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Original Study

Cross-Country Validation of the Association Between Oral Health and General Health in Community-Dwelling Older Adults

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A B S T R A C T

Objective: Oral health is known to be associated with general health, but longitudinal relationships between oral health and general health indicators have not yet been fully explored in international research.
Setting and participants: The sample consisted of 3 longitudinal databases: a sample from Belgium from the Protocol 3 project (n = 8359), a combined sample from 6 European countries (n = 2501) from the IBenC study (Belgium, Finland, Iceland, Germany, Italy, and the Netherlands), and a sample from New Zealand (n = 15,012). All clients were 65 years or older and received long-term home care services.
Methods: Bayesian models were used to analyze the associations between 3 oral health indicators (chewing difficulty, nonintact teeth, and dry mouth) and 4 aspects of general health (activities of daily living functioning, cognition, depression, and health instability). In addition, the models explored the associations between current oral health and general health status and future oral health and general health status.
Results: Clients who had poorer oral health had a higher risk of suffering from poor general health. Especially chewing difficulty was associated with all general health indicators in all data sets (odds ratios > 1). Dry mouth and nonintact teeth showed significant associations with almost all general health indicators. Additionally, having poor oral health (respectively general health) was predictive of poor general health (respectively oral health) at future assessments (significant cross-lagged parameters).
Conclusions/Implications: The results point out the need of the inclusion of oral health assessment and advice from dentists or oral health practitioners into the multidisciplinary conversation. In addition, identifying older people with oral health problems is essential in order to provide treatment and monitoring. Raising awareness for oral health is important, and policy makers should foster oral health promotion and care for older adults in order to keep them in good health.

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International scientific literature shows that oral health is associated with general health outcomes, functional performance, and well-being.[1–6] Several studies identify poor oral health as a major risk factor of aspiration pneumonia.[7–9] Reduction in saliva flow, which is often a side effect from medication use, leads to a higher risk of oral infections[10,11] such as caries or periodontitis, which in turn is associated with increased risk for diabetes and cardiovascular disease.[12,13] Also impaired chewing function can affect a person's general health and well-being.[14,15]

A recently published Belgian longitudinal study showed higher risk of poor general health status for older people having poor oral health.[16] This study showed evidence of the predictive association of oral health for general health (and vice versa). This second study aims at examining and comparing the association between oral health and general health in 3 cross-country databases of older people receiving long-term home care services. Another objective is to examine the predictive associations between the current oral health and general health status and their future status.

This study is exploratory. The rationale of the study is to apply a set of algorithms in different country databases to explore the longitudinal associations between oral health and general health and vice versa, making predictions for future assessments. No assumptions are made about how the results differ or are similar across countries. The goal is rather to verify whether associations between oral health and general health are held across samples.

Methods

Sample Selection

Three longitudinal databases were included in the study: (1) a sample from Belgium consisting of participants in the Protocol 3 project with data collection from 2010 until 2016; (2) a combined sample from 6 European countries participating in the IBenC study (Finland, Iceland, Germany, Italy, the Netherlands, and an additional sample from Belgium), with data collected between 2014 and 2016; and (3) a sample from New Zealand, where the interRAI Home Care (HC) instrument was implemented nationally. Details about the study design and data collection of the 3 samples can be found in Almeida Mello et al,[17] Garms-Homolová et al,[18] and interRAI New Zealand.[19] Protocol 3 consists of an evaluation project for home care interventions aimed at avoiding or delaying nursing home admission. The IBenC project stands for Identifying best practices for care-dependent elderly by Benchmarking Costs and outcomes of community care. This project aimed at developing a novel method to benchmark community care organizations by taking into account the quality of care and costs of care utilization. The data from New Zealand consists of a database of older people receiving care in the community.

All clients were 65 years or older and received long-term home care services. Assessments were performed every 6 months by registered health or care professionals delivering home care. They filled out the interRAI-HC instrument, an internationally validated comprehensive assessment compiling information on several domains (functional, clinical, psychosocial, environmental, and social).[20,21] If a client died, or home care services stopped before the 6-month period, the client's assessment was not included in the longitudinal analysis. On average, clients were receiving care for 14 months after baseline in the Belgian sample, for 12 months in the European sample, and for 18 months in the sample from New Zealand. The samples from New Zealand and the European countries had no missing values. Missing values for oral health items in the Belgian sample have been studied previously.[22]

Ethics Approval

The data collection from Belgium was approved by the Belgian Privacy Commission and by the ethics committees of the Université Catholique de Louvain and KU Leuven with dossier number B40320108337. The data from IBenC was approved from authorized medical ethical committees according to local country regulations. In New Zealand, national data access protocols ensured appropriate ethical clearance. Written consent was sought from all participants from all countries.

Outcome Measures

Three items from the interRAI-HC indicating oral health status were used: nonintact teeth, chewing difficulty, and dry mouth. "Nonintact teeth" means that the client has broken, fragmented, or loose natural teeth. The item about "dry mouth" indicates that the client does not make enough saliva to keep the mouth moist or that there is difficulty in moving a food bolus in the mouth due to dryness. The item about chewing difficulty indicates that the client is unable to chew food easily and without pain or difficulties, regardless of the cause (eg, the person uses ill-fitting dentures or has a neurologically impaired chewing mechanism, temporomandibular joint pain, or a painful tooth). These 3 items are scored by asking the clients whether these conditions are present, by observations during meals, or by clients spontaneously reporting the problems.[23]

In order to measure general health, 4 interRAI validated scales were administered: the Activities of Daily Living Hierarchy scale (ADL scale), the Cognitive Performance Scale (CPS scale with 5 items), the Depression Rating Scale (DRS), and the Changes in Health, End-Stage Disease, Signs, and Symptoms Scale (CHESS).[24–27] The interRAI ADL and CPS scales measure ADL and cognitive function, and have a 0 to 6 range. The interRAI DRS (0-14 range) measures the presence of depressive symptoms. The CHESS (0-5 range) identifies clients at risk of adverse outcomes and with health instability. For all these scales, higher values indicate greater severity. In addition, the following characteristics were included in the analysis as covariates: age, gender, living situation (alone or not), and having at least 1 informal caregiver (yes or no). In the sample from Belgium, a covariate was added to account for the type of innovative home care project older people were enrolled in (case management, occupational therapy at home, night care, etc). In Belgium, older people were receiving home care interventions by nurses, occupational therapists, physiotherapists, and other professional caregivers. In the European sample and in the sample from New Zealand, clients were receiving nursing care as usual.

Analyses

All analyses were performed in the Bayesian framework.[28] The models were implemented in R (version 3.2.5) using runjags[29] and rstan packages.[30] Four chains were run, and convergence was checked by examining the trace-plots. The proportional odds model was applied to analyze the associations between general health indicators and oral health indicators. In addition, 12 modified bivariate autoregressive models were fit for the pairs between the oral health indicators (3 items) and the general health indicators (4 items).[31]

The first analysis explored the association between the items from the oral health section of the interRAI-HC and interRAI scales. Associations were expressed as odds ratios. The second analysis examined the predictive association of a given oral health (or general health) status combined with a general health (or oral health) status to predict general health (or oral health) at a time point in the future.

Results

Table 1 presents descriptive characteristics of the individuals in the samples. The mean age of clients was similar; however, female clients were less frequent in the New Zealand sample. The median scores on the interRAI scales did not differ for ADL. For the other scales, the differences

Table 1
Descriptive Characteristics of the 3 Samples

Characteristics	Belgium (n = 8359)	IBenC (n = 2501)	New Zealand (n = 15,012)
Age, mean (SD)	81.2 (7.0)	82.7 (7.3)	83.0 (7.4)
Gender, % female	68.3	67.9	59.4
ADL Hierarchy (0-6), median	2	2	2
ADL 3-6, %	45.70	44.66	25.98
CPS score 0-6, median	1	1	2
CPS score 3-6, %	29.56	34.56	29.98
DRS score 0-14, median	1	0	0
DRS score 3-14, %	28.16	23.50	16.96
CHESS score 0-5, median	1	1	2
CHESS score 3-5, %	9.69	9.80	27.96
Nonintact teeth, %	13.1	12.9	10.3
Chewing difficulty, %	11.0	11.0	10.0
Dry mouth, %	13.6	14.9	10.7
Living alone, %	55.1	59.1	30.8
Has at least 1 informal caregiver, %	78.6	93.4	97.0

SD, standard deviation.

were of 1 point. Almost half of the clients in the Belgian and in the IBenC project samples showed moderate to severe ADL impairment, whereas it was 26% in the New Zealand sample. Cognitive impairment was the highest in the IBenC sample (34.6%) and very similar between the samples from Belgium and New Zealand (about 30%). In the Belgian sample, about 28% of the clients showed depressive symptoms, followed by the clients in the IBenC sample and New Zealand. The largest difference emerged from the CHESS. About 28% of the clients in the New Zealand sample showed health instability, whereas only about 10% in the samples from Belgium and IBenC project. People receiving full interRAI-HC assessments in New Zealand seem to have more clinical issues than in the European countries. This can be explained by the fact that formal home care provided by nurses is more widely available in the European countries than in New Zealand. In the European countries, nurses also give all types of ADL help, whereas in New Zealand this task is mostly provided by home support workers (health aides). Nurses focus more on clinical tasks and on incontinence care. In addition, clients in the New Zealand sample were the least likely to live alone (31%). Clients in the Belgian sample were the least likely to have an informal caregiver (79%). Between 10% and 15% of the clients presented oral health problems, and the most common problem was dry mouth.

Association Between Oral Health and General Health

Table 2 shows the associations (odds ratios) from the proportional odds model between oral health status and general health indicators. Most of the significant odds ratios were higher than 1. This means that clients with oral health problems were more likely to suffer from poor general health, compared with older persons without these problems. Among the 3 oral health items, chewing difficulty was highly associated with all general health items in all 3 samples. In the sample from Belgium, the odds ratio for chewing difficulty and CPS was 5 times higher than in the other samples. In addition, nonintact teeth was associated with CPS and DRS in the 3 samples. In the samples from IBenC project and New Zealand, nonintact teeth was also associated with ADL functioning, and in the IBenC sample, the odds ratio was almost 4 times higher than in the sample from New Zealand. Moreover, nonintact teeth was associated with CHESS for Belgium and for the IBenC sample, but not for New Zealand.

Dry mouth was significantly associated with DRS and CHESS in all 3 samples, but this indicator was only associated with ADL impairment in the Belgian data set. In the other samples, there was no association between dry mouth and ADL function. A significant inverted association between dry mouth and cognitive function (CPS) was found in the samples from IBenC project and New Zealand. An inverse association means that people with dry mouth showed less cognitive problems. For Belgium, the results pointed in the same direction although the association was not significant.

Predictive Association of Oral Health and General Health Items

Figures 1, 2, and 3 show the significant pairs of associations between oral health and general health indicators. The arrows were drawn from the estimates for the cross-lagged parameters (Supplementary Tables S1, S2, and S3; gamma estimates: γ_{12} and γ_{21}). A full arrow means a prediction with a positive association, showing that the presence of a current health problem is associated with an increased likelihood of the presence, or worsening, of another health problem at a future assessment. Therefore, a full arrow starting at an oral health item and pointing to a general health item indicates a positive association between these indicators, meaning that given a certain general health status, the presence of an oral health problem is associated with greater severity or impairment on the general health status at a future assessment. A bidirectional arrow means that the association is reciprocal, so it is significant in both directions, from an oral health item to a general health item and vice versa.

A dotted arrow means a prediction with an inverse association, showing that the presence of a current problem is associated with higher odds of an improvement or absence of another problem in the future.

The numbers on the arrows indicate the estimates for the cross-lagged parameters (gamma estimates: γ_{12} and γ_{21}). As the highest

Table 2
Odds Ratios of ADL, CPS, DRS, and CHESS Scores for Clients With Oral Health Problems Compared to Individuals Without

Oral Health Indicators	General Health Indicators	Belgium (n = 8359)			IBenC (n = 2501)			New Zealand (n = 15,012)		
		Odds Ratio	95% Credible Interval		Odds Ratio	95% Credible Interval		Odds Ratio	95% Credible Interval	
NT (yes = 1)	ADL	1.19	0.92	1.56	**4.32**	2.49	7.45	**1.14**	1.03	1.26
CD (yes = 1)		**3.45**	2.63	4.55	**2.12**	1.18	3.76	**1.90**	1.72	2.09
DM (yes = 1)		**1.39**	1.09	1.80	0.76	0.45	1.29	1.03	0.93	1.14
NT (yes = 1)	CPS	**2.38**	1.63	3.46	**2.84**	1.67	4.87	**1.17**	1.02	1.35
CD (yes = 1)		**10.88**	7.35	16.29	**2.06**	1.17	3.61	**1.75**	1.53	2.00
DM (yes = 1)		0.97	0.68	1.37	**0.60**	0.37	0.99	**0.58**	0.51	0.66
NT (yes = 1)	DRS	**1.71**	1.29	2.26	**1.62**	1.04	2.56	**1.15**	1.01	1.29
CD (yes = 1)		**3.70**	2.77	5.04	**3.60**	2.24	5.84	**1.69**	1.49	1.92
DM (yes = 1)		**3.71**	2.85	4.86	**2.54**	1.72	3.75	**2.46**	2.18	2.76
NT (yes = 1)	CHESS	**1.29**	1.07	1.55	**1.56**	1.09	2.24	1.01	0.92	1.11
CD (yes = 1)		**3.10**	2.52	3.83	**2.54**	1.68	3.84	**1.72**	1.57	1.89
DM (yes = 1)		**2.69**	2.23	3.23	**3.65**	2.55	5.19	**2.27**	2.08	2.48

Note. Bold values indicate significant odds ratios.
CD, chewing difficulty; DM, dry mouth; NT, nonintact teeth.
Analysis controlled for age, gender, living situation, and presence of at least 1 informal caregiver.

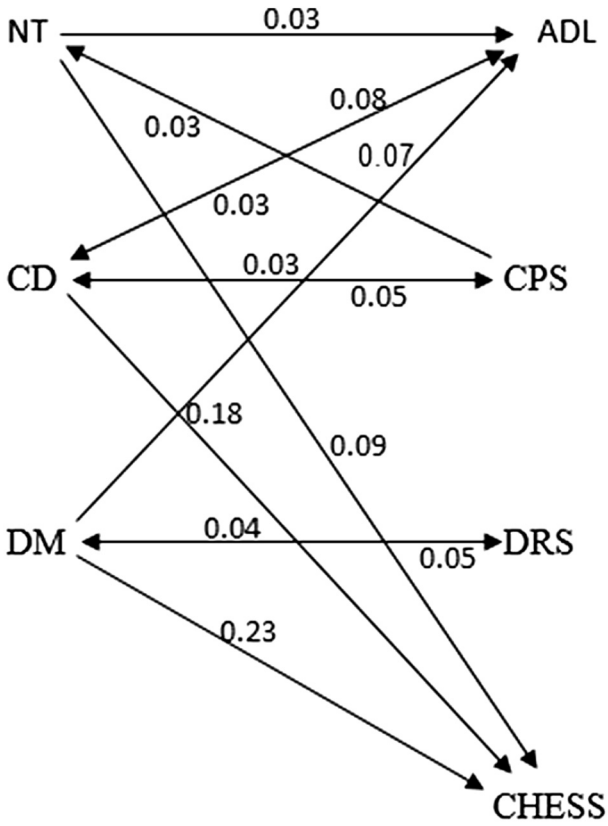

Fig. 1. Significant associations of the current oral health (respectively general health) status to the future general health (respectively oral health) in the Belgian data set.

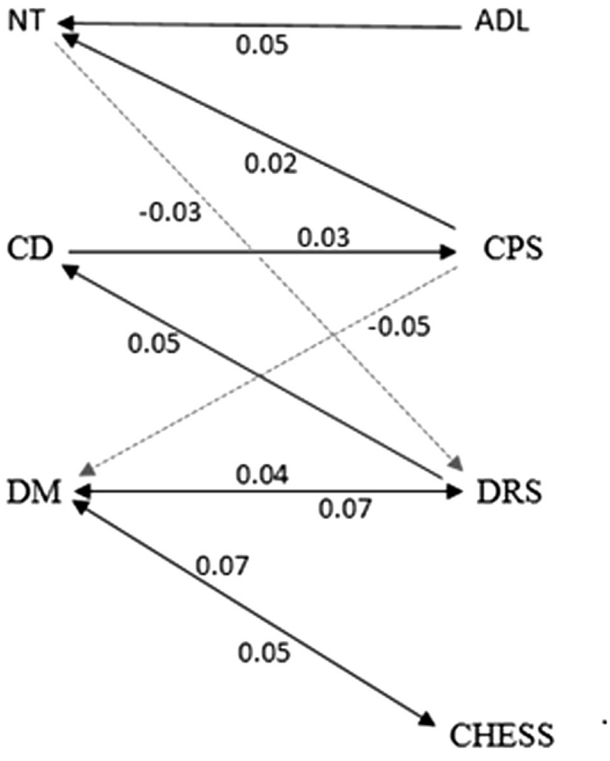

Fig. 2. Significant associations of the current oral health (respectively general health) status to the future general health (respectively oral health) in the IBenC data set.

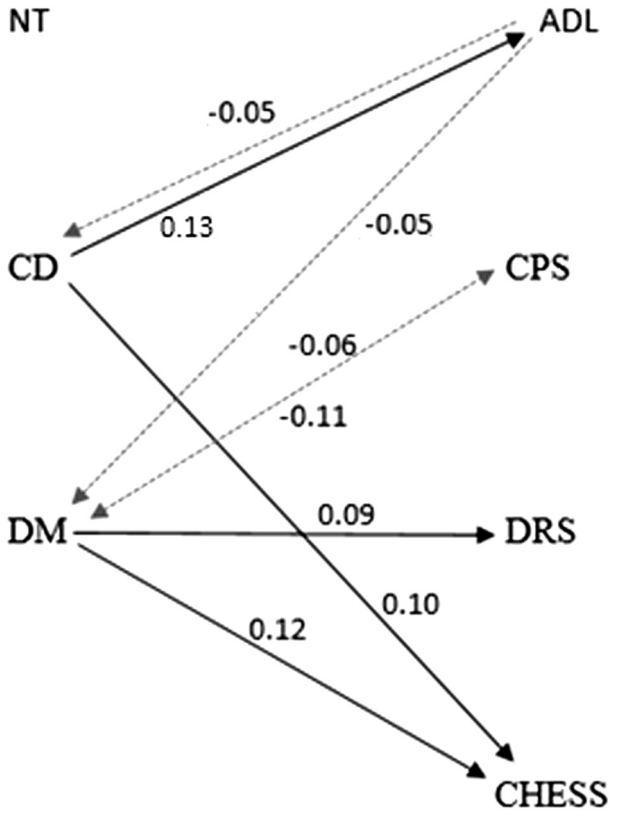

Fig. 3. Significant associations of the current oral health (respectively general health) status to the future general health (respectively oral health) in the IBenC data set from New Zealand.

part of the prediction is made by the parameters γ_{11} and γ_{22}, which are the parameters related to the situation of the same indicator in the previous time period, these values are often close to 1. The values of the cross-lagged parameters are normally much lower than 1 as most of the prediction is made by the parameters γ_{11} and γ_{22}. The cross-lagged parameter γ_{12} (respectively γ_{21}) is an indication of the amount of extra information that the current oral health (respectively general health) indicator provides to the future general health (respectively oral health) indicator. In case the cross-lagged parameters are significant, like all the estimates shown in the figure, this means that they are able to add to the prediction in the model.

Figure 1 shows the significant associations between oral health and general health indicators in the Belgian sample. The results show that, given current ADL, current chewing status is predictive of ADL status at the next time point. The bidirectional arrow shows that current ADL status is also predictive of chewing difficulty at the next time point. In summary, the estimate for the cross-lagged parameters indicates that given the current status of ADL (respectively chewing difficulty), the current chewing difficulty (respectively ADL) provides a significant amount of information in predicting the future value of ADL (respectively chewing difficulty). Chewing difficulty was also predictive of health instability and cognitive impairment. The bidirectional arrow also shows that CPS, unlike CHESS, was predictive of chewing difficulty at the next time point. Nonintact teeth was predictive of CHESS and ADL at the next time point, but only CPS was predictive of nonintact teeth. Dry mouth was predictive of DRS at the next time point and vice versa, showing that current dry mouth status was associated with more depressive symptoms at follow-up and vice versa. Dry mouth was also predictive of ADL at the next time point. In

addition, given the current health instability status, dry mouth was predictive of health instability at the next time point.

The results for the pairs of associations between oral health and general health indicators from the IBenC data set can be found in Figure 2. In this model, given current DRS and CHESS, current dry mouth predicts both DRS and CHESS at a time point in the future. DRS and CHESS can also predict dry mouth at the next time point. In addition, DRS is predictive of chewing difficulty. The results also show that CPS and ADL are both predictive of nonintact teeth.

The dotted arrow from nonintact teeth to DRS shows a significant inverse association between these indicators, as well as the dotted arrow from CPS to dry mouth. This means that a decrease in cognitive problems is associated with increased odds for dry mouth in the future and that presence of nonintact teeth is associated with less depressive symptoms in the future.

Figure 3 shows the associations between oral health and general health indicators from the New Zealand sample. The results point out that given a current ADL status, chewing difficulty is predictive of ADL. The dotted line in the opposite direction shows a significant inverse association between ADL and chewing difficulty. In addition, given current CHESS, chewing difficulty is predictive of CHESS in the future. Dry mouth is predictive of DRS and CHESS at a time point in the future, but no associations were found between nonintact teeth and the health indicators.

The dotted lines show a significant inverse association between ADL and dry mouth, as well as between CPS and dry mouth and vice versa.

In summary, the predictive association between dry mouth and health instability emerged in all 3 samples, as well as between dry mouth and depressive symptoms. An inverse predictive association was found between dry mouth and CPS in the samples from IBenC and New Zealand but not in the Belgian sample. For CPS and the prediction of nonintact teeth, the association emerged for the samples from Belgium and IBenC, but not for New Zealand, as well as the prediction between nonintact teeth and ADL. Chewing difficulty showed predictive association for ADL and CHESS for Belgium and New Zealand.

Discussion

This research paper shows evidence of the association between oral health and general health using large cross-country databases: Belgium, IBenC project, and New Zealand. When comparing the odds ratios for oral health and general health for the 3 study populations, most cross-sectional associations were similar. The associations between chewing difficulty and ADL, cognition, depressive symptoms, and health instability were confirmed. Moreover, the associations between nonintact teeth and cognition, as well as nonintact teeth and depressive symptoms, were verified, as were the associations between dry mouth and depressive symptoms and dry mouth and health instability. The results show the relevance of oral health in relation to general health and vice versa. Strong significant associations between oral health and general health were confirmed in the 3 data sets, providing evidence of robust interrelation between oral health and general health.

In practice, the results indicate that an oral health assessment and the treatment of oral health problems should be fostered, and that this can help older people to remain in good health. The treatment of oral health problems, especially when complemented with tailored nutritional advice, can avoid nutritional intake deficiencies, which in turn can prevent general health problems.[32–34] In addition, associations show that if older people have good general health, they seem to have better oral health.[16]

In our results, chewing difficulty was associated with each of the general health indicators. Chewing difficulty indicates difficulty in masticating and can have many causes (eg, ill-fitting dentures, neurologic impairment, temporomandibular joint pain, painful tooth, etc); however, the cause itself is not being registered within the interRAI assessment, but is the occurrence of the problem. The problem can be detected as a result of the comprehensiveness of the assessment and the systematic follow-up. Further examination is needed to find the direct cause and to start adequate treatment.[34-36] Dry mouth and nonintact teeth showed significant associations with almost all general health indicators in the 3 countries. The association between nonintact teeth and general health is not well documented in the scientific literature, and this study can trigger further research. Nonintact teeth, however, is a rather vague description of a dental condition and can imply both infectious (caries) and noninfectious (eg attrition, erosion) dental conditions. The mechanism underlying the association between nonintact teeth and general health conditions depends on the specific etiology of the dental disease.

The results also suggest that dry mouth is associated with better cognitive function. The latter finding may be explained by the fact that drugs for dementia often induce dry mouth and that the drug-induced cognitive improvement is thereby associated with dry mouth.[37,38]

In the population of our study, we suspect that the highest contributor to dry mouth is medication use, seen by the prevalence of polypharmacy in older adults.[39] On the other hand, functional loss or cognitive problems are most likely the contributors to nonintact teeth and chewing difficulty as older people lose their capacity to perform self-care sufficiently. Addressing dry mouth, nonintact teeth, and chewing difficulty will require different approaches. A review of the medication could be a possible strategy to treat dry mouth, as well as nondrug treatments for depression and anxiety.[37,40–42] For nonintact teeth and chewing difficulty, dental checkups and care, including support with daily oral self-care, could be effective.[43,44]

The predictions from the second analysis differed in some cases but the model provided validation for the ability to predict outcomes, and the results were significant. This finding is important in order to work on prevention of oral health and general health problems. The inclusion of oral health indicators in longitudinal research of health outcomes, although important, is rarely done. Raising awareness for oral health assessment and treatment is advisable. Policy makers should foster oral health promotion and care in order to keep older adults in good health.

Although the interRAI assessments are comprehensive and have proven validity for many aspects of general health (cognition, functional performance, depressive symptoms, health instability, etc), some authors point out that the items about oral health from the previous version of the interRAI instruments (RAI 2.0) did not detect all oral health problems present, contesting their validity.[45–47] This is due to lack of completeness and unclear wording of the items, or due to lack of training. A European study found substantial agreement with regard to inter-rater reliability and a kappa of 0.81 for test-retest reliability on the interRAI items about nutrition and oral status, among nursing home residents.[48] In our study, professional caregivers received training to fill out the items in general, and the assessment was not only based on self-report. This may have mitigated the problem, but further research is needed to evaluate whether these items should be adapted or replaced by more valid and sensitive oral health items.

Strengths and Limitations

A strength of the present study was the availability of large longitudinal databases. The tested Bayesian models can be considered more appropriate than regression analysis because of the complexity of the data. Further, this approach was chosen for the more flexible modeling tools in Bayesian software such as Stan.

A limitation of the study was the selection bias, as only clients receiving home care were included. The population in the study is thus not representative of a general population of older people in the community. Because of the General Data Protection Regulation,[49] the

3 data sets could not be merged and, therefore, parameter differences between the samples and the models could not be tested and the construction of 1 large model was not possible. In addition, no data on medication use or diagnoses could be included in the analysis. Underdetection of oral health problems using the interRAI items was previously mentioned in other studies but could not be tested or evaluated in this study.

Conclusions and Implications

The results point out the need of the inclusion of oral health assessment and advice from dentists or oral health practitioners into the multidisciplinary conversation. This would allow for the development of care plans focusing also on preventing oral health problems, with the broader goal of improving general health. The interRAI assessments can be used to trigger decision-support algorithms called Client Assessment Protocols (CAPs).[21] An oral health CAP has not yet been developed but it would be an asset in order to identify clients who have current oral health problems and clients who are at risk of developing them.

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Appendix 1

Supplementary Table S1
Parameter Estimates and 95% Credible Intervals for All γ′s for All Pairs of 1 Oral Health and 1 General Health Indicator: Belgium

Pair	γ_{11}			γ_{12}			γ_{21}			γ_{22}		
	Estimate	95% Credible Interval		Estimate	95% Credible Interval		Estimate	95% Credible Interval		Estimate	95% Credible Interval	
ADL and NT	0.83	0.82	0.84	**0.03**	**0.001**	**0.06**	0.00	−0.02	0.03	0.98	0.98	0.99
ADL and CD	0.83	0.82	0.84	**0.08**	**0.04**	**0.11**	**0.03**	**0.002**	**0.06**	0.97	0.95	0.98
ADL and DM	0.83	0.82	0.84	**0.07**	**0.04**	**0.11**	0.00	−0.03	0.03	0.96	0.95	0.97
CPS and NT	0.93	0.93	0.94	0.02	0.00	0.04	**0.03**	**0.01**	**0.06**	0.98	0.98	0.99
CPS and CD	0.93	0.93	0.94	**0.03**	**0.01**	**0.05**	**0.05**	**0.02**	**0.08**	0.96	0.95	0.97
CPS and DM	0.93	0.93	0.94	0.02	−0.01	0.04	0.02	−0.01	0.06	0.96	0.95	0.97
DRS and NT	0.88	0.86	0.89	0.01	−0.02	0.03	0.01	−0.02	0.03	0.98	0.98	0.99
DRS and CD	0.87	0.86	0.88	0.02	−0.01	0.05	0.01	−0.02	0.04	0.97	0.95	0.98
DRS and DM	0.87	0.86	0.88	**0.04**	**0.01**	**0.07**	**0.05**	**0.01**	**0.08**	0.96	0.94	0.97
CHESS and NT	0.57	0.54	0.60	**0.09**	**0.05**	**0.14**	0.02	−0.01	0.04	0.98	0.98	0.99
CHESS and CD	0.56	0.53	0.59	**0.18**	**0.13**	**0.23**	0.01	−0.02	0.05	0.97	0.96	0.98
CHESS and DM	0.55	0.52	0.59	**0.23**	**0.18**	**0.28**	0.00	−0.03	0.03	0.96	0.95	0.97

Note. Bold values indicate significant estimates for γ12 and γ21.
CD, chewing difficulty; DM, dry mouth; NT, nonintact teeth.

Appendix 2

Supplementary Table S2
Parameter Estimates and 95% Credible Intervals for All γ′s for All Pairs of 1 Oral Health and 1 General Health Indicator: IBenC Sample

Pair	γ_{11}			γ_{12}			γ_{21}			γ_{22}		
	Estimate	95% Credible Interval		Estimate	95% Credible Interval		Estimate	95% Credible Interval		Estimate	95% Credible Interval	
ADL and NT	0.93	0.93	0.94	0.02	0.00	0.04	**0.05**	**0.02**	**0.08**	0.98	0.98	0.99
ADL and CD	0.93	0.93	0.94	0.00	−0.02	0.02	0.01	−0.01	0.04	0.98	0.98	0.99
ADL and DM	0.93	0.93	0.94	−0.01	−0.03	0.01	−0.02	−0.05	0.00	0.98	0.97	0.98
CPS and NT	0.93	0.93	0.94	0.01	−0.01	0.03	**0.02**	**0.002**	**0.05**	0.98	0.98	0.99
CPS and CD	0.93	0.93	0.93	**0.03**	**0.003**	**0.05**	0.00	−0.03	0.03	0.98	0.98	0.99
CPS and DM	0.93	0.93	0.94	0.01	−0.01	0.03	**−0.05**	**−0.08**	**−0.03**	0.97	0.96	0.98
DRS and NT	0.89	0.89	0.91	**−0.03**	**−0.06**	**0.001**	0.02	0.00	0.04	0.98	0.98	0.99
DRS and CD	0.89	0.89	0.91	0.01	−0.02	0.04	**0.05**	**0.02**	**0.08**	0.98	0.97	0.99
DRS and DM	0.89	0.89	0.90	**0.04**	**0.01**	**0.06**	**0.07**	**0.04**	**0.10**	0.97	0.96	0.98
CHESS and NT	0.73	0.71	0.75	0.02	−0.02	0.07	0.03	0.00	0.05	0.98	0.98	0.99
CHESS and CD	0.73	0.70	0.75	0.05	0.00	0.09	0.02	−0.01	0.05	0.98	0.98	0.99
CHESS and DM	0.73	0.70	0.75	**0.07**	**0.03**	**0.12**	**0.05**	**0.02**	**0.08**	0.97	0.96	0.98

Note. Bold values indicate significant estimates for γ12 and γ21.
CD, chewing difficulty; DM, dry mouth; NT, nonintact teeth.

Appendix 3

Supplementary Table S3
Parameter Estimates and 95% Credible Intervals for All γ′s for All Pairs of 1 Oral Health and 1 General Health Indicator: New Zealand

Pair	γ_{11}			γ_{12}			γ_{21}			γ_{22}		
	Estimate	95% Credible Interval		Estimate	95% Credible Interval		Estimate	95% Credible Interval		Estimate	95% Credible Interval	
ADL and NT	0.24	0.20	0.28	0.01	−0.05	0.07	0.02	−0.02	0.06	0.96	0.95	0.97
ADL and CD	0.23	0.20	0.27	**0.13**	**0.07**	**0.19**	**−0.05**	**−0.09**	**−0.01**	0.93	0.91	0.95
ADL and DM	0.24	0.20	0.28	0.05	−0.01	0.10	**−0.05**	**−0.10**	**−0.01**	0.92	0.89	0.93
CPS and NT	0.66	0.63	0.68	−0.04	−0.09	0.01	0.00	−0.04	0.03	0.96	0.95	0.97
CPS and CD	0.66	0.63	0.68	0.01	−0.04	0.06	−0.01	−0.05	0.03	0.92	0.90	0.94
CPS and DM	0.66	0.63	0.68	**−0.06**	**−0.10**	**−0.01**	**−0.11**	**−0.15**	**−0.06**	0.91	0.88	0.93
DRS and NT	0.62	0.59	0.64	0.00	−0.05	0.05	−0.03	−0.07	0.02	0.96	0.95	0.97
DRS and CD	0.62	0.59	0.64	0.03	−0.03	0.08	0.00	−0.05	0.04	0.93	0.90	0.94
DRS and DM	0.61	0.59	0.64	**0.09**	**0.05**	**0.14**	0.03	−0.02	0.07	0.92	0.89	0.93
CHESS and NT	0.30	0.26	0.33	−0.05	−0.11	0.01	0.00	−0.03	0.04	0.96	0.95	0.97
CHESS and CD	0.29	0.26	0.33	**0.10**	**0.05**	**0.16**	−0.02	−0.06	0.02	0.93	0.90	0.94
CHESS and DM	0.29	0.26	0.33	**0.12**	**0.06**	**0.17**	−8E−04	−0.04	0.04	0.92	0.90	0.94

Note. Bold values indicate significant estimates for γ12 and γ21.
CD, chewing difficulty; DM, dry mouth; NT, nonintact teeth.