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Removable dental prostheses and difficulties with chewing among frail individuals: Results from the Swiss SAPALDIA cohort

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Abstract

Oral healthcare among the frail is an underestimated geriatric care element. While neglected oral health (OH) is a well-established risk factor for frailty, frailty can be a risk factor for subsequent OH problems.

The cross-sectional investigation nested into the SAPALDIA sub-cohort of citizens aged 52 years and older, aims to stimulate longitudinal research into aspects that accelerate poor OH among frail individuals. The hypothesis investigated was that (pre-) frail individuals are more likely to have missing teeth replaced with removable dental prostheses (RDP) resulting in difficulties with chewing.

The study included 1489 participants undergoing geriatric assessments and oral examination. The main predictor was frailty status (non-frail; pre-frail; frail), based on Fried's frailty phenotype. The main outcomes of interest were non-functional dentition (presence of ≤ 19 natural teeth), presence of any RDP and self-reported difficulties with chewing.

Pre-frailty and frailty were not associated with the presence of ≤ 19 natural teeth, but were associated with a higher RDP prevalence. The presence of at least one complete denture (CD) had 1.71 fold and 2.54 folds higher odds among pre-frail and frail, respectively, compared to non-frail individuals. Frail individuals with CD reported chewing difficulties 7.8 times more often than non-frail individuals without CD.

The results are in line with the hypothesis that (pre-) frail individuals may be more likely to have tooth loss restored by RDPs. Future longitudinal research needs to assess potential barriers to oral hygiene and fixed dental prostheses among (pre-) frail and to study their oral health-related quality of life.

Introduction

The number and proportion of older adults are globally increasing; by 2050 over 400 million individuals aged 80 and older are expected (World Health Oraganization, 2022). Frailty remains one of the most challenging clinical conditions for geriatricians (Hoogendijk et al., 2019; Walston et al., 2018).

Care for pre-frail and frail individuals should integrate adequate oral health (OH) care. While neglected OH is a well established risk factor for the development of frailty (Castrejón-Pérez et al., 2012; Castrejón-Pérez et al., 2017; Hakeem et al., 2019, 2021; Iwasaki et al., 2018; MacEntee & Donnelly, 2016), states of (pre-) frailty can also be a risk factor for subsequent OH problems (Everaars et al., 2021). For example, frailty in older people could increase the risk of OH deterioration and corresponding tooth loss as a result of elevated inflammatory markers (Castrejón-Pérez et al., 2012) and failure to meet the basic OH care requirements (Parisius et al., 2022). Pre-frail and frail older adults have reduced muscular ability to perform oral hygiene, and might have lack of interest or reduced ability to adhere to OH care services visits (MacEntee & Donnelly, 2016). In previous studies, it was shown that impaired vision, lack of physical balance, acute disease, or depression hindered performing personal oral hygiene in older adults (Koistinen et al., 2021). Weak grip strength, a key feature of frailty, was found to be related with poor oral hygiene and tooth loss (Yun & Lee, 2020). Frails' perceptions on OH and self-efficacy (Niesten et al., 2013), could negatively affect personal OH care behavior, irrespective to their physical abilities. Assistance in oral hygiene in care facilities or homecare deliveries may be inadequate. On one hand, older persons may distrust the caregiver or may have privacy concerns. On the other hand, caregivers' tight schedules may not allow sufficient time for delivering appropriate oral hygiene care to their patients (Koistinen et al., 2021).

Against this background it is important to understand the OH state of pre-frail and frail individuals in Switzerland and in particular how missing teeth are replaced, given that Swiss basic insurance does not cover OH care costs (Wolff et al., 2011). Frailty was generally found to be associated with the increased need of fixed or removable dental prostheses (RDP) (Torres et al., 2015). Schmidt et al. found that among Swiss adults fixed dental prostheses are generally more common than RDP (Schmidt et al., 2020), but whether this is also true for pre-frail and frail individuals in Switzerland has not been studied. A predominance of removable restorations was observed in older age groups in Switzerland, with the incidence of RDP being 43% in the 75–84 years age group and 60% in the ≥84 years age group in 2012 (Schneider et al., 2017). RDPs can be less invasive and expensive than fixed prostheses, allow replacement of multiple teeth or even all teeth (Thomason et al., 2007), and may be the preferred option for frail individuals particularly because of the ease of assisted oral care.

The current study investigated the hypothesis that individuals with pre-frailty and frailty are more likely to have non-functional dentition and RDPs, and whether non-functional dentition and RDPs go along with elevated problems with chewing. The cross-sectional investigation, nested into the Swiss SAPALDIA sub-cohort on aging among citizens aged 52 years and older, aims to stimulate future longitudinal research into aspects that accelerate poor OH and related quality of life among (pre-) frail individuals, an under-studied topic in frailty research.

Materials and methods

In the reporting of this study, the relevant items of Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement were applied (von Elm et al., 2007).
The Swiss cohort on Air Pollution And Lung and Heart Diseases In Adults (SAPALDIA) is a population-based longitudinal cohort, which was initiated in 1991 (SAPALDIA-1, n=9651), to explore the influence of long-term exposure to air pollution on health in a sample of Swiss residents aged between 18 and 60 years (Martin et al., 1997). The first follow-up assessment (SAPALDIA-2, n=8047) was in 2001-2003, followed by the second (SAPALDIA-3, n=6088) in 2010-2011, and the third (SAPALDIA-4, n=5149) in 2017-2018. At baseline, participants were randomly sampled from different municipalities (Basel, Davos, Wald, Lugano, Montana, Payerne, Geneva, and Aarau) that represented the different linguistic regions, environmental, and climatic conditions of Switzerland. Participation in SAPALDIA consisted of a mixture between interviews and health examinations, with a focus on air pollution and respiratory health and a broad focus on aging and its determinants. Details of the SAPALDIA study design have been described elsewhere (Martin et al., 1997).
The current analyses were based on the SAPALDIA-4 52+ geriatric health assessment substudy, which has been described in detail (Aebi et al., 2020). In brief, among SAPALDIA-4 participants, those having completed the online or paper questionnaires and being ≥ 52 years old were invited to attend the geriatric health assessment in one of the regional study centers. From 2921 eligible SAPALDIA-4 participants, 1746 (60%) answered a questionnaire focused on healthy ageing, including for the first time questions about their OH and were defined as SAPALDIA-4 52+ participants. Of those, 1673 participants (96%) underwent the geriatric health examination conducted by field healthcare workers. The visit included an oral examination, an anthropometric assessment and short physical performance tests including walking speed, handgrip strength, and objectively measured physical activity by accelerometry. Field healthcare workers who conducted the oral examinations were not OH professionals, but were trained in repeated sessions on counting natural teeth; measuring probing pocket depths (PPD); and identifying fixed as well as removable dental prostheses by SAPALDIA's OH professionals, under the lead of NUZ and JCS (Schmidt et al., 2020). In addition to the training before the data collection, the field healthcare workers received a refresher training at the data collection day.

Variables and measurements

Main predictor: Fried's Frailty Phenotype (FP)

Fried's FP original instrument was used to define frailty status in the current sample. This instrument categorizes individuals into non-frail, pre-frail, or frail, according to their total count of FP's criteria (Fried et al., 2001).
An adjusted version of the FP instrument was created using data from SAPALDIA-4's questionnaires and examinations. The independent variable of the adjusted-FP tool was a categorical variable that assigned participants into one of three frailty categories, based on a score ranging from 0 to 5 possessed criteria. Zero score point was considered as non-frail, 1-2 score points were considered as pre-frail, and 3-5 score points were assigned to frail (Fried et al., 2001). Consistent with the original FP's five components' definitions and cutoffs

(Supplementary Table S6, Additional file 1), the adjusted-FP's five binary variables in this study were measured as follows (See supplementary Table S1, Additional file 1):

1. Shrinking: To construct this component, the difference in measured weight between SAPALDIA-3 and SAPALDIA-4 was calculated in kilograms (Kg). Shrinking participants were those with 5 kg or more of lost weight.
2. Weakness: The lowest 20% mean handgrip strength measurements, stratified by Body Mass Index's (BMI) quartiles and sex, were used as a cutoff in defining weakness.
3. Exhaustion: It was present if the self-reported "feeling tired or having little energy" occurred in the past 4 weeks and at least "on more than half of the days".
4. Slowness: The average speed of two measurements of walking 4 meters in seconds was used. The sex-specific and median height-adjusted 20^{th} percentile was defined as a cutoff.
5. Low physical activity: The weekly expenditure of Kilo calories (Kcals), in the adjusted-FP, was first predicted using linear regression and derived from counts per minutes (CPM) data from SAPALDIA-4's ActiGraph accelerometry data (Aebi et al., 2020), according to Williams Work energy formula (Kcals=CPM ×0.0000191×body mass in Kg) (*Williams, R 1998; What is the difference among the Energy Expenditure Algorithms?*, 2018). To reduce the sample's attrition, resulting from missing accelerometry, the measured Kcals were regressed on a list of predictors selected by a backward selection procedure. The retained predictors were the derived minutes/week of physical activity from the life style questionnaire, age, sex, weight, BMI, waist circumference, smoking status, and the total score of the short physical performance battery. The resulting beta regression coefficients allowed the prediction of Kcals for participants with self-reported levels of physical activity. For case definition, the lowest sex-specific 20% weekly Kcals were used as the cutoff for this criterion.

Outcomes

The following data were used in this study and were collected in the oral examination of SAPALDIA-4 for the upper and lower jaw:

- Teeth count, excluding wisdom teeth. Edentulous sextants were noted during the measurements of PPD, according to the FDI (Fédération Dentaire Internationale) teeth numbering system (FDI, 2016).
- Presence of RDPs, including Removable Partial Denture (RPD) in partially edentulous arches or CD in completely edentulous arches.

The following binary outcome variables were derived from SAPALDIA-4's 52+ examination and questionnaire data:

<u>Primary (dichotomized) outcomes:</u>

1. Presence of non-functional dentition indicated by having ≤ 19 natural teeth, as opposed to having ≥ 20 natural teeth, while excluding wisdom teeth and irrespective of the presence of RDP. Provided that loss in the molar region occurs first, the threshold of 20 teeth present correspond to a shortened dental arch situation and a functional dentition. This variable implied non-functional dentition due to partial or complete tooth loss, irrespective of the location of the remaining natural teeth (Atanda et al., 2022).

2. Presence of any type of RDP (RPD and/or CD) in either one or both jaws, as opposed to not having any RDP. This variable implied restored partial and complete tooth loss.
3. Presence of CD either in one or both jaws, as opposed to not having any CD, irrespective of RPD presence. This variable implied restored edentulism in one or both jaws.

Secondary (dichotomized) outcome:

4. Presence of self-reported difficulty with chewing certain food based on the following question: “Do you have trouble chewing certain food?” that was asked in the geriatric health assessment questionnaire.

Covariates

Primary and secondary analyses were adjusted for the following *a priori* selected potential confounders: age (continuous, cubic, and quadratic terms), sex (female vs. male), socioeconomic status (answers to "How well do you manage with the money that is available to support you?” very good; fairly good; not good/bad), cumulative highest educational level (low: primary school; middle: secondary school, middle school or apprenticeship; high: technical college or university), cumulative smoking status (never; former; current), presence of non-communicable diseases (at least one self-reported diagnosis of chronic obstructive pulmonary disease; emphysema; cardiovascular diseases; diabetes) and the area of the study center. Age and sex were *a priori* considered for effect modification.

Statistical analysis

First, to evaluate participation bias, characteristics at baseline (SAPALDIA-1) were compared for those participating in the SAPALDIA-4 52+ assessment and those who did not participate in the SAPALDIA-4 52+ assessment, but had attained age 52+ at the time of SAPALDIA-4 (Aebi et al., 2020). Second, the participants’ characteristics were presented stratified by frailty status and sex as mean and standard deviation for the numerical continuous variables, and as number and percentage for the categorical variables. Third, unadjusted and adjusted multivariable mixed logistic models with a random effect for examination centers were applied to estimate independently the associations between the primary outcome variables and frailty status. Associations were quantified as odds ratios (OR) and 95% confidence interval (CI).
The first multivariable analysis tested the association between frailty status and the prevalence of ≤ 19 natural teeth; RDP; and CD as outcomes of interest. Effect modification of frailty status with age and sex, respectively, was tested by adding interaction terms in the adjusted models as products of age/sex with dummy variables for pre-frailty and frailty, respectively.
The second multivariable analysis tested the joint association of frailty status and present ≤ 19 natural teeth, RDP, and CD with self-reported difficulty with chewing. Interaction terms between the respective tooth loss indicator and the dummy variables for pre-frailty and frailty were included in the models.
Sensitivity analyses were conducted by excluding participants with at least one unrestored edentulous sextant and noted with no RDP (n=20) from the reference group when studying the association between RDP and frailty.

The level of significance was set to $\alpha = 0.05$ (p-values <0.05 were interpreted as statistically significant). Statistical analyses were performed using Stata Software version 15 (Supplementary Table S7, Additional file 1).

Results

Among the participants who had complete data from the 52+ health assessment (n=1671), 1510 had complete information for deriving the frailty score. After the exclusion of additional participants with missing data in the other covariates, 1470 participants were included in analyses with the outcome ≤ 19 natural teeth, and 1489 participants were included in the analyses with RDP or CD, respectively, as outcomes (Supplementary Figure S1, Additional file 1).
Participants included in the 52+ health assessment generally exhibited more healthy attributes at study inception than those excluded as they were more likely never smokers and were less likely overweight or obese. In addition, men, employed individuals, younger age groups, and individuals with higher education more often participated in the SAPALDIA-4 52+ follow-up and therefore in this analysis (Supplementary Table S8, Additional file 1) (Aebi et al., 2020).
Participant characteristics for the current study are presented in Table 1, stratified by frailty status and sex. Participants in this study were 48% females with mean age of 67.6, and 52% males with mean age of 68.2 years. On average 59% of females and 53% of males were in a very good socioeconomic condition. The prevalence of pre-frailty and frailty was 49% and 3% among females, and 51% and 3% among males. The five adjusted-FP criteria were balanced between males and females, while the “exhaustion” element of adjusted-FP in females was proportionally higher than males. With regards to OH status, 17% of females and 19% of males had ≤ 19 natural teeth, 16% of females and 19% of males had at least one RDP (RPD and/or CD), and in both sexes around 9% had at least one CD. These percentages were higher among participants categorized as pre-frail or frail.

Table 1. Characteristics of the study sample, overall and stratified by frailty status[1] and sex

N (%) or Mean (SD)	**All**		**Non-frail**		**Pre-frail**		**Frail**	
	Females	**Males**	**Females**	**Males**	**Females**	**Males**	**Females**	**Males**
Total [N= 1489]	711 (47.8)	778 (52.2)	339 (48.5)	360 (51.5)	350 (46.9)	397 (53.2)	22 (51.2)	21 (48.8)
Age $_{years}$	67.6 (7.8)	68.2 (7.9)	65.1 (6.0)	66.1 (6.3)	69.6 (8.6)	69.6 (8.6)	74.5 (9.6)	77.1 (8.5)
Weight $_{Kg}$	66.9 (12.5)	82.8 (12.8)	67.7 (11.8)	84.8 (13.2)	66.2 (12.9)	81.6 (12.0)	64.8 (16.1)	71.6 (12.2)
Height $_{cm}$	161.7 (6.5)	174.7 (6.6)	163.2 (5.8)	175.9 (6.1)	160.6 (6.8)	173.9 (6.8)	156.5 (6.1)	168.4 (5.6)
Socioeconomic status[2]								
Very good	417 (58.7)	411 (52.8)	211 (62.2)	182 (50.6)	198 (56.6)	220 (55.4)	8 (36.4)	9 (42.9)
Pretty good	274 (38.5)	347 (44.6)	121 (35.7)	169 (46.9)	140 (40.0)	167 (42.1)	13 (59.1)	11 (52.4)
Not good + Bad	20 (2.8)	20 (2.6)	7 (2.1)	9 (2.5)	12 (3.4)	10 (2.5)	1 (4.6)	1 (4.8)
Education level[3]								
Low	33 (4.6)	15 (1.9)	9 (2.7)	7 (1.9)	24 (6.9)	8 (2.0)	0	0
Middle	512 (72.0)	413 (53.1)	256 (75.5)	194 (53.9)	239 (68.3)	208 (52.4)	17 (77.3)	11 (52.4)
High	166 (23.4)	350 (44.9)	74 (21.8)	159 (44.2)	87 (24.9)	181 (45.6)	5 (22.7)	10 (47.6)
Smoking status								
Never	345 (48.5)	274 (35.2)	158 (46.6)	135 (37.5)	174 (49.7)	135 (34.0)	13 (59.1)	4 (19.1)
Former	277 (38.9)	394 (50.6)	145 (42.8)	184 (51.1)	130 (37.1)	197 (49.6)	2 (9.1)	13 (61.9)
Current	89 (23.4)	110 (14.1)	36 (14.1)	41 (11.4)	46 (13.1)	65 (16.4)	7 (31.8)	4 (19.05)
Non Communicable Diseases[4]								
No	391 (54.9)	305 (39.20)	201 (59.29)	161 (59.29)	186 (53.1)	140 (35.3)	4 (18.2)	4 (19.1)
Yes	320 (18.2)	473 (18.2)	138 (40.7)	199 (55.3)	164 (46.9)	257 (64.7)	18 (81.8)	17 (80.9)
Outcome variables								
RDP: (Removable Dental Prostheses)[5]								
No RDP	598 (84.1)	631 (81.1)	301 (88.8)	315 (87.5)	281 (80.3)	304 (76.6)	16 (72.7)	12 (57.1)
Present RDP	113 (15.9)	147 (18.9)	38 (11.2)	45 (12.5)	69 (19.7)	93 (23.4)	6 (27.3)	9 (42.9)
CD: Complete Denture (one or two)[6]								
No CD	648 (91.1)	708 (91.0)	320 (94.4)	343 (95.3)	312 (89.1)	348 (87.7)	16 (72.7)	17 (80.9)
Present CD	63 (8.9)	70 (9.0)	19 (5.6)	17 (4.7)	38 (10.9)	49 (12.3)	6 (27.3)	4 (19.1)
Total [N=1470][7]	704 (47.9)	766 (52.1)	335 (48.5)	356 (51.5)	346 (47.0)	390 (52.9)	23 (53.5)	20 (46.5)

Presence of ≤ 19 natural teeth[8]								
No ≤ 19 natural teeth	584 (82.9)	618 (80.7)	269 (88.4)	301 (84.6)	273 (78.9)	308 (78.9)	15 (65.2)	9 (45.0)
Present ≤ 19 natural teeth	120 (17.1)	148 (19.3)	39 (11.6)	55 (15.5)	73 (21.1)	82 (21.0)	8 (34.8)	11 (55.0)

Note. N = Number [Bracket contains the total sample size of each model], SD = Standard Deviation, RDP=Removable Dental Prosthesis, RPD = Removable Partial Denture, CD = Complete Denture, COPD = Chronic Obstructive Pulmonary Disease

[1] Modified Fried et al. (2001) frailty measurement instrument, categorized depending on the number of present criteria out of five frailty criteria as follows: 0 criterion= Non-frail, 1-2 criteria= Pre-frail and 3-5 criteria= Frail. The modifications were based on the available data from SAPALDIA study.

[2] Socioeconomic status was defined upon the following question (Q55_4): "How well do you manage with the money that is available to support you?". Answers categories were: 1 = Very good, 2 = Fairly good, 3 = Not good 4 = Bad. The last two categories were merged for this analysis.

[3] Educational level was defined according to the highest educational level achieved, according to the highest level obtained: 1= Low (primary school), 2 = Middle (secondary school, middle school or apprenticeship), 3 = High (Technical College or University)

[4] Non-Communicable Diseases (NCD) is a binary variable, which was present if the SAPALDIA-4 52+ participants have self-reported a diagnosis of at least one of the following (COPD, emphysema, cardiovascular diseases and diabetes).

[5] This variable indicates the presence of at least one RDP (CD or RPD), in at least one jaw.

[6] This variable indicates the presence of at least one CD, irrespective of the presence of RPD.

[7] See Figure S1 in Supplementary appendices

[8]This variable indicated the presence of 19 or more natural remaining teeth, during the oral examination not considering wisdom teeth and irrespective of the presence of RDP.

The associations between frailty status and having less than 20, RDP, and CD are presented in Table 2. Participants with ≤ 19 natural teeth were slightly more prevalent among those with pre-frailty and frailty (adjusted $OR_{pre\text{-}frailty}$= 1.1, 95% CI= 0.8 - 1.5; adjusted $OR_{frailty}$= 1.9, 95% CI= 0.9 - 4.1), yet the associations did not reach statistical significance. Associations were attenuated upon adjustment for current smoking, socioeconomic status and age, which were themselves mostly independently associated with ≤ 19 natural teeth (Supplementary Table S2, Additional file 1).

Pre-frailty was associated with the presence of RDP (adjusted $OR_{pre\text{-}failty}$ = 1.42, 95% CI =1.01 - 1.98). The association between frailty and RDP was stronger than for pre-frailty, yet not statistically significant (adjusted $OR_{frailty}$= 1.63, 95% CI= 0.75 - 3.52). The comparison between unadjusted and multivariate analysis showed an attenuation of the association upon adjustment for current smoking, better socioeconomic status, high education level, age, and female sex, which were themselves mostly independently associated with RDP (Supplementary Table S3, Additional file 1). The exclusion of participants with edentulous sextants from the control group of RDP did not materially change associations with frailty status as presented in Table 2 (Supplementary Table S5, Additional file 1).

Pre-frailty and frailty were both significantly associated with the presence of at least one CD (adjusted $OR_{pre\text{-}frail}$= 1.71, 95% CI=1.08 - 2.71; adjusted OR_{frail}= 2.54, 95% CI=1.03 - 6.3). Associations were attenuated upon adjustment for current or past smoking, better socioeconomic status, high level of education, age, and female sex, which were mostly independently associated with CD (Supplementary Table S4, Additional file 1).

Age and sex were not found to modify the associations between frailty status and the three tooth loss indicators presented in Table 2 (Supplementary Table S9, Additional file 1).

Table 2. Crude and adjusted associations of frailty status with the presence of and ≤19 natural remaining teeth, removable and complete denture

Frailty status[1]	Number of Present/absent	Crude Odds Ratio	95% confidence intervals	Adjusted[2] Odds Ratio	95% confidence intervals
Association between frailty and presence of ≤19 natural teeth[3] [N=1470]					
Non-frail	95/597	Reference		Reference	
Pre-frail	155/581	1.7	1.3 - 2.2 [c]	1.1	0.8 - 1.5
Frail	19/24	5.0	2.7 - 9.5 [c]	1.9	0.9 - 4.1
Association between frailty status and presence of any RDP[4] [N=1489]					
Non-frail	83/616	Reference		Reference	
Pre-frail	162/585	2.1	1.5 - 2.7 [c]	1.4	1.0 - 1.9 [a]
Frail	15/28	3.9	2.0 - 7.8 [c]	1.6	0.8 - 3.5
Association between frailty and presence of any CD[5] [N=1489]					
Non-frail	36/663	Reference		Reference	
Pre-frail	87/660	2.4	1.6 - 3.6 [c]	1.7	1.1 - 2.7 [a]
Frail	10/33	5.6	2.9 - 12.2 [c]	2.5	1.0 - 6.3 [a]

Note. N = Number [Bracket contains the total sample size of each model], RDP = Removable Dental Prosthesis, RPD = Removable Partial Denture, CD = Complete Denture

[1] Main predictor according to Fried et al. (2001) frailty instrument, categorized depending on the number of present criteria out of five frailty criteria as follows: 0 criterion= Non-frail, 1-2 criteria= Pre-frail and 3-5 criteria= Frail.

[2] Adjusted for: smoking (never, former and current), socioeconomic status (bad, good, not good or bad), education level (low, middle, high), age, sex (female=1, male=0), and the area of study center as a random effect.

[3] Comparing participants with 19 or less natural teeth to participants with more than 19 natural teeth (missing wisdom teeth not counted; irrespective of the presence of RDP).

[4] Comparing participants with any type of RDP (CD or RPD) to participants without any RDP (neither CD nor RPD).

[5] Comparing participants with one or two CDs to participants without any CD, irrespective of the presence of RPD.

[a] P-value <0.05, [b] P-value =0.001, [c] P-value < 0.001

Table 3 summarizes the results of the adjusted combined associations of frailty status and tooth loss indicators (≤ 19 natural teeth; RDP; CD) with self-reported difficulty with chewing certain food. Pre-frailty and frailty states in the presence of ≤ 19 natural teeth, RDP, or CD were consistently and positively associated with a higher likelihood of self-reported chewing difficulties compared to non-frail individuals with at least 20 natural teeth and without RDP or CD. The strongest association with chewing difficulties was observed for frail individuals with CD compared to non-frail individuals without CD (adjusted OR_{frail}= 7.8, 95% CI=1.9-31.9)

Table 3. Adjusted[1] combined associations of frailty status and tooth loss indicators with self-reported difficulty with chewing certain food[2]

Frailty status[3]	Odds ratio (95% Confidence Interval)	Odds ratio (95% Confidence Interval)
Model 1: Frailty status and presence of ≤ 19 natural teeth[4] [N= 1,446][5]		
	>19 natural teeth	**Present ≤ 19 natural teeth**
Non-frail	Reference	3.6 (1.8 - 7.3) [c]
Pre-frail	1.2 (0.7 - 1.9)	5.5 (2.9 - 10.4) [c]
Frail	0.9 (0.1 - 7.5)	7.3 (2.2 - 24.6) [b]
Model 2: Frailty status and the presence of any RDP[6] [N=1464][7]		
	No RDP	**Present RDP**
Non-frail	Reference	2.8 (1.3 - 5.9) [a]
Pre-frail	1.0 (0.6 -1.7)	5.4 (2.9 - 9.9) [c]
Frail	0.6 (0.1 - 4.8)	6.3 (1.7 - 23.4) [a]
Model 3: Frailty status and the presence of any CD[8] [N=1464][7]		
	No CD	**Present CD**
Non-frail	Reference	3.0 (1.2 - 7.8) [a]
Pre-frail	1.2 (0.8 - 1.9)	4.4 (2.2 - 8.6) [c]
Frail	0.4 (0.1 - 3.4)	7.8 (1.9 - 31.9) [a]

Note. N = Number [Bracket contains the total sample size of each model], Incl. = Including, RDP = Removable Dental Prosthesis, RPD = Removable Partial Denture, CD = Complete Denture

[1] Adjusted for: Smoking (never, former and current), socioeconomic status (bad, good, not good or bad), education level (low, middle, and high), age, sex (female=1, male=0), and the area of study center as a random effect.

[2] Comparing participants who reported present difficulty with chewing certain food based on the following question: "Do you have trouble chewing certain food?" that was asked in the geriatric health assessment questionnaire, as opposed to participants who answered it with absent.

[3] Main predictor according to Fried et al. (2001) phenotype frailty instrument, categorized depending on the number of present criteria out of five frailty criteria as follows: 0 criterion= Non-frail, 1-2 criteria= Pre-frail and 3-5 criteria= Frail.

[4] Comparing participants with examined present 19 or less natural teeth to participants with more than 19 natural teeth (missing wisdom teeth not counted; irrespective of presence of RDP).

[5] (N=24) missing self-reported difficulty with chewing data were excluded from the data set (n=1470). See Figure S1

[6] Participants with RDP (CD or RPD); participants without RDP (neither RPD nor CD).

[7] (N=25) missing self-reported difficulty with chewing data were excluded from the data set (n=1489). See Figure S1.

[8] Participants with CD have one or two CDs irrespective of the presence of RPD; participants without any CD, irrespective of the presence of RPD.

[a] P-value <0.05, [b] P-value =0.001, [c] P-value < 0.001

Discussion

In this general population study sample from a high-income country without universal basic OH coverage, pre-frail and frail individuals above age 52+ were more likely to have RDPs and in particular CDs. Pre-frailty and frailty in the presence of RDP and especially CD went along with difficulties with chewing certain food, which puts these individuals at risk for nutritional deficits. The presence of ≤ 19 natural teeth without consideration of RDP or CD was not associated with pre-frailty or frailty, however it also put pre-frail and frail individuals at extra risk of reporting chewing problems.

The current results which suggest pre-frail and frail individuals may be more likely to have RDPs compared to non-frail, are in line with previous studies concluding that RDPs, were more

prevalent among the frail (Everaars et al., 2021). Due to the cross-sectional nature of the current study it is not possible to assess the direction of the association, e.g. whether RDPs are indicators of tooth loss leading to frailty, or whether frailty leads to tooth loss and replacement by RDP. But the observation that the frailty states were specifically associated with the presence of RDPs and in in particular CDs, is in line with the hypothesis that individuals with frailty are more likely to have tooth loss restored by RDPs compared to a) having tooth loss unrestored (see next paragraph) or b) having tooth loss restored by Fixed Dental Prostheses (FDP) (see paragraph after the next).

Regarding (a): The stronger association of frailty states with having tooth loss restored by RDPs rather than have it unrestored is supported by the fact that most people in Switzerland can afford to have missing teeth replaced (Swiss dental association, 2022).

Regarding (b): The strong association of frailty states with having tooth loss restored with RDPs implies a lower likelihood of having tooth loss restored by FDPs. In comparison to tooth loss replacements that include FDPs and dental implants, conventional RDPs tend to be associated with reduced costs, thus, preferably chosen when financial assets are limited (Bandiaky et al., 2022; Wöstmann et al., 2005). Evidence suggests that frailty in European contexts is associated with lower socio-economic status (Sirven et al., 2020). The Swiss basic health insurance neither includes dental insurance nor covers dental care among adults (Guessous et al., 2014). In the SAPALDIA 52+ sub-cohort it has been previously shown that the proportion of RPD and CD were more prevalent in the presence of socio-economic differences (Schmidt et al., 2020). In addition to financial constraints underlying the observed associations, pre-frail or frail individuals may have reduced willingness to endure relatively demanding and/or invasive restorations such as long-span tooth- or implant-supported FDPs (Dudley, 2015). Patients in a Swedish short-term stay facility reported that declined health and energy shortage would be the reason for ignoring OH services visits (Koistinen et al., 2021).

In this study, the presence of RDPs and in particular CDs among individuals in frailty states had a remarkable association with reported difficulty with chewing. This observation agrees with the evidence that denture wearers had less quality of eating compared to people with natural teeth (Moynihan & Varghese, 2021). RDPs and in particular CDs are treatment options for oral rehabilitation in conditions with tooth loss, to facilitate mastication, speech, and appearance, enhancing the quality of diet (Moynihan & Varghese, 2021), self-esteem, and socialization (Abbas et al.; Andrew & Keefe, 2014). However, poor fitting, impaired retention, braded artificial teeth, and the inability to chew certain food with dentures were reasons for disappointment among denture wearers (Koistinen et al., 2021). Yet, those with ill-fitting RDPs and less efficient chewing considered the dentist visit as lower priority, as they did not think it was worth repairing their dentures and they had no dental pain (Koistinen et al., 2021). Therefore, in addition to not seeking timely OH care for avoiding extended tooth loss in the first place, not seeking OH care in the presence of RDPs may have contributed to chewing difficulties. More attention should be given to chewing efficiency and adherence to regular check-ups, among frail individuals, as difficult chewing could lead to poor dietary habits among the elderly (Bastos et al., 2021; Toniazzo et al., 2018), thereby leading to sarcopenia and aggravating frailty (Fried et al., 2001).

Strength and limitations

As a strength, this population-based study was nested into a large cohort sampled from the general population. The results of the study are therefore generalizable in principle to the Swiss population in three language regions. But as in any long-term cohort, non-participation at baseline, and loss-to-follow-up after almost 30 years (Aebi et al., 2020) may have biases including survivor bias, the direction of which cannot be estimated in the absence of OH examination at baseline and the first follow-up examinations of SAPALDIA. According to the comparison of some other baseline characteristics it was observed that participants included in the current analysis smoked less and were less likely overweight at baseline and more likely of higher educational and socio-economic status. This suggests that the association between frailty and extended tooth loss, the presence of RPD/CD, and chewing difficulties was possibly underestimated. Those with unhealthier lifestyle and less financial resources were more likely to have extended tooth loss when developing frailty at older age. The detailed characterization of the cohort allowed for detailed consideration of confounding. Despite the assistance and facilitation that were offered for participants with impaired vision or disabilities (Schmidt et al., 2020), the study might have missed participation by the frailest and most dependent. Despite being carefully trained by a team of dental experts, the field healthcare workers still lacked a professional dental background. The reliability of dental assessments by the field healthcare workers was not formally assessed. Calibration of missing teeth data is therefore not possible. Some misclassification of the teeth count may occurred, such as counting FDPs' pontics as natural teeth, and this may explain in part the absence of a statistically significant association between frailty and non-functional dentition (≤ 19 natural teeth present). Due to the lack of precise data on tooth loss, such as its location and distribution of the missing teeth, this study could not compare the linkage between frailty and several levels of tooth loss, irrespective of the presence of replacements.
Frailty status may have been misclassified in the absence of the complete information needed to classify participants precisely according to Fried's definition (Fried et al., 2001). Weight loss had to be defined as excessive weight loss between two SAPALDIA follow-up examinations in the absence of information on whether the weight loss was unintentional. As the FP instrument was found to have high specificity but low sensitivity (Op Het Veld et al., 2019), some true frailty cases might have been missed, while some participants might have been misclassified as pre-frail or frail. In the absence of the precise Fried criteria the SAPALDIA derived and adapted instrument could not be validated against the gold standard Fried frailty. This cross-sectional analytical study could not infer causality or directionality between frailty and tooth loss. The associations from the perspective of the less studied effect of frailty on OH were presented with the intention to stimulate further longitudinal in-depth studies. In the absence of longitudinal data, mediation analysis could not be conducted such as mediation by socio-economic status, dental insurance, or dental service utilization in the pathway from frailty to tooth loss, its restoration and subsequent difficulties with chewing. In the SAPALDIA study information on private dental insurance and OH service visits were not available. Difficulties with chewing were self-reported and not further characterized with regard to the source of the problem or the types of foods eaten. Finally, confidence intervals were wide, pointing to restrictions in the statistical power of the present study, in particular with regard to the state of frailty. The low prevalence of frailty reflects the fact that the study population was still relatively young with a starting age of 52 years.

Conclusions

The findings highlight the importance of good OH knowledge among professionals involved in the care for the elderly and frail. Longitudinal research with sufficiently long follow-up time is needed to assess the impact of factors associated with frailty on the deterioration of OH and its restoration approaches and to investigate pathways from frailty to OH-related nutritional problems.

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- Ethics approval and consent to participate: SAPALDIA's study protocol respected the Declaration of Helsinki ("World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects," 2013). Ethical approval was obtained from the Ethics Committee northwest/central Switzerland (EKNZ) as lead agents (EKNZ PB_2016-02348) as well as from the respective regional ethics committees. Participants have given their written informed consent to all parts of the study, and at each SAPALDIA survey separately.
- Consent for publication: Participants have given their written informed consent to all parts of the study, and at each SAPALDIA survey separately.
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Zusammenfassung

Einleitung

Die orale Gesundheit gebrechlicher Menschen ist ein wichtiger, aber unterschätzter Bestandteil der geriatrischen Versorgung. Eine vernachlässigte Zahngesundheit ist ein etablierter Risikofaktor für die Entstehung von Gebrechlichkeit, aber Gebrechlichkeit kann die Zahngesundheit auch weiter verschlechtern.
Diese Studie untersucht in einer allgemeinen Bevölkerungsstichprobe von Schweizer Erwachsenen im Alter von 52 Jahren und älter die Hypothese, dass Zahnverlust bei gebrechlichen Menschen häufiger durch herausnehmbaren Zahnersatz korrigiert wird und dies vermehrt zu Schwierigkeiten beim Kauen führt.

Material und Methoden

Die Querschnittsstudie umfasst 1489 Teilnehmer der SAPALDIA Kohorte, die sich 2017-2018 einem geriatrischen Assessment und einer oralen Untersuchung unterzogen. Hauptprädiktor der statistischen Auswertung war der Gebrechlichkeits-Status gemäss modifizierter Version des Frailty-Phänotypisierungs-Instrumentes von Fried (nicht gebrechlich; Vorstufe zu gebrechlich; gebrechlich). Endpunkte der statistischen Auswertung waren Indikatoren für ein nicht funktionsfähiges Gebiss aufgrund von Zahnverlust (≤ 19 natürliche Zähnen; Zahnersatz mit herausnehmbarem Zahnersatz) und Schwierigkeiten beim Kauen.

Resultate

Vorgebrechlichkeit und Gebrechlichkeit waren nicht mit dem Vorhandensein von ≤ 19 natürlichen Zähnen assoziiert, wohl aber mit einer höheren Prävalenz von herausnehmbarem Zahnersatz insbesondere Totalprothesen. Das Vorhandensein von mindestens einer Totalprothese war bei Vorgebrechlichen und Gebrechlichen im Vergleich zu Nichtgebrechlichen um das 1,71-fache bzw. 2,54-fache erhöht. Die Kombination von Gebrechlichkeit und einer Totalprothese erhöhte die Wahrscheinlichkeit von Schwierigkeiten beim Kauen um das mehr als 7 fache im Vergleich zu Nichtgebrechlichen ohne Totalprothese.

Diskussion

Die Ergebnisse deuten darauf hin, dass ein Zahnverlust bei (vor-)gebrechlichen Personen mit größerer Wahrscheinlichkeit durch eine herausnehmbare und insbesondere Totalprothese versorgt wird und dies mit Kauproblemen einhergeht. Künftige Längsschnittuntersuchungen sollten potenzielle Hindernisse für den Zugang zu adäquater Mundhygiene und feststitzendem Zahnersatz bei (prä-)gebrechlichen Menschen und ihre mundgesundheitsbezogene Lebensqualität untersuchen.

Résumé

Introduction

La santé bucco-dentaire des personnes fragiles est un élément important, mais sous-estimé, des soins gériatriques. Une santé dentaire négligée est un facteur de risque établi pour l'apparition de la fragilité, mais la fragilité peut également détériorer davantage la santé dentaire. Cette étude examine, dans un échantillon général de population d'adultes suisses âgés de 52 ans et plus, l'hypothèse selon laquelle la perte de dents chez les personnes fragiles est plus souvent corrigée par des prothèses dentaires amovibles, ce qui entraîne davantage de difficultés à mâcher.

Matériels et méthodes

L'étude transversale porte sur 1489 participants de la cohorte SAPALDIA ayant pris part à une évaluation gériatrique et un examen bucco-dentaire en 2017-2018. Le principal facteur d'intérêt de l'analyse statistique était le statut de fragilité déterminé à partir d'une version modifiée de l'instrument du phénotype de fragilité de Fried (non-fragile ; pré-fragile ; fragile). Les variables dépendantes analysées étaient les indicateurs d'une dentition non fonctionnelle en raison de la perte de dents (≤ 19 dents naturelles ; prothèses dentaires amovibles) et de difficultés à mastiquer.

Résultats

La pré-fragilité et la fragilité n'étaient pas associées avec la présence de mois de 19 dents naturelles, mais avec une prévalence plus élevée de prothèses dentaires amovibles, notamment de prothèses totales. La présence d'au moins une prothèse dentaire totale était 1,71 fois et 2,54 fois plus fréquente chez les pré-fragiles et les fragiles, respectivement, que chez les non-fragiles. La présence d'une prothèse totale chez les personnes fragiles multipliait par plus de 7 la probabilité de difficultés de mastication par rapport aux personnes non fragiles ne portant pas de prothèse totale.

Discussion

Les résultats indiquent que la perte de dents chez les personnes (pré)fragiles est plus susceptible d'être restaurée par une prothèse amovible, et en particulier par une prothèse totale, et par suite d'être associée à des problèmes de mastication. De futures études longitudinales devraient examiner les obstacles potentiels à l'accès à une hygiène buccale adéquate et aux prothèses fixes chez les personnes (pré)fragiles, ainsi que leur qualité de vie liée à la santé bucco-dentaire.

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Supplementary Appendices

Table S1: Distribution of the modified[1] Frailty instrument's components over sex and frailty status [Bracket contains the total sample size of category]

N (%)	**All** [N= 1489]		**Non-frail** [N=699]		**Pre-frail** [N=747]		**Frail** [N=43]	
	Females	Males	Females	Males	Females	Males	Females	Males
Frailty phenotype tool criteria:								
Shrinking (Weight loss)[2]								
No	644 (90.6)	695 (89.3)	339 (100)	360 (100)	296 (84.6)	326 (82.1)	9 (40.9)	9 (42.9)
Yes	67 (9.42)	83 (10.7)	0	0	54 (15.4)	71 (17.9)	13 (59.1)	12 (57.1)
Weakness (grip strength)[3]								
No	586 (82.4)	633 (81.4)	339 (100)	360 (100)	244 (69.7)	270 (68.0)	3 (13.6)	3 (14.3)
Yes	125 (17.6)	145 (18.6)	0	0	106 (30.3)	127 (32.0)	19 (86.4)	18 (85.7)
Exhaustion[4]								
No	665 (93.5)	747 (96.02)	339 (100)	360 (100)	315 (90.0)	372 (93.7)	11 (50.0)	15 (71.4)
Yes	46 (6.5)	31 (3.9)	0	0	35 (10.0)	25 (6.3)	11 (50.0)	6 (28.6)
Slowness (Walking speed)[5]								
No	576 (81.0)	622 (79.9)	339 (100)	360 (100)	222 (63.4)	250 (62.9)	15 (68.2)	12 (57.1)
Yes	135 (19.0)	156 (20.1)	0	0	128 (36.6)	147 (37.0)	7 (31.8)	9 (42.9)
Low Physical activity[6]								
No	572 (80.5)	629 (80.9)	339 (100)	360 (100)	229 (65.4)	267 (67.3)	4 (18.2)	2 (9.5)
Yes	139 (19.6)	149 (19.2)	0	0	121 (34.6)	130 (32.8)	18 (81.8)	19 (90.5)

BMI: body mass index, Kg: Kilograms, N: number

[1] Modified Fried's frailty instrument (Fried et al. 2001), categorized depending on the number of present criteria out of five frailty criteria as follows: 0 criterion= Non-frail, 1-2 criteria= Pre-frail and 3-5 criteria= Frail. The modifications were based on the available data from SAPALDIA study.

[2] Weight loss was (present) if equal or greater than the cut-off. The gender specific cut-off was losing 5 Kg or more between SAPALDIA-3 and SAPLADIA-4 weight measurements (SECA877 flat scale).

[3] Weakness was (present) if below the cut-off. Cut-offs were the lowest 20% grip strength measurement in Kg of the dominant hand (by Jamar Hydraulic Hand Dynamometer) of each BMI quartile of each sex (BMI quartile → Cut-off point). Females: <=22.0 →20;>22,<=24.8 →19.66;>24.8,<=28.5→19;>28.5,<=55.9→19. Males: <=24.47→ 30.6;>24.47,<=26.7→32.3;>26.7,<=29.2→32.3;>29.2,<=43.3→32.3.

[4] Exhaustion: (present) if the following question (lifestyle questionnaire Q45-86-d) was with answered (c) or (d): "Over the past 4 weeks, how often have you felt affected by the following ailments? D) Feeling tired or having no energy". Answers: a) not at all, b) on deposit days, c) On more than half of the days, d) Every day or almost every day.

[5] Slowness was (present) if the gate speed (walking speed for 4 meters in seconds) was below the cut-off. Cut-offs were the 20th percentile gate speed stratified by median height and sex (Median height→Cutoff). Females: >=162 → 2.9, <162 →3.1. Males: >=174.7 → 2.8, <174.7 →3.05

[6]Low physical activity was (present) if the derived Kcals expenditure is lower than the cut-off. Cut-off were the lowest 20 % of the derived Kilocalories (Kcals) expenditure per week stratified by sex: females (0.29), males (0.37).

Citation: Fried, L. P., C. M. Tangen, J. Walston, A. B. Newman, C. Hirsch, J. Gottdiener, T. Seeman, R. Tracy, W. J. Kop, G. Burke, and M. A. McBurnie. "Frailty in Older Adults: Evidence for a Phenotype." *J Gerontol A Biol Sci Med Sci* 56, no. 3 (Mar 2001): M146-56. https://dx.doi.org/10.1093/gerona/56.3.m146.

Table S2: Adjusted odds ratios of mixed logistic regression of the association between frailty status[1] and the presence of ≤19 natural remaining teeth [2] [Total sample size=1470]

Predictor	Odds Ratio	Standard Error	95% Confidence Interval
Frailty status			
pre-frail	1.1	0.2	0.8 - 1.5
Frail	1.9	1.7	0.9 - 4.1
Smoking			
Former	1.5	0.3	1.0 - 2.1
Current	2.6	0.6	1.7 - 4.2
Socioeconomic status[3]			
Fairly good	1.9	0.3	1.4 - 2.5
Not good + bad	9.7	3.9	4.3 - 21.7
Education level[4]			
Middle	0.5	0.2	0.3 - 1.0
High	0.2	0.1	0.1 - 0.5
NCD[5]	1.4	0.2	0.9 - 1.9
Age centered[6]	1.1	0.0	1.1 - 1.2
Age quadratic	0.9	0.0	0.9 - 0.9
Age cubic	1.0	0.0	0.9 - 1.0
Female	0.8	0.1	0.6 - 1.1
constant	0.2	0.1	0.1 - 0.5
Area[7] (random effect)			

N: number, RDP: Removable Dental Prosthesis, RPD: Removable Partial Denture, CD: Complete Denture, NCD: Non-Communicable Diseases, COPD: Chronic Obstructive Pulmonary Disease

[1] Main predictor according to modified Fried's frailty instrument (Fried et al 2001), categorized depending on the number of present criteria out of five frailty criteria as follows: 0 criterion= Non-frail, 1-2 criteria= Pre-frail and 3-5 criteria= Frail. The modifications were based on the available data from SAPALDIA study.

[2] Comparing participants with examined present 19 or less natural teeth to participants with more than 19 natural teeth (missing wisdom teeth not counted; irrespective of presence of RDP).

[3] Socioeconomic status was defined upon the following question (Q55_4): "How well do you manage with the money that is available to support you?" Answers categories were: 1 = Very good, 2 = Fairly good, 3 = Not good 4 = Bad. The last two categories were merged for this analysis.

[4] Educational level was defined according to the highest educational level achieved, according to the highest level obtained: 1 = Low (primary school), 2 = Middle (secondary school, middle school or apprenticeship), 3 = High (Technical College or University)

[5] NCD is a binary variable which was present if the SAPALDIA-4 52+ participants have self-reported a diagnosis of at least one of the following (COPD, emphysema, cardiovascular diseases and diabetes).

[6] Centered age around its mean.

[7] Area of the study center (Basel, Davos, Wald, Lugano, Montana, Payerne, Geneva, and Aarau).

Citation: Fried, L. P., C. M. Tangen, J. Walston, A. B. Newman, C. Hirsch, J. Gottdiener, T. Seeman, R. Tracy, W. J. Kop, G. Burke, and M. A. McBurnie. "Frailty in Older Adults: Evidence for a Phenotype." *J Gerontol A Biol Sci Med Sci* 56, no. 3 (Mar 2001): M146-56. https://dx.doi.org/10.1093/gerona/56.3.m146.

Table S3: Adjusted odds ratios of mixed logistic regression of the association between frailty status[1] and the presence of removable dental prostheses[2] [Total sample size=1489]

Predictor	Adjusted odds Ratio	95% Confidence Interval
Frailty status		
pre-frail	1.4	1.0 - 1.9
frail	1.6	0.8 - 3.5
Smoking		
Former	1.4	0.9 - 1.9
Current	2.6	1.6 - 4.1
Socioeconomic status[3]		
Fairly good	2.0	1.5 - 2.8
Not good + bad	6.6	3.0 - 14.2
Education level[4]		
Middle	0.7	0.4 - 1.4
High	0.3	0.2 - 0.7
NCD[5]	1.2	0.9 - 1.7
Age centered[6]	1.1	1.1 - 1.1
Age quadratic	0.9	0.9 - 0.9
Age cubic	1.0	1.0 - 1.0
Female	0.8	0.6 - 1.1
constant	0.2	0.1 - 0.4
Area[7] (random effect)		

N: number, RDP: Removable Dental Prosthesis, RPD: Removable Partial Denture, CD: Complete Denture, NCD: Non-Communicable Diseases, COPD: Chronic Obstructive Pulmonary Disease

[1] Main predictor according to modified Fried's frailty instrument (Fried et al. 2001), categorized depending on the number of present criteria out of five frailty criteria as follows: 0 criterion= Non-frail, 1-2 criteria= Pre-frail and 3-5 criteria= Frail. The modifications were based on the available data from SAPALDIA study.

[2] Comparing participants with any type of RDP (CD or RPD) to participants without any RDP (neither CD nor RPD).

[3] Socioeconomic status was defined upon the following question (Q55_4): "How well do you manage with the money that is available to support you?" Answers categories were: 1 = Very good, 2 = Fairly good, 3 = Not good 4 = Bad. The last two categories were merged for this analysis.

[4] Educational level was defined according to the highest educational level achieved, according to the highest level obtained: 1 = Low (primary school), 2 = Middle (secondary school, middle school or apprenticeship), 3 = High (Technical College or University)

[5] NCD is a binary variable which was present if the SAPALDIA-4 52+ participants have self-reported a diagnosis of at least one of the following (COPD, emphysema, cardiovascular diseases and diabetes).

[6] Centered age around its mean.

[7] Area of the study center (Basel, Davos, Wald, Lugano, Montana, Payerne, Geneva, and Aarau).

Citation: Fried, L. P., C. M. Tangen, J. Walston, A. B. Newman, C. Hirsch, J. Gottdiener, T. Seeman, R. Tracy, W. J. Kop, G. Burke, and M. A. McBurnie. "Frailty in Older Adults: Evidence for a Phenotype." *J Gerontol A Biol Sci Med Sci* 56, no. 3 (Mar 2001): M146-56. https://dx.doi.org/10.1093/gerona/56.3.m146.

Table S4: Adjusted odds ratios of a mixed logistic regression of the association between frailty status[1] and the presence of complete dentures[2] [Total sample size=1489]

Predictor	Adjusted odds Ratio	95% Confidence Interval
Frailty status		
pre-frail	1.7	1.1 - 2.7
frail	2.5	1.0 - 6.3
Smoking		
Former	1.7	1.0 - 2.6
Current	3.4	1.9 - 6.1
Socioeconomic status[3]		
Fairly good	2.3	1.5 - 3.5
Not good + bad	7.3	3.1 - 16.9
Education level[4]		
Middle	0.5	0.2 - 1.1
High	0.3	0.1 - 0.6
NCD[5]	1.5	0.9 - 2.4
Age centered[6]	1.1	1.0 - 1.1
Age quadratic	0.9	0.9 - 0.9
Age cubic	1.0	1.0 - 1.0
Female	1.0	0.7 - 1.6
constant	0.1	0.0 - 0.2
Area[7] (random effect)		

N: number, RDP: Removable Dental Prosthesis, RPD: Removable Partial Denture, CD: Complete Denture, NCD: Non-Communicable Diseases, COPD: Chronic Obstructive Pulmonary Disease

[1] Main predictor according to modified Fried's frailty instrument (Fried et al. 2001), categorized depending on the number of present criteria out of five frailty criteria as follows: 0 criterion= Non-frail, 1-2 criteria= Pre-frail and 3-5 criteria= Frail. The modifications were based on the available data from SAPALDIA study.

[2] Comparing participants with one or two CDs to participants without any CD, irrespective of the presence of RPD.

[3] Socioeconomic status was defined upon the following question (Q55_4): "How well do you manage with the money that is available to support you?"

Answers categories were: 1 = Very good, 2 = Fairly good, 3 = Not good 4 = Bad. The last two categories were merged for this analysis.

[4] Educational level was defined according to the highest educational level achieved, according to the highest level obtained: 1 = Low (primary school), 2 = Middle (secondary school, middle school or apprenticeship), 3 = High (Technical College or University)

[5] NCD is a binary variable which was present if the SAPALDIA-4 52+ participants have self-reported a diagnosis of at least one of the following (COPD, emphysema, cardiovascular diseases and diabetes).

[6] Centered age around the its mean

[7] Area of the study center (Basel, Davos, Wald, Lugano, Montana, Payerne, Geneva, and Aarau).

Citation: Fried, L. P., C. M. Tangen, J. Walston, A. B. Newman, C. Hirsch, J. Gottdiener, T. Seeman, R. Tracy, W. J. Kop, G. Burke, and M. A. McBurnie. "Frailty in Older Adults: Evidence for a Phenotype." *J Gerontol A Biol Sci Med Sci* 56, no. 3 (Mar 2001): M146-56. https://dx.doi.org/10.1093/gerona/56.3.m146.

Table S5: Adjusted[1] odds ratios of mixed logistic regression of the association between frailty status[2] and the presence of removable dental prostheses[3] with excluding participants (N=20) with at least one edentulous sextant from the reference group [N=1469]

Frailty status[3]	Odds Ratio	95% Confidence Interval
pre-frail	1.4	1.0 - 2.0
frail	1.7	0.8 - 3.7

N: Number, RDP: Removable Dental Prosthesis, RPD: Removable Partial Denture, CD: Complete Denture

[1] Adjusted for: Smoking (never, former and current), socioeconomic status (bad, good, not good or bad), education level (low, middle, high), age, sex (female=1, male=0), and the area of study center as a random effect.

[2] Main predictor according to modified Fried's frailty instrument (Fried et al. 2001), categorized depending on the number of present criteria out of five frailty criteria as follows: 0 criterion= Non-frail, 1-2 criteria= Pre-frail and 3-5 criteria= Frail.

[3] Comparing participants with any type of RDP (CD or RPD) to participants without any RDP (neither CD nor RPD). Participants (N=20) with at least one edentulous sextant and have no RDP where excluded from the reference group.

Citation: Fried, L. P., C. M. Tangen, J. Walston, A. B. Newman, C. Hirsch, J. Gottdiener, T. Seeman, R. Tracy, W. J. Kop, G. Burke, and M. A. McBurnie. "Frailty in Older Adults: Evidence for a Phenotype." *J Gerontol A Biol Sci Med Sci* 56, no. 3 (Mar 2001): M146-56. https://dx.doi.org/10.1093/gerona/56.3.m146.

Table S6: Fried's Frailty Phenotype[1] five criteria and measurements

Component	Measurement
Shrinking	The question: "In the last year, have you lost more than 10 pounds unintentionally (i.e., not due to dieting or exercise)?" If yes → frail for this criterion If no → non-frail for this criterion
Weakness	Handgrip strength in Kilograms. The lowest 20% was the gender- and BMI-specific cutoff.
Exhaustion	"CES–D Scale: The question: "How often in the last week did you feel this way?" "(a) I felt that everything I did was an effort" "(b) I could not get going." " choices: 0 = rarely or none of the time (,1 day), 1 =some or a little of the time (1–2 days), 2 =a moderate amount of the time (3–4 days), or 3 = most of the time." Who answered "2" or "3" to either of the two questions (a & b) were categorized as frail for this criterion
Slowness	Time in seconds of walking speed for 15 feet. The slowest 20% gender-specific cutoff by medium height was used.
Low physical activity	"Based on the short version of the Minnesota Leisure Time Activity questionnaire, asking about walking, chores (moderately strenuous), mowing the lawn, raking, gardening, hiking, jogging, biking, exercise cycling, dancing, aerobics, bowling, golf, singles tennis, doubles tennis, racquetball, calisthenics, swimming." Kcals per week expenditure was calculated using statistical modeling. The lowest 20% Kcals were the gender-specific cutoff.

BMI: Body Mass Index, Kcals: Kilo calories, CES-D Scale: Center for Epidemiologic Studies Depression Scale

[1]Source: Appendix "Criteria used to define frailty" : Fried, L. P., C. M. Tangen, J. Walston, A. B. Newman, C. Hirsch, J. Gottdiener, T. Seeman, R. Tracy, W. J. Kop, G. Burke, and M. A. McBurnie. "Frailty in Older Adults: Evidence for a Phenotype." *J Gerontol A Biol Sci Med Sci* 56, no. 3 (Mar 2001): M146-56. https://dx.doi.org/10.1093/gerona/56.3.m146.

Table S7: Soft wares and online resources used throughout the entire project

Name of the resource	Used for
Online Diagram Software & Visual Solution | Lucidchart.com	Design and export the figure charts
STATA IC 16.1, (StataCorp. 2017. Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC.).	Data analyses

Table S8[1]: Baseline characteristics at SAPALDIA1 of participants who reached the age of 52+ at the time of SAP52+ assessments, stratified by participant status in the SAP52+ sub-study.

	Not in SAP52+ substudy2		In SAP52+ substudy2		OR (95% CI)
	n	%	n	%	
Sex					
Male	3341	48.0	723	51.9	1.00
Female	3617	52.0	669	48.1	0.85 (0.76–
Age (years)					
26–38	2263	32.5	529	38.0	1.00
39–48	2151	30.9	566	40.7	1.13 (0.99–1.29)
49+	2544	36.6	297	21.3	0.50 (0.43–
BMI (kg/m2)					
<25.0	4258	61.2	1017	73.1	1.00
25–29.9	2105	30.3	322	23.1	0.64 (0.56–
≥30	595	8.6	53	3.8	0.37 (0.28–
Language region					
German	3479	50.0	769	55.2	1.00
French	2365	34.0	459	33.0	0.88 (0.77–
Italian	1114	16.0	164	11.8	0.67 (0.56–
Employment					
Employed	5570	80.1	1198	86.1	1.00
House person	1114	16.0	174	12.5	0.73 (0.61–
Pensioner	34	0.5	5	0.4	0.68 (0.27–1.75)
Other	240	3.4	15	1.1	0.29 (0.17–
Education					
Low	1369	19.7	114	8.2	1.00
Middle	4472	64.3	930	66.8	2.50 (2.04–
High	1117	16.1	348	25.0	3.74 (2.99–
Civil status					
Married	4972	71.5	1020	73.3	1.00
Divorced	504	7.2	107	7.7	1.03 (0.83–1.29)
Widowed	153	2.2	15	1.1	0.48 (0.28–
Single	1329	19.1	250	18.0	0.92 (0.79–1.07)
Smoking status					
Never	2794	40.2	669	48.1	1.00
Former	1727	24.8	361	25.9	0.87 (0.76–1.01)
Current	2437	35.0	362	26.0	0.62 (0.54–

CI = confidence interval; OR = odds ratio; * p-value ≤0.05; ** p-value ≤0.01; *** p-value ≤0.001

[1] Source: Aebi NJ, Bringolf-Isler B, Schaffner E, Caviezel S, Imboden M, Probst-Hensch N. Patterns of cross-sectional and predictive physical activity in Swiss adults aged 52+: results from the SAPALDIA cohort. Swiss Med Wkly. 2020;150:w20266.

[2] The sample size in the SAP52+ subgroup is somewhat lower than the sample size of the current analysis, as in this comparison the few subjects not participating the accelerometry part of the SAP52+ were additionally excluded from the participant group.

Table S9: Overall interaction p-values, and adjusted odds ratios[1] of the interaction terms between frailty status[2] and age/sex, for each tooth loss indicator as an outcome. [Brackets contains the total sample size of each model]

Interaction Model	**Adjusted odds ratios (95% Confidence Interval)**		**Overall p-value of the interaction***
	Frail	Pre-frail	
Model 1: Outcome is the presence of ≤ 19 natural teeth[3] [N=1470]			
Age $_{centered}$	0.9 (0.9 - 1.1)	1.0 (0.9 - 1.1)	0.7
Female	0.5 (0.1 - 2.1)	1.3 (0.7- 2.4)	0.4
Model 2: Outcome is the presence of any RDP[4] [N=1489]			
Age $_{centered}$	0.9 (0.9 - 1.1)	0.9 (0.9 - 1.0)	0.7
Female	0.4 (0.1 - 1.9)	0.7 (0.4 - 1.4)	0.4
Model 3: Outcome is the presence of any CD[5] [N=1489]			
Age $_{centered}$	0.9 (0.8 - 1.1)	1.0 (0.9 - 1.1)	0.5
Female	1.1 (0.2 - 6.2)	0.6 (0.2 - 1.4)	0.4

RDP: Removable Dental Prostheses, CD: Complete Denture, RPD: Removable partial denture

[1] Adjusted for: smoking (never, former and current), socioeconomic status (bad, good, not good or bad), education level (low, middle, high) , age, sex (female=1, male=0), and the area of study center as a random effect.

[2] Main predictor according to modified Fried et al. frailty instrument (Fried et al. 2001), categorized depending on the number of present criteria out of five frailty criteria as follows: 0 criterion= Non-frail, 1-2 criteria= Pre-frail and 3-5 criteria= Frail. The modifications were based on the available data from SAPALDIA study.

[3] Comparing participants with examined present 19 or less natural teeth to participants with more than 19 natural teeth (missing wisdom teeth not counted; irrespective of presence of RDP).

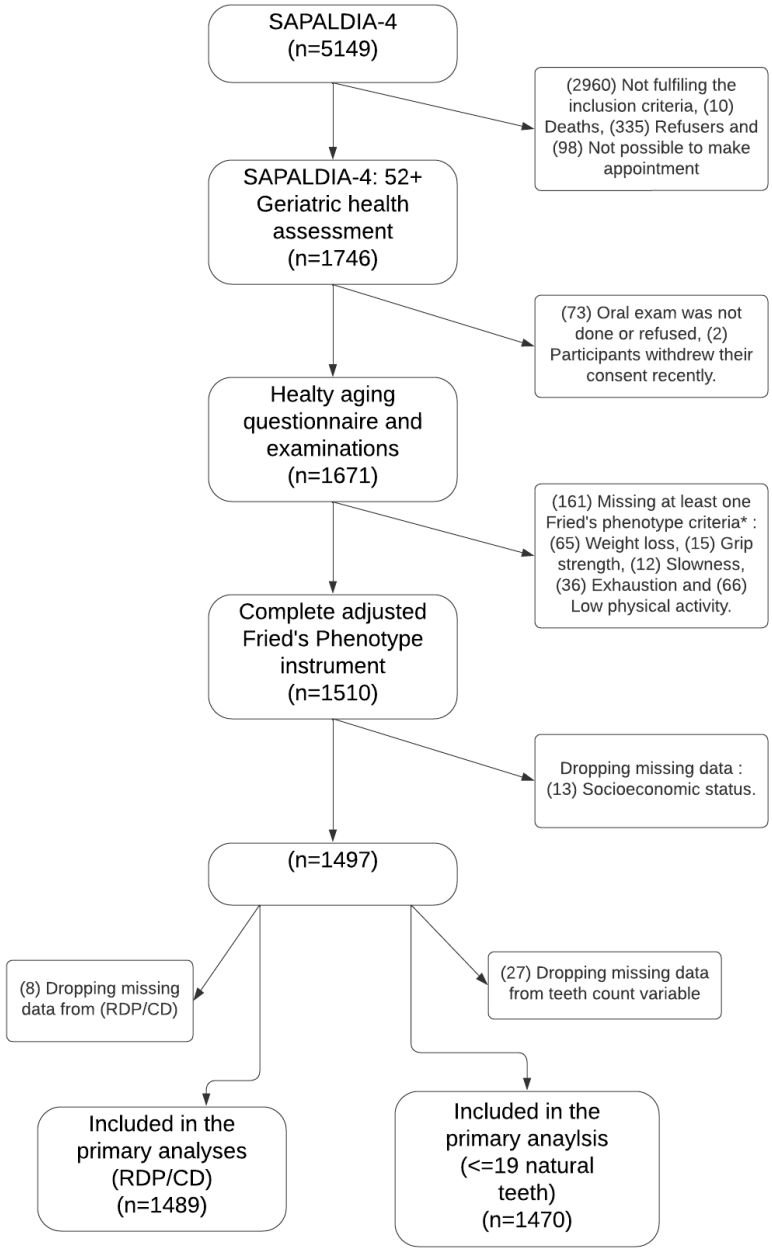
[4] Comparing participants with RDP (CD or RPD) to participants without RDP (neither RPD nor CD).

[5] Comparing participants with one or two CDs to participants without any CD, irrespective of the presence of RPD.

*P-values of the interaction were derived from the likelihood ratio test that was applied to compare the simpler model (without interaction term) nested in the more complex model (with the interaction terms).

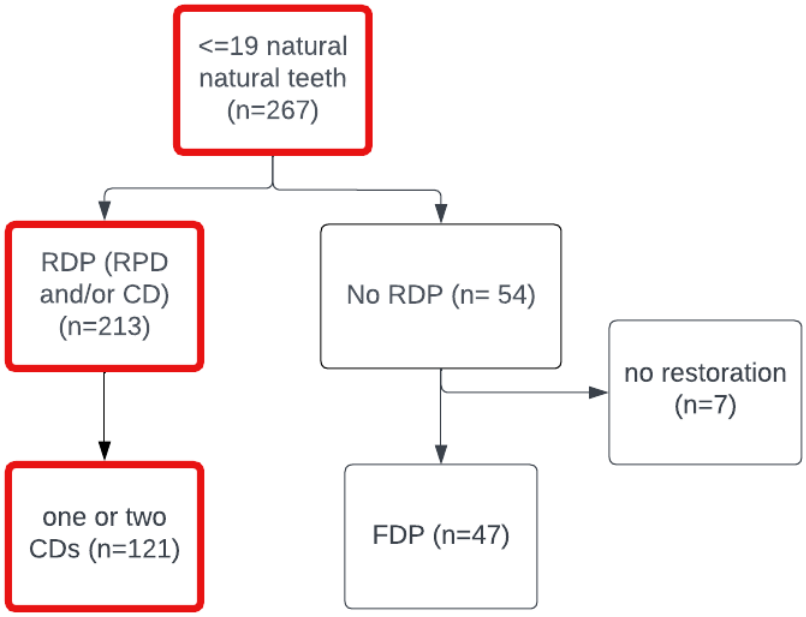
Citation: Fried, L. P., C. M. Tangen, J. Walston, A. B. Newman, C. Hirsch, J. Gottdiener, T. Seeman, R. Tracy, W. J. Kop, G. Burke, and M. A. McBurnie. "Frailty in Older Adults: Evidence for a Phenotype." *J Gerontol A Biol Sci Med Sci* 56, no. 3 (Mar 2001): M146-56. https://dx.doi.org/10.1093/gerona/56.3.m146.

Figure S1: Inclusion flowchart for participants of SAPALDIA-4 in the current primary cross-secional analyses



*One dropped observation can have more than one missing criterion.
RDP: Removable Dental Prostheses
CD: Complete Denture

Figure S2: Distribution of the dental prostheses among the study sample with 19 or less natural remaining teeth



Abbreviations
RDP: Removable Dental Prosthesis
RPD: Removable Partial Denture
CD: Complete Denture
FDP: Fixed Dental Prosthesis
Primary analyses outcome variables