·59)	1 (ref)	1 (ref)	1 (ref)
20–27	8841	1·76 (1·62–1·90)	1·29 (1·07–1·55)	1·32 (1·09–1·58)	1·24 (1·03–1·49)
10–19	5363	2·25 (2·06–2·45)	1·55 (1·28–1·87)	1·51 (1·25–1·83)	1·49 (1·23–1·80)
1–9	3492	2·87 (2·60–3·16)	1·80 (1·48–2·19)	1·77 (1·46–2·16)	1·67 (1·37–2·03)
0	1773	3·30 (2·91–3·74)	1·86 (1·50–2·31)	1·77 (1·42–2·20)	1·50 (1·21–1·87)
Objective masticatory performance					
Quartile 4 (highest)	5438	1·15 (1·02–1·29)	1 (ref)	1 (ref)	1 (ref)
Quartile 3	5207	1·57 (1·41–1·74)	1·34 (1·14–1·57)	1·29 (1·10–1·51)	1·25 (1·07–1·47)
Quartile 2	5595	2·22 (2·04–2·42)	1·84 (1·59–2·14)	1·71 (1·47–1·98)	1·65 (1·43–1·92)
Quartile 1 (lowest)	5641	3·65 (3·41–3·91)	2·83 (2·46–3·26)	2·49 (2·16–2·87)	2·25 (1·95–2·60)
Periodontal tissue status					
Edentulous	1661	3·42 (3·01–3·89)	NA	NA	NA
Normal	4569	1·55 (1·39–1·74)	1 (ref)	1 (ref)	1 (ref)
Mild status	8570	1·91 (1·77–2·06)	1·22 (1·06–1·39)	1·18 (1·03–1·35)	1·17 (1·02–1·33)
Moderate status	6362	2·38 (2·21–2·58)	1·47 (1·28–1·69)	1·41 (1·23–1·62)	1·37 (1·19–1·57)
Severe status	719	3·42 (3·01–3·89)	2·22 (1·78–2·78)	2·09 (1·66–2·61)	2·00 (1·60–2·50)
Subjective masticatory performance					
Able to masticate	14 841	1·89 (1·78–2·01)	1 (ref)	1 (ref)	1 (ref)
Unable to masticate	7040	2·60 (2·42–2·78)	1·25 (1·14–1·37)	1·20 (1·10–1·31)	1·21 (1·11–1·33)
Functional dysphagia: RSST time, s					
<30 (good)	19 831	1·98 (1·89–2·08)	1 (ref)	1 (ref)	1 (ref)
≥30 (poor)	2050	3·62 (3·24–4·05)	1·78 (1·57–2·00)	1·54 (1·36–1·74)	1·53 (1·36–1·74)
Tongue mobility					
Good	21 579	2·10 (2·00–2·20)	1 (ref)	1 (ref)	1 (ref)
Poor	302	4·32 (3·33–5·61)	1·94 (1·49–2·52)	1·52 (1·16–1·99)	1·59 (1·22–2·08)
Articulation					
Good	21 410	2·07 (1·97–2·16)	1 (ref)	1 (ref)	1 (ref)
Poor	471	5·22 (4·29–6·36)	2·06 (1·68–2·53)	1·68 (1·37–2·06)	1·70 (1·38–2·09)
Oral hygiene					
Good	19 987	1·94 (1·85–2·04)	1 (ref)	1 (ref)	1 (ref)
Poor	1894	4·26 (3·82–4·75)	2·00 (1·77–2·26)	1·85 (1·63–2·08)	1·80 (1·59–2·03)
Number of decayed teeth					
<3 (low)	19 732	2·04 (1·94–2·14)	1 (ref)	1 (ref)	1 (ref)
≥3 (high)	2149	3·08 (2·72–3·49)	1·50 (1·31–1·71)	1·43 (1·25–1·63)	1·40 (1·23–1·60)
Inadaptation of denture of upper jaw					
No	18 197	1·96 (1·87–2·07)	1 (ref)	1 (ref)	1 (ref)
Yes	3684	3·04 (2·76–3·34)	1·46 (1·31–1·62)	1·45 (1·31–1·62)	1·38 (1·24–1·53)
Inadaptation of denture of lower jaw					
No	17 747	1·97 (1·87–2·08)	1 (ref)	1 (ref)	1 (ref)
Yes	4134	2·87 (2·62–3·14)	1·34 (1·20–1·48)	1·28 (1·15–1·42)	1·26 (1·13–1·40)
Oral mucosal disease					
No	21 124	2·11 (2·02–2·21)	1 (ref)	1 (ref)	1 (ref)
Yes	757	2·74 (2·21–3·38)	1·38 (1·11–1·72)	1·31 (1·05–1·62)	1·23 (0·99–1·53)
Dry mouth					
No	17 651	2·06 (1·95–2·17)	1 (ref)	1 (ref)	1 (ref)
Yes	4230	2·41 (2·20–2·63)	1·12 (1·01–1·24)	1·05 (0·94–1·16)	1·08 (0·98–1·20)

Each oral health status was individually incorporated into a Cox proportional hazards model. Model 1 was adjusted for sex, age, and BMI. Model 2 was adjusted for sex, age, BMI, and medical history. Model 3 was adjusted by calculating propensity scores from all adjustment variables. The edentulous group was not included in the analysis of periodontal tissue status. NA=not applicable. RSST=repetitive saliva swallowing test.

Table 2: **Association between oral health status and functional disability**

all 13 aspects of oral health assessed showed associations with the incidence of mortality. Model 2 yielded similar results. Model 3 similarly revealed significant associations between all aspects of oral health status and mortality. For the sensitivity analysis excluding participants who died between baseline and 1 year of follow-up (n=20 523),

	Participants, n	Deaths per person-month (95% CI)	Hazard ratio (95% CI)		
			Model 1	Model 2	Model 3
Number of remaining teeth					
≥28	2489	1·06 (0·88–1·27)	1 (ref)	1 (ref)	1 (ref)
20–27	9146	1·23 (1·12–1·34)	1·26 (1·02–1·54)	1·26 (1·02–1·55)	1·14 (0·93–1·40)
10–19	5584	1·51 (1·36–1·67)	1·52 (1·23–1·88)	1·49 (1·20–1·85)	1·36 (1·10–1·68)
1–9	3653	1·81 (1·61–2·03)	1·75 (1·40–2·18)	1·69 (1·36–2·11)	1·54 (1·24–1·92)
0	1875	2·08 (1·79–2·42)	1·85 (1·45–2·36)	1·76 (1·37–2·25)	1·63 (1·27–2·09)
Objective masticatory performance					
Quartile 4 (highest)	5614	1·02 (0·90–1·16)	1 (ref)	1 (ref)	1 (ref)
Quartile 3	5393	1·17 (1·04–1·32)	1·20 (1·01–1·42)	1·17 (0·98–1·39)	1·14 (0·96–1·35)
Quartile 2	5822	1·54 (1·40–1·70)	1·58 (1·35–1·86)	1·53 (1·30–1·79)	1·48 (1·26–1·74)
Quartile 1 (lowest)	5918	2·03 (1·86–2·22)	2·13 (1·82–2·49)	1·94 (1·66–2·28)	1·87 (1·60–2·19)
Periodontal tissue status					
Edentulous	1754	2·06 (1·76–2·41)	NA	NA	NA
Normal	4726	1·22 (1·07–1·38)	1 (ref)	1 (ref)	1 (ref)
Mild status	8878	1·28 (1·17–1·40)	1·06 (0·91–1·23)	1·04 (0·90–1·21)	1·02 (0·88–1·19)
Moderate status	6625	1·55 (1·41–1·71)	1·22 (1·05–1·43)	1·20 (1·02–1·40)	1·19 (1·02–1·39)
Severe status	764	2·41 (1·93–3·00)	1·86 (1·44–2·39)	1·82 (1·41–2·35)	1·82 (1·41–2·35)
Subjective masticatory performance					
Able to masticate	15383	1·30 (1·22–1·39)	1 (ref)	1 (ref)	1 (ref)
Unable to masticate	7364	1·71 (1·58–1·86)	1·23 (1·11–1·37)	1·19 (1·07–1·32)	1·20 (1·08–1·33)
Functional dysphagia: RSST time, s					
<30 (good)	20614	1·14 (1·33–1·49)	1 (ref)	1 (ref)	1 (ref)
≥30 (poor)	2133	1·81 (1·56–2·11)	1·36 (1·16–1·60)	1·25 (1·07–1·48)	1·25 (1·06–1·47)
Tongue mobility					
Good	22421	1·42 (1·35–1·50)	1 (ref)	1 (ref)	1 (ref)
Poor	326	2·83 (2·10–3·81)	1·74 (1·29–2·36)	1·56 (1·15–2·11)	1·64 (1·21–2·23)
Articulation					
Good	22236	1·41 (1·33–1·48)	1 (ref)	1 (ref)	1 (ref)
Poor	511	3·14 (2·48–3·97)	1·69 (1·32–2·15)	1·49 (1·17–1·90)	1·53 (1·20–1·97)
Oral hygiene					
Good	20744	1·36 (1·29–1·44)	1 (ref)	1 (ref)	1 (ref)
Poor	2003	2·33 (2·02–2·68)	1·44 (1·24–1·68)	1·36 (1·17–1·59)	1·40 (1·20–1·63)
Number of decayed teeth					
<3 (low)	20499	1·40 (1·33–1·49)	1 (ref)	1 (ref)	1 (ref)
≥3 (high)	2248	1·85 (1·59–2·16)	1·27 (1·08–1·49)	1·22 (1·04–1·44)	1·24 (1·05–1·45)
Inadaptation of denture of upper jaw					
No	18888	1·36 (1·28–1·44)	1 (ref)	1 (ref)	1 (ref)
Yes	3859	1·90 (1·70–2·13)	1·38 (1·22–1·57)	1·35 (1·18–1·53)	1·31 (1·15–1·49)
Inadaptation of denture of lower jaw					
No	18419	1·35 (1·27–1·44)	1 (ref)	1 (ref)	1 (ref)
Yes	4328	1·86 (1·67–2·08)	1·36 (1·20–1·54)	1·30 (1·15–1·48)	1·29 (1·14–1·46)
Oral mucosal disease					
No	21946	1·42 (1·35–1·50)	1 (ref)	1 (ref)	1 (ref)
Yes	801	2·06 (1·63–2·61)	1·50 (1·18–1·90)	1·41 (1·11–1·80)	1·40 (1·10–1·78)
Dry mouth					
No	18311	1·39 (1·21–1·48)	1 (ref)	1 (ref)	1 (ref)
Yes	4436	1·64 (1·48–1·82)	1·17 (1·04–1·32)	1·14 (1·01–1·29)	1·13 (1·00–1·28)

Each oral health status was individually incorporated into a Cox proportional hazards model. Model 1 was adjusted for sex, age, and BMI. Model 2 was adjusted for sex, age, BMI, and medical history. Model 3 was adjusted by calculating the propensity scores from all covariates. The edentulous group was not included in the analysis of periodontal tissue status. NA=not applicable. RSST=repetitive saliva swallowing test.

Table 3: **Association between oral health status and mortality**

the findings were consistent with the main results, with the exception of articulation and dry mouth (appendix 2 p 11).

The discrimination of the model using the adjustment of estimated propensity scores for the association between oral health status and functional disability or mortality

	Functional disability PAF, % (95% CI)	Mortality PAF, % (95% CI)
Number of remaining teeth		
≥28	Ref	Ref
20–27	6·33% (1·24 to 11·16)	4·12% (−2·19 to 10·04)
10–19	8·50% (5·11 to 11·76)	6·78% (2·65 to 10·73)
1–9	8·68% (6·11 to 11·18)	7·23% (4·25 to 10·12)
0	4·15% (2·33 to 5·93)	4·62% (2·79 to 6·41)
Objective masticatory performance		
Quartile 4 (highest)	Ref	Ref
Quartile 3	3·56% (1·28 to 5·80)	2·31% (−0·64 to 5·18)
Quartile 2	10·62% (8·18 to 12·99)	8·90% (5·87 to 11·82)
Quartile 1 (lowest)	23·10% (20·42 to 25·69)	16·47% (13·44 to 19·40)
Periodontal tissue status		
Edentulous	NA	NA
Normal	Ref	Ref
Mild status	5·68% (0·95 to 10·18)	0·85% (−5·11 to 6·47)
Moderate status	9·74% (6·03 to 13·31)	5·47% (0·51 to 9·91)
Severe status	3·00% (2·32 to 3·67)	2·82% (1·93 to 3·69)
Subjective masticatory performance		
Able to masticate	Ref	Ref
Unable to masticate	7·33% (4·13 to 10·41)	6·77% (3·01 to 10·39)
Functional dysphagia: RSST time, s		
<30 (good)	Ref	Ref
≥30 (poor)	5·51% (4·23 to 6·77)	2·39% (0·82 to 3·95)
Tongue mobility		
Good	Ref	Ref
Poor	1·10% (0·61 to 1·59)	1·20% (0·63 to 1·77)
Articulation		
Good	Ref	Ref
Poor	2·10% (1·47 to 2·73)	1·72% (0·93 to 2·51)
Oral hygiene		
Good	Ref	Ref
Poor	7·35% (6·23 to 8·46)	4·02% (2·48 to 5·54)
Number of decayed teeth		
<3 (low)	Ref	Ref
≥3 (high)	3·76% (2·51 to 5·00)	2·29% (0·71 to 3·85)
Inadaptation of denture of upper jaw		
No	Ref	Ref
Yes	6·14% (4·37 to 7·88)	5·04% (2·93 to 7·10)
Inadaptation of denture of lower jaw		
No	Ref	Ref
Yes	4·95% (2·91 to 6·94)	5·27% (2·97 to 7·51)
Oral mucosal disease		
No	Ref	Ref
Yes	0·81% (0·03 to 1·59)	1·43% (0·56 to 2·28)
Dry mouth		
No	Ref	Ref
Yes	1·92% (−0·46 to 4·25)	2·86% (0·14 to 5·50)

PAFs were calculated from the relationship between each oral health status aspect and outcomes, after adjustment for propensity scores. The edentulous group was not included in the analysis of periodontal tissue status. NA=not applicable. PAF=population-attributable fraction. RSST=repetitive saliva swallowing test.

Table 4: **PAFs of oral health status for functional disability and mortality**

is shown in appendix 2 (pp 7–8), in addition to the goodness of fit of each model for the association between oral health status and functional disability or mortality, calculated using the Akaike information criterion (appendix 2 p 9).

Table 4 shows the PAFs of oral health status for functional disability and mortality. Calculation of PAF showed that the three aspects of oral health status with the highest degree of impact on functional disability were objective masticatory performance (PAF 23·10% [95% CI 20·42–25·69] for quartile 1 and 10·62% [8·18–12·99] for quartile 2), periodontal tissue status (9·74% [6·03–13·31] for moderate status), and number of remaining teeth (8·68% [6·11–11·18] for 1–9 teeth; table 4). In addition, the three factors with highest impact on mortality were objective masticatory performance (PAF 16·47% [13·44–19·40] for quartile 1 and 8·90% [5·87–11·82] for quartile 2), number of teeth (7·23% [4·25–10·12] for 1–9 teeth and 6·78% [2·65–10·73] for 10–19 teeth), and subjective masticatory performance (6·77% [3·01–10·39] for unable to masticate).

Discussion

This study simultaneously examined the relationship of various aspects of oral health status with functional disability and mortality in detail. These results showed that tooth loss, low objective masticatory performance, deterioration of periodontal tissue status, subjective inability to masticate, functional dysphagia, poor tongue movability, articulation, poor oral hygiene, higher number of decayed teeth, and non-adaptation of dentures of the upper or lower jaw are associated with functional disability or increased mortality. Furthermore, the results from the analysis of PAF suggest that objective masticatory performance has the strongest influence on functional disability and mortality. Oral mucosal disease and dry mouth were only associated with increased mortality in fully adjusted models. These findings suggest that the oral health status of older adults is a significant risk factor for functional disability and mortality.

Our results showed that objective masticatory performance had the largest influence on functional disability and mortality according to the PAF analysis. In a previous study,[15] the PAF of factors including the number of teeth, masticatory disability, cough reflex, and subjective dry mouth was calculated for mortality. Among oral indicators, the number of teeth had the greatest effect on mortality; when compared with other non-oral factors, the PAF for number of teeth was the second highest for men and seventh highest for women. Although a direct comparison with this previous study is not feasible because of the different methodologies used, the present study found that objective masticatory performance had a greater impact than the number of remaining teeth. Considering the differences observed in these results, objective masticatory performance appears to reflect functional aspects (conditions of occlusion or dentition) beyond mere tooth presence, emphasising usability rather than mere retention of teeth.[24]

Our findings are consistent with several aspects of oral health status reported by Dibello and colleagues.[14] For example, the number of teeth, masticatory function, difficulty swallowing, oral health, and dry mouth were

associated with functional disability and mortality in both studies. Notably, our study also found that other aspects of oral health status during oral check-ups—such as periodontal tissue status, tongue mobility, articulation, and inadaptation of upper or lower jaw dentures—were associated with both functional disability and increased mortality. Although moderate evidence has been established for the relationship between periodontal disease and mortality,[14] previous results have been inconsistent regarding an association between periodontal disease and functional disability, which remains to be explored.[25] Previous studies have reported that oral diadochokinesis and reduced tongue pressure are associated with physical frailty.[26,27] Therefore, our findings show some consistency with those of previous studies.[26] Our study also found that upper or lower jaw denture inadaptation was associated with functional disability and mortality. A previous study reported that the number of occlusal contacts was associated with the total score of physical, cognitive, and social frailty.[28] We consider that upper and lower jaw evaluation, as done in this study, provides valuable information for future studies. Although our study showed associations between various aspects of oral health and mortality and functional disability, we cannot exclude the possibility of spurious correlations among the aspects of oral health and the potential additive effects of various oral factors.[12,29] The Japan Dental Association recommends a multifaceted evaluation of an individual's life, oral environments, and oral functions.[12,17] Future studies are necessary to elucidate the effects of each aspect of oral health status on different outcomes, and to ascertain their underlying mechanisms of action.

Several mechanisms have been proposed to explain how oral health status deterioration might lead to functional disability or mortality. Oral health status deterioration, such as a decrease in the number of teeth, could potentially lead to a decline in nutritional status and contribute to systemic non-communicable diseases and cognitive impairment.[10,30] These severe diseases are known to cause functional disability and increase mortality. The relationship between such severe diseases and oral health markers can be considered through several possible pathways. A possible underlying mechanism might be the inflammatory response to periodontitis, which could increase the risk of developing various systemic diseases, including cardiovascular diseases, mediated by the inflammatory cytokines associated with periodontal tissue destruction.[31] Additionally, for older adults, tooth loss can lead to social isolation.[32] From a psychosocial perspective, a bidirectional relationship has been suggested between psychological stress and periodontitis, in which both immune response dysregulation and oral microbiome alterations have potential health implications.[33] Consequently, sociopsychological factors might be involved in the relationship between oral health status and adverse health outcomes. Furthermore, oral health markers have been shown to be associated with a decline in muscle strength and physical ability in later years.[11] Poor oral health can lead to difficulties in chewing and swallowing, which can result in inadequate nutrition and, consequently, muscle loss.

This study has several limitations. First, although we adjusted for basic demographic and disease-related confounding factors, we could not exclude the residual confounding effects of other unmeasured factors (eg, vision-related and hearing-related diseases, types and number of medications, and social vulnerability). Potential unmeasured confounders or mediators might influence the relationship between oral health status, functional disability, and mortality. However, this study was unable to clarify these detailed relationships since it focused on all-cause mortality and disability rather than detailed causes, highlighting the need for further research. Second, although the sample size of our study was large, it was not obtained through random sampling but was limited to individuals who underwent oral health check-ups. Therefore, there is a possibility of bias as health-conscious and highly health-literate older adults might have been over-represented. Third, although we confirmed the validity of commercially available Sugarless Fine gummy jelly in the assessment of objective masticatory performance (allowing us to measure a wider range of populations at a low cost), there is little evidence on the validity, reliability, and inter-rater reliability of this evaluation method, and thus measurement accuracy remains unconfirmed. Furthermore, measurement using this method can be challenging in patients with health conditions such as dementia. In addition, periodontal tissue status, tongue mobility, and upper or lower jaw denture inadaptation were based on subjective dentist diagnosis. Therefore, there are concerns regarding the validity and reliability of the evaluation. Finally, the assessment of oral health status was done at a single baseline timepoint. Consequently, the relationship between oral health status and outcomes might have been underestimated because of the potential changes in oral health status over time. For example, oral diseases are cumulative, making it difficult to fully restore oral health. While oral health check-ups in older adults are crucial, it is also necessary to regularly assess the oral health of younger adults.

In conclusion, this study showed that various aspects of oral health status in older Japanese adults are associated with adverse health outcomes. Objective masticatory performance was the most influential aspect of oral health status on outcomes. Therefore, considering the clinical implications of the study results, oral health check-ups in Japan could aid in the early detection and prevention of major adverse health outcomes among older adults. Furthermore, it is crucial to implement interventions aimed at improving the oral health status (eg, objective masticatory performance) of older adults following oral health check-ups. Future research should elucidate whether such efforts could contribute to a reduction in functional disability and mortality.

Contributors

SY, TA, and KT conceptualised and designed the study. TA collected data. TA and KT accessed and verified the data underlying the study and wrote the first draft of the manuscript. All authors interpreted, accessed, and verified

data reported in the manuscript; contributed to the critical review of the manuscript; provided their final approval and agreed to be accountable for all aspects of this study; and took final responsibility for the decision to submit the manuscript for publication.

Declaration of interests

We declare no competing interests.

Data sharing

The datasets generated and analysed in the current study are not publicly available because the study protocol did not include a provision for data to be shared publicly. To request the provision of de-identified data, approval must be obtained through the Medical Research Ethics Committee of Shimane University Faculty of Medicine (kenkyu@med.shimane-u.ac.jp). Additionally, individual permission must be obtained from the Shimane Extended Union of Medical Care System for the Latter-Stage Elderly People, who manage the original data for this study.

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