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RESEARCH

Development and validation of a dynamic nomogram for predicting cognitive impairment risk in older adults with dentures: analysis from CHARLS and CLHLS data

Tongtong Guo[1,2,3], Xiaoqing Zhao[2,4], Xinyi Zhang[2,4], Yang Xing[5], Zhiwei Dong[1,2], Haiyan Li[1,2,3], Runguo Gao[2], Zhiping Huang[6], Xue Bai[7], Wengui Zheng[2,4*], Qi Jing[1,2,3*] and Shanquan Chen[8]

Abstract

Background and aims Cognitive impairment is a common issue among older adults, with denture use identified as a potential, easily recognizable clinical risk factor. However, the link between denture wear and cognitive decline in older Chinese adults remains understudied. This study aimed to develop and validate a dynamic nomogram to predict the risk of cognitive impairment in community-dwelling older adults who wear dentures.

Methods We selected 2066 elderly people with dentures from CHARLS2018 data as the development and internal validation group and 3840 people from CLHLS2018 as the external validation group. Develop and treat the concentrated unbalanced data with the synthetic minority oversampling technique, select the best predictors with the LASSO regression ten-fold cross-validation method, analyze the influencing factors of cognitive impairment in the elderly with dentures using Logistic regression, and construct a nomogram. Subject operating characteristic curves, sensitivity, specificity, accuracy, precision, F1 score, calibration curve, and decision curve were used to evaluate the validity of the model in terms of identification, calibration, and clinical validity.

Results We identified five factors (age, residence, education, instrumental activities of daily living, and depression) to construct the nomogram. The area under the curve of the prediction model was 0.854 (95%CI 0.839–0.870) in the development set, 0.841 (95%CI 0.805–0.877) in the internal validation set, and 0.856 (95%CI 0.838–0.873) in the external validation set. Calibration curves indicated significant agreement between predicted and actual values, and decision curve analysis demonstrated valuable clinical application.

Conclusions Five risk factors, including age, place of residence, education, instrumental activities of daily living, and depression level, were selected as the final nomogram to predict the risk of cognitive impairment in elderly denture wearers. The nomogram has acceptable discrimination and can be used by healthcare professionals and community health workers to plan preventive interventions for cognitive impairment among older denture-wearing populations.

Keywords Dentures, Cognitive impairment, Risk prediction, Nomogram

*Correspondence:
Wengui Zheng
wgzheng@sdsmu.edu.cn
Qi Jing
jingq@sdsmu.edu.cn
Full list of author information is available at the end of the article

Introduction

Dementia is the seventh leading cause of death globally and a major contributor to disability and dependency among older adults [1]. In 2019, approximately 50 million people worldwide suffered from dementia, a figure expected to double by 2050 [2]. In China, dementia-related mortality has risen sharply since 1990, reaching a rate of 22.5 per 100,000 people. By 2050, the number of individuals aged 60 and above with dementia in China is projected to reach 48.98 million. [3] Despite significant research efforts, there is currently no cure for dementia, making early detection and intervention crucial for slowing its progression. [4] Studies indicate that mild cognitive impairment (MCI), a critical stage in the progression from healthy aging to dementia, can be partially reversed with early detection and intervention. [5] Therefore, early identification of individuals at high risk of cognitive decline is essential for slowing disease progression.

Oral health serves as a vital indicator of overall well-being in older adults and has garnered increasing attention due to its potential link with cognitive function [6, 7]. Studies have demonstrated that oral diseases impact physiological functions such as chewing, pronunciation, and swallowing, and are closely associated with cognitive decline [8]. Factors such as tooth loss and the use of dentures may contribute to brain health deterioration through mechanisms like chronic inflammation and neurodegenerative processes. Especially for older adults who wear dentures, the changes in the oral environment may exacerbate the complexity of this association [9]. A recent community cohort study found that 76% of adults over 65 years of age have experienced tooth loss and up to 29% wear dentures, with a strong association between denture wearing and cognitive impairment [10]. Dentures are a key clinical indicator of oral health in older adults, and focused research on this group can help clarify the cognitive health risks they face, offering insights into targeted prevention strategies.

Few previous studies have focused on predicting cognitive impairment in people who wear dentures. A meta-analysis indicated that tooth loss is a risk factor for cognitive impairment and dementia, rather than specifically predicting cognitive impairment risk in individuals with tooth loss [5]; Another cohort study demonstrated that denture use was strongly associated with the risk of cognitive impairment; [11] Other studies have demonstrated that some clinical predictors, such as fasting glucose, hemoglobin A1c, and vitamin intake, provide modest predictive power for the risk of cognitive impairment in people with poor oral conditions [12, 13]. However, collecting and screening these predictors is difficult and expensive, and models built based on these predictors may not be appropriate for use by the general population [14]. Wearing dentures is an easily identifiable, cost-effective, and relatively efficient indicator of oral health status. Based on this, this study aims to assess the risk of cognitive impairment in older people with dentures and provide a new perspective and tool for further promoting oral health management and cognitive impairment prevention in elderly people. It has crucial practical significance, especially in communities or remote settings where there is a lack of professional healthcare workers.

Therefore, this study developed and validated a dynamic nomogram using data from the China Health and Retirement Longitudinal Study (CHARLS) and the Chinese Longitudinal Healthy Longevity Survey (CLHLS) to predict the risk of cognitive impairment in Chinese older adults with dentures. This provides a scientific foundation for early intervention and personalized management strategies.

Methods

Participants

This study utilized data from the CHARLS and CLHLS datasets. CHARLS surveys individuals aged 45 and older across 28 provinces, 150 counties, and 450 villages in China, covering over 10,000 households and 17,000 individuals. The survey collects data on demographics, health, medical and insurance status, employment, income, expenses, and assets, with five waves of data released. CLHLS, a collaboration between Peking University and Duke University since 1998, has conducted seven follow-up surveys in 22 provinces (2000–2018). It focuses on older individuals and their families, gathering information on psychological characteristics, cognition, personality, health, and lifestyle.

In the 2018 CHARLS dataset, which initially included 10,983 participants aged 60 years and above, we applied the following inclusion criteria: (i) age $\geq$ 60 years; (ii) participants who wear dentures. We excluded samples with incomplete data or missing key variables such as cognitive assessment, resulting in the exclusion of 8,917 samples. This left us with a final sample of 2,066 for model development. To ensure the robustness of the model, the data were randomly split in a 7:3 ratio, with 70% allocated for model development and 30% for internal validation. The 2018 CLHLS dataset included 15,854 samples aged 60 years and above. After excluding 12,014 irrelevant or missing samples, we had 3,840 samples available for external model verification, the specific inclusion and exclusion criteria of the data were consistent with CHARLS. Supplementary Fig. 1. demonstrates the procedure of data inclusion and exclusion.

Assessment of denture

The assessment for dentures in CHARLS is "Do you wear dentures?" The assessment for dentures in CLHLS is consistent with this. Participants were categorized into 'denture wearing' and 'not denture wearing' according to their participants of 'no' or 'yes', respectively. Only older adults who answered "yes" were included in our study.

Assessment of cognitive impairment

The cognitive assessment utilized in CHARLS is adapted from the Health and Retirement Study (HRS) and based on the Telephone Interview for Cognitive Status (TICS) [15]. Prior research has established that the global cognitive function score derived from this assessment demonstrates strong validity and reliability in the middle-aged and older Chinese population [16, 17]. The assessment evaluates two key domains: episodic memory and executive function. The memory task involves immediate and delayed recall of 10 unrelated words, with a memory score calculated as the sum of both recall tasks, ranging from 0 to 10 [18]. Executive function includes components from the TICS mental status examination, such as identifying the current year, month, day, day of the week, and season, along with serial subtraction of 7 from 100 five consecutive times. Additionally, a drawing task assesses visuospatial abilities, where participants are required to replicate a given image . The executive function score totals 11 points. Overall cognitive function is measured by summing the episodic memory and executive function scores, with a total possible score of 21, where higher scores indicate better cognitive performance. Cognitive impairment is defined as a score below 6 [19].

CLHLS assessed cognitive function with the Chinese version of the Mini-Mental State Test (MMSE). It comprises four dimensions: cognitive orientation, computation, recall, and language ability. Several questions of CMMSE were altered regarding cultural acceptability; some previous studies have also shown its reliability and validity. Specifically, previous studies have shown that when respondents present with poor health or cognitive limitations, They are less likely to be able to handle relatively complex tasks [20]. As such, we categorize "unanswerable" answers as false answers in line with previous studies [21]. This method was applied in earlier studies across the board and does not introduce any potential biases [22]. The total MMSE score is from 0 to 30, while the cognitive impairment is from CMMSE below 18 points.

Candidate predictors

To strengthen the applicability and comprehensiveness of the prediction model, we expanded the scope of our literature review. While we focused primarily on individuals aged 60 and above, we also considered studies involving middle-aged adults, particularly those experiencing early onset of oral health issues, to explore potential early indicators of cognitive impairment. Variables were selected based on several criteria: (i) a direct or well-established indirect relationship with cognitive impairment, (ii) feasibility for assessment through simple questions without the need for invasive procedures, and (iii) studies encompassing both middle-aged and elderly populations. Additionally, although our primary interest was in denture use, we also reviewed broader aspects of oral health, such as edentulism, to ensure a more comprehensive evaluation of cognitive risks. Based on this review, we identified potential predictors, including sex, age, education, marital status, residence, sleep duration, sleep quality, smoking status, alcohol intake, self-rated health (SRH), physician-diagnosed chronic diseases, edentulism, depression, activities of daily living (ADL) and instrumental activities of daily living (IADL).

Depression was assessed using the 10-item Center for Epidemiologic Studies Depression Scale (CES-D 10), a widely used tool known for its reliability and validity in evaluating depression among older adults in China [23]. The CES-D 10 includes ten items, each rated on a four-point scale from 0 = "rarely" to 3 = "most of the time." For the two positively worded items, "I was happy" and "I felt hopeful about the future," scores were reverse-coded before summation. The maximum score on the CES-D 10 is 30, with higher scores indicating greater depression severity. A score of 10 or higher suggests the presence of depression symptoms.

Physical function was evaluated using the Katz Basic Activities of Daily Living (ADL) and Lawton Instrumental Activities of Daily Living (IADL) [24]. An ADL disability was identified if an individual could not independently perform any of the six ADL tasks (bathing, dressing, toileting, transfers, continence, and eating). Similarly, an IADL disability was noted if a person could not independently complete the eight IADL tasks (visiting neighbors, shopping, preparing food, washing clothes, walking one kilometer, carrying 5 kg, crouching and standing three times, and using public transportation).

Specific descriptions of the variables can be found in the supplementary Table 1.

Statistical analysis

Continuous variables were presented as mean (M)± standard deviation (SD) and analyzed using the rank sum test. Categorical variables were described as counts and percentages, with comparisons conducted using the χ^2 test. The number of individuals suffering from cognitive impairment is much smaller than those with normal cognition, resulting in an imbalance in the data. To solve the bias caused by the sample imbalance, this study adopts the SMOTE algorithm to convert the unbalanced data into a balanced form. The least absolute shrinkage and selection operator (LASSO) technique was utilized to identify key predictors, and a prediction model was developed through logistic regression. Variables with a two-tailed $P < 0.1$ were further selected to create a nomogram for quantification. The area under the curve (AUC) was used to assess the discriminative ability of the nomograms, with values ranging from 0–1. An AUC value of 0.5 indicates no discriminative ability and a value closer to 1 indicates better discriminative ability [25]. Sensitivity, specificity, accuracy, precision, and F1 Score were used to evaluate the performance of the model, and a calibration curve was drawn to assess the prediction nomogram accuracy. The decision curve analysis (DCA) was used to evaluate the clinical practicability of the nomogram.

Data analysis and image rendering were conducted in R 4.4.0. statistical analyses also involved two-tailed, with statistical significance set at $P < 0.05$.

Results

Participant characteristics

This study used data from CHARLS 2018 and CLHLS 2018, which included a total of 2066 participants in CHARLS and 3840 participants in CLHLS. Table 1 presents the baseline characteristics of older adults with dentures. from the presence of cognitive impairment in older participants was selected as the dependent variable. We used LASSO to select variables, and tenfold cross-validation helped determine the best Lambda value. The regularization parameter (λ) corresponding to the minimum deviation of a standard error is selected as the optimal λ. The optimal λ was found to be 0.034, under which there are five potential predictors: age, residence, depression, IADL, and education, as shown in Fig. 1.

Nomogram for predicting cognitive impairment in older adults with dentures

A total of 15 relevant variable features were included in this study, and 5 potential predictors were screened using LASSO and incorporated into the logistic regression model. Table 2 shows that age, residence, depression, IADL, and education are independent influencing factors for cognitive impairment in older people with dentures. Accordingly, a nomogram was constructed based on these five independent factors, with a higher total score

Table 1 Baseline characteristics of older adults with dentures

Characteristics	2018 CHARLS (*n* = 2066)	2018 CLHLS (*n* = 3840)
Age, M±SD	68.44±6.07	82.78±10.80
Sleep duration	6.64±2.23	7.37±2.18
Sex, n (%)		
Male	846(40.9)	1805(47.0)
Female	1220(59.1)	2035(53.0)
Residence		
Urban	600(29.0)	746(19.4)
Rural	1466(71.0)	3094(80.6)
Martial		
Married and living with spouse	1587(76.8)	1833(47.7)
Other	479(23.2)	2007(52.3)
Education		
Illiterate	517(25.1)	1468(38.2)
Primary school	953(46.1)	1444(37.6)
Middle school and above	596(28.8)	928(24.2)
Chronic disease		
Yes	1112(53.8)	2897(75.4)
No	954(46.2)	943(24.6)
Depression		
Yes	847(41.0)	938(24.4)
No	1219(59.0)	2902(75.6)
Smoking status		
Yes	472(22.8)	617(16.1)
No	1594(77.2)	3223(83.9)
Alcohol intake		
Yes	638(30.9)	585(15.2)
No	1428(69.1)	3255(84.8)
ADL		
Disability	558(27.0)	719(18.7)
Normal	1508(73.0)	3121(81.3)
IADL		
Disability	686(33.2)	2307(60.1)
Normal	1380(66.8)	1533(39.9)
Edentulism		
Yes	295(14.3)	1718(44.7)
No	1771(85.7)	2122(55.3)
Sleep quality		
Good	1233(59.6)	2108(54.9)
Fair	340(16.5)	1166(30.4)
Bad	493(23.9)	566(14.7)
Self-rated health		
Good	333(16.1)	1958(51.0)
Fair	1038(79.3)	1449(37.7)
Bad	695(33.6)	433(11.3)

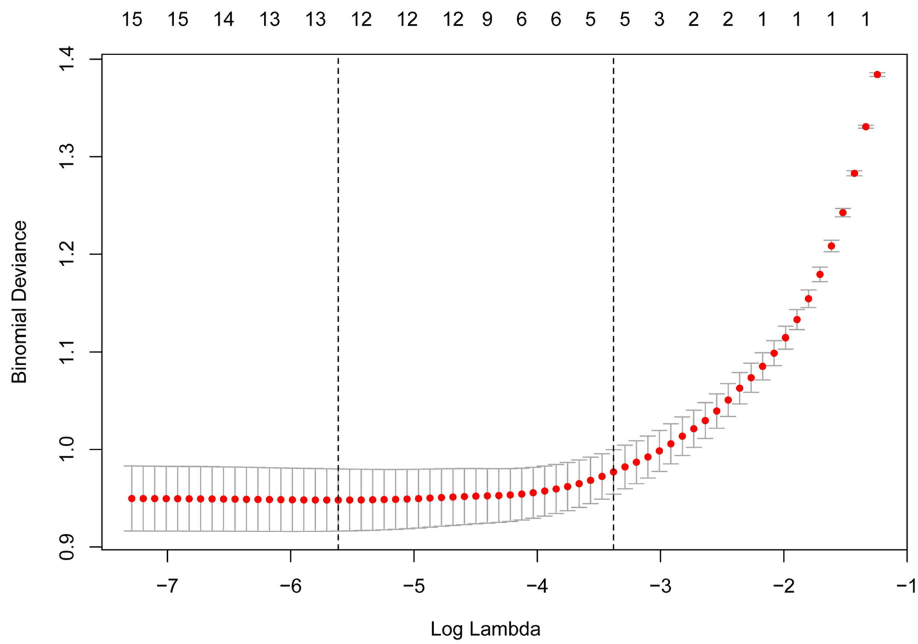

Fig. 1 Ten-fold cross-validation for the best variable selection The tenfold cross-validation filters λ. Plotting at one standard error of the lowest and maximum criterion is a vertical dashed line. The model with the fewest parameters and high performance is denoted by λ.1se

Table 2 Logistic analysis of cognitive impairment in older adults with dentures

Characteristics	*β*	Odds Ratio	95% *CI*		*P* Value
Constant	**−3.308**	**0.037**	**0.010**	**0.128**	**< 0.01**
Age	0.064	1.066	1.047	1.086	< 0.01
Residence					
Rural	Ref				
Urban	−0.640	0.527	0.392	0.708	< 0.01
Depression					
No	Ref				
Yes	0.350	1.419	1.130	1.782	< 0.01
IADL					
Normal	Ref				
Disability	0.779	2.178	1.730	2.744	0.003
Education					< 0.01
Illiterate	Ref				
Primary school	−2.018	0.133	0.105	0.168	< 0.01
Middle school and above	−3.693	0.025	0.016	0.038	< 0.01

Ref reference, *CI* confidence interval

indicating an increased risk (Fig. 2A). This study also established an online dynamic nomogram (Fig. 2B). The predicted probability and 95% *CI* of cognitive impairment in older adults with dentures can be obtained from the input interface on the left side of the web page after entering the relevant feature information.

Discrimination and calibration

After building the model using a development set, we verify its predictive power using internal and external validation sets. Receiver Operating characteristics (ROC) analysis based on logistic regression results showed that the AUC of the development set, the internal verification set, and the external verification set were 0.854 (95%CI 0.839–0.870), 0.841 (95%CI 0.805–0.877), 0.856 (95%CI 0.838–0.873), both exceeding 0.5, indicating good differentiation (Fig. 3). The sensitivity of the development set, the internal verification, and the external verification set were 0.779, 0.752, 0.682, the specificity 0.792, 0.792, 0.886, and the accuracy 0.785, 0.761, and 0.699, respectively. The precision was 0.797, 0.919, and 0.985, and the F1 Score was 0.788, 0.827, and 0.806, respectively, indicating that the model was good. The calibration curve (Fig. 4) further verifies the consistency between the values predicted by the nomogram and the actual observed values.

Clinical practicability

DCA was utilized to evaluate the clinical applicability of the nomogram (Supplementary Fig. 3). The results indicate that within the threshold range of 5% to 95% for the development set, the nomogram demonstrates superior net benefits compared to both extremes. For the internal validation set, the net benefit is also higher than the two extremes. When the threshold value on the external validation set is between 1 and 40%, the

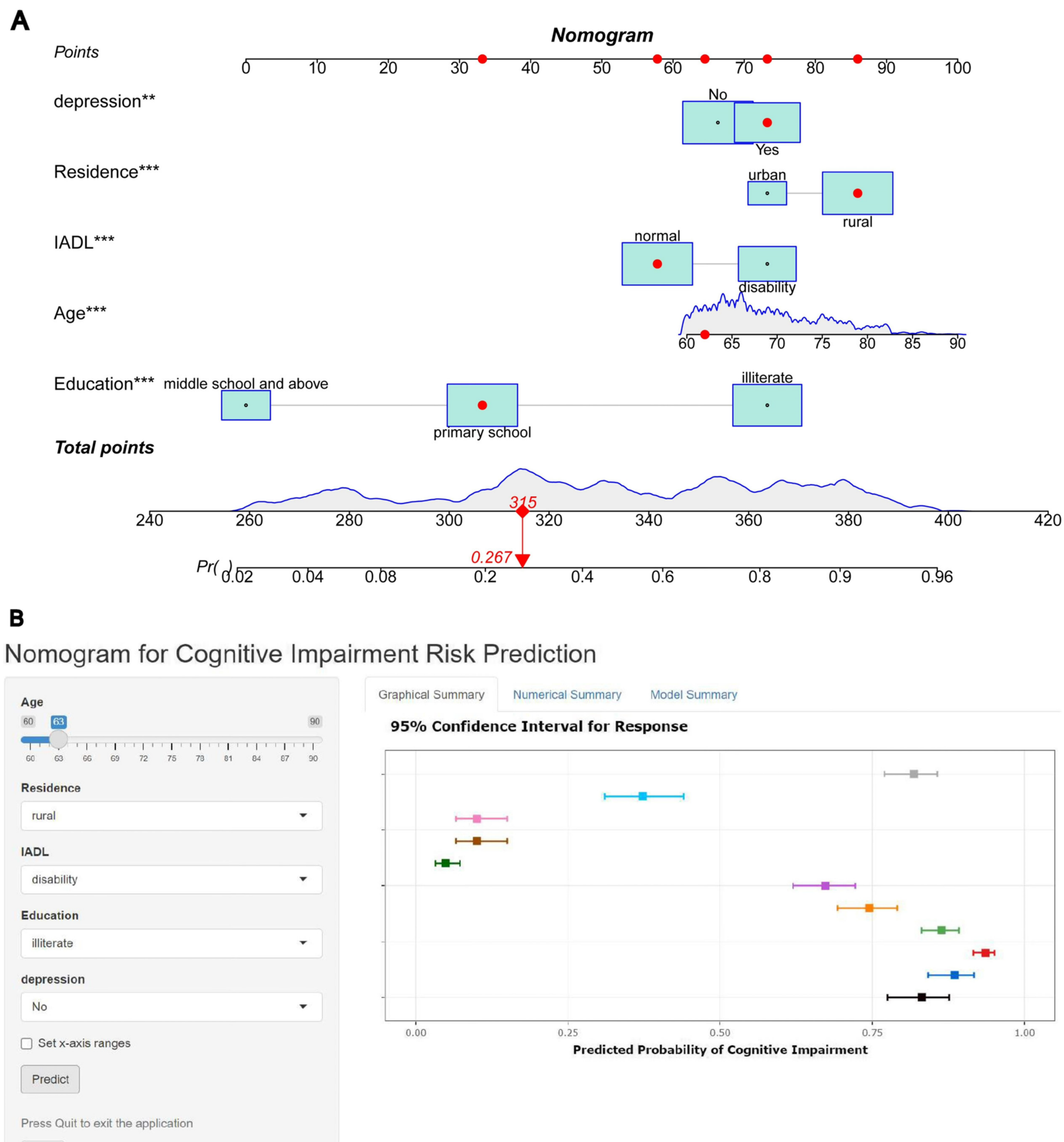

Fig. 2 Nomogram of risk factors for CI in older adults with dentures (**A**) and Dynamic nomogram of risk factors for CI in older adults with dentures (**B**), (**A**) The y-axis represents the net benefit, while the x-axis represents the threshold probability. The red solid line indicates the prediction model's net advantage. The nomogram model shows a higher net advantage, but only within a specific range. **B** https://dynnom1234.shinyapps.io/dynnomapp/

net benefit surpasses the two extreme cases. Although the effective threshold range is smaller than that of the development and internal validation sets, the nomogram still demonstrates strong practical value when applied to new data.

Discussion

In this study, CHARLS was used for model development and internal validation, while CLHLS provided external validation. The model demonstrated strong robustness in predicting cognitive impairment risk in Chinese

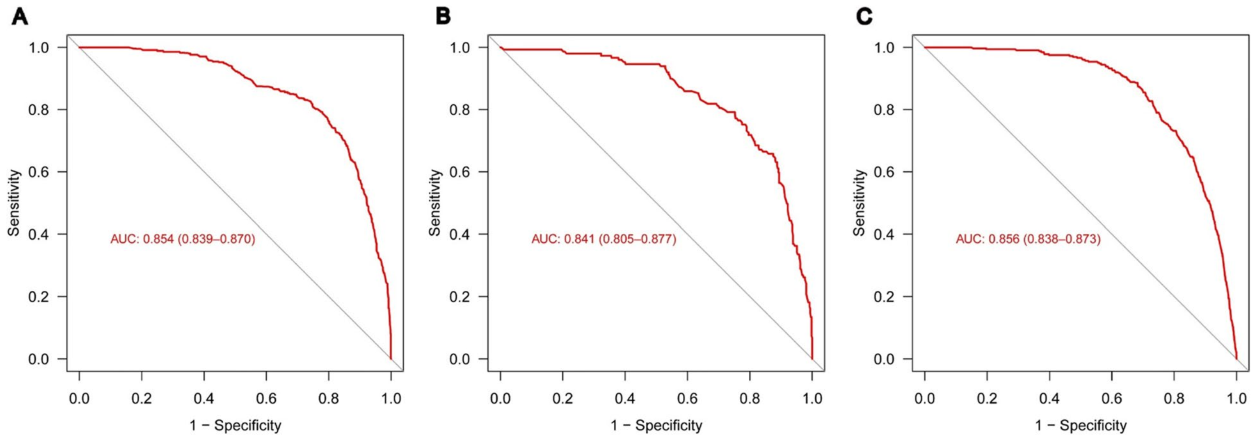

Fig. 3 ROC curves for the proposed nomogram model in (**A**) the development set, (**B**) the internal validation set, and (**C**) the external validation set

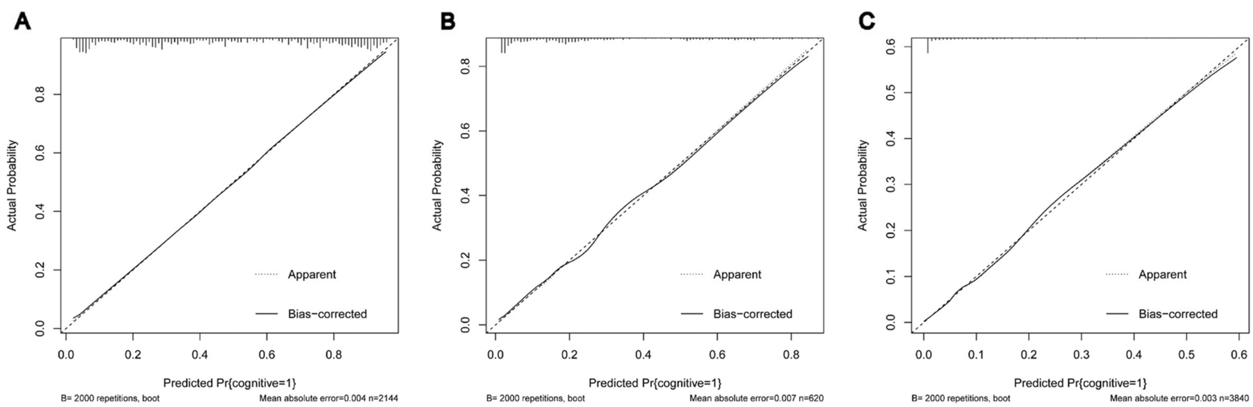

Fig. 4 Calibration curve for the proposed nomogram model in (**A**) the development set, (**B**) the internal validation set, and (**C**) the external validation set

older adults with dentures. Additionally, a user-friendly dynamic nomogram was developed to assist medical professionals and community health workers in quickly assessing cognitive impairment risk in this population.

This study identified age as a significant risk factor for cognitive impairment among older individuals with dentures. Advancing age correlates with a higher prevalence of oral health issues such as tooth loss and decay [26]. Studies show that tooth loss weakens chewing and swallowing functions, [27] potentially leads to changes in brain regions related to cognition [28]. Additionally, some elderly individuals may primarily use full-mouth removable dentures. Improper dentures can limit occlusion function, [10] decrease appetite or food intake, cause weight loss or malnutrition, and increase the risk of cognitive impairment [12]. However, not all denture wearers are fully edentulous; individuals with partial tooth loss may also rely on dentures, which can contribute to varying degrees of occlusal functionality and nutritional outcomes. The precise mechanisms underlying these associations remain ambiguous and warrant further investigation in subsequent studies.

The results indicate that cognitive impairment is more prevalent in older denture wearers in rural areas compared to urban areas. Older adults in rural areas have limited access to medical resources and technology, and their denture adaptation and quality are lower, [29] exacerbating mastication disorders and affecting central nervous system stimulation. [30]Additionally, older individuals in rural areas face challenges accessing healthcare and dental services, particularly regarding oral health education, which increases their risk of cognitive decline [31, 32]. This suggests the need for early interventions to prevent oral diseases before cognitive impairment occurs. Policymakers should accelerate the construction of rural oral health institutions and implement oral health education activities, such as free dental check-ups, to raise awareness among the older adults in rural areas about their oral health.

This study indicated, consistent with the findings of several other surveys, that older adults with dentures who have lower education levels are at greater risk for cognitive impairment [33, 34] The educational level may affect the oral health knowledge rate of the older adults, with those having higher education paying more attention to oral hygiene. Importantly, wearing dentures requires older adults to maintain higher standards of oral habits and hygiene. According to earlier cohort studies, wearing dentures overnight increases the risk of aspiration pneumonia and is linked to infrequent brushing, plaque buildup, and an increased likelihood of cognitive deterioration [35, 36]. This suggests the importance of spreading knowledge about good oral habits, and in the future oral health teams should join forces with community health teams to integrate this important matter into the primary care network to achieve cross-cutting disease prevention [37].

This study identified a significant association between depressive symptoms and the risk of cognitive impairment among elderly individuals who wear dentures. This is consistent with the results of a recent CHARLS study, which indicate that worsening depressive symptoms may further impair cognitive function [38]. In our development set, the prevalence of depression among denture wearers was 41% (Table 1), which is higher than the general elderly population (≥60 years), consistent with studies in South Korea (KLOSA) and Chile (NHS) [39, 40]. Notably, the severity of depressive symptoms was positively correlated with cognitive impairment, suggesting a potential interaction between the two. The fit of dentures affects not only aesthetics and speech clarity but also chewing function, which may contribute to self-image issues and lower quality of life, increasing the risk of depression [41, 42]. Furthermore, depressive symptoms may exacerbate the risk of cognitive impairment by affecting cognitive domains such as attention, memory, and executive function, leading to physiological changes, including chronic inflammation and neurobiological alterations [43]. Therefore, addressing the mental health of elderly denture wearers is vital for preventing cognitive impairment, and clinical practice should prioritize individualized denture fitting and psychological support to improve their quality of life and cognitive health.

In our research, IADL was favorably connected with cognitive impairment in elderly people with dentures. Many previous studies have shown that IADL is closely related to cognitive function status, and IADL is commonly used as an important means of cognitive screening in elderly people [44, 45]. As an important manifestation of poor oral health in the elderly, wearing dentures may have a more complex oral environment. The type of denture, its position, and how long it is worn can affect the function of the denture [46] Older adults with poor IADL often have difficulty independently brushing their teeth and using oral care tools such as floss and dental irrigators, resulting in worse oral health [47]. These adverse effects reduce chewing ability in older adults. Decreased chewing ability weakens spatial memory ability and inhibits hippocampus cells [48]. In addition, quantitative changes in sensory input due to reduced chewing activity may affect brain circuits, neurotransmission systems, and neural activity, leading to cognitive impairment [49]. Interestingly, this study found that chewing ability, as an important manifestation of the health status of the elderly, was closely correlated with denture wearing and cognitive function. Follow-up investigations will further explore the correlation mechanism.

Our findings provide new evidence and practical implications for preventing cognitive impairment. This study introduces the first dynamic nomogram specifically designed for older adults with dentures, offering a unique approach compared to traditional tools like the MMSE. By incorporating easily obtainable variables, the nomogram enables proxy assessments, thereby broadening the scope of screening to include individuals who are less mobile or uncooperative. Its simplicity and adaptability make it ideal for large-scale community use, allowing health workers to monitor cognitive health through oral health education and screening programs, offering a valuable tool for policymakers to enhance early interventions.

This study has a few limitations. First, to enhance the practicality of the model and minimize future implementation costs, we excluded physicochemical indicators. Second, this study focused on older adults with dentures to explore their unique cognitive risk factors. Future studies could compare denture wearers and non-wearers to further clarify these differences. Third, the nomogram developed in this study mainly identifies the elderly population in China, which may have limitations for other countries. Lastly, due to data constraints, we could not distinguish between different types of denture users. Future studies should explore subgroup classifications to better understand their distinct impacts on cognitive impairment risk.

Conclusion

This study developed and validated a nomogram as a preliminary screening tool to predict the risk of cognitive impairment in older adults wearing dentures, subsequently translating it into an accessible online application. By offering a practical and user-friendly solution, this tool potentially provides community medical workers with a valuable supplementary method for identifying individuals aged 60 years and older who may be at risk of cognitive impairment. Furthermore, future exploration of strategies to integrate this tool into routine geriatric and dental care settings is essential to maximize its practical utility and broader impact.

Abbreviations

SMOTE	Synthetic minority over-sampling technique
LASSO	Least absolute shrinkage and selection operator
MCI	Mild cognitive impairment
ADL	Activities of daily living
IADL	Instrumental activities of daily living
ROC	Receiver operating characteristics
AUC	Area under curve
DCA	Decision curve analysis
CES-D	Center for epidemiologic studies depression scale

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12877-025-05758-3.

Additional file 1: Supplementary Figure 1. Flowchart of the participant's selection process

Additional file 2: Supplementary Figure 2. Coefficient curve of variable Each curve on the graph represents the trajectory of the independent variable's coefficient. The x-axis represents Log Lambda, while the y-axis denotes the coefficients of the variables. Each curve corresponds to a specific variable, illustrating how its coefficient evolves as regularization intensifies. As the regularization parameter increases, some coefficients shrink to zero, indicating features excluded by the model under the given parameters. The optimal Log Lambda is identified through regression cross-validation curves, guiding the selection of variables to retain or eliminate. (This figure serves as a visualization of the internal operation of the software to assist in understanding the variable selection process, complementing Figure 1 in the main text).

Additional file 3: Supplementary Figure 3. Decision curve analysis for the proposed nomogram in (A) the development set, (B) the internal validation set, and (C) the external validation set. The y-axis represents the net benefit, while the x-axis represents the threshold probability. The red solid line indicates the nomogram net advantage. The nomogram model shows a higher net advantage, but only within a specific range.

Additional file 4.

Additional file 5.

Acknowledgements
Not applicable.

Authors' contributions
All authors participated in the decision to submit the manuscript. The concept and design of this study were developed by Tongtong Guo, Qi Jing, and Haiyan Li. Data acquisition was carried out by Xiaoqing Zhao, Xinyi Zhang, and Zhiwei Dong, while formal analysis and interpretation of data were conducted by Tongtong Guo, Yang Xing, and Xinyi Zhang. Statistical analysis was performed by Xiaoqing Zhao, Tongtong Guo, and Runguo Gao. The manuscript was drafted by Tongtong Guo, Xiaoqing Zhao, and Haiyan Li, and critical revisions for important intellectual content were made by Zhiping Huang, Xue Bai, Shanquan Chen, Haiyan Li, Runguo Gao, Wengui Zheng, and Qi Jing.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The CHARLS was approved by the Ethics Committee of Pecking University (00001052–11, 014) and the CLHLS was approved by the Ethics Committee of Peking University and Duke University (IRB00001052-13074).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]School of Management, Shandong Second Medical University, Weifang, China. [2]Health Shandong Collaborative Innovation Center for Severe Social Risk Prediction and Governance, Weifang, China. [3]China Academy of Rehabilitation and Health, Shandong Second Medical University, Weifang, China. [4]School of Public Health, Shandong Second Medical University, Weifang, China. [5]Weifang People'S Hospital, Shandong Second Medical University, Weifang, China. [6]School of Information Engineering, Beijing Institute of Graphic Communication, Beijing, China. [7]Department of Applied Social Sciences and Research Centre for Gerontology and Family Studies, The Hong Kong Polytechnic University, Hong Kong, China. [8]International Centre for Evidence in Disability, London School of Hygiene and Tropical Medicine, London, UK.

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References

1. World Health Organization. Dementia. 2023 [15 August]; WHO Press - World Health Organization, Geneve, Switzerland. Available from: https://www.who.int/news-room/fact-sheets/detail/dementia
2. Matthews KA, Xu W, Gaglioti AH, et al. Racial and ethnic estimates of Alzheimer's disease and related dementias in the United States (2015–2060) in adults aged ≥65 years. Alzheimers Dement. 2019;15(1):17–24. https://doi.org/10.1016/j.jalz.2018.06.3063.
3. Chen S, Chen X, Hou X, et al. Temporal trends and disparities of population attributable fractions of modifiable risk factors for dementia in China: a time-series study of the China health and retirement longitudinal study (2011–2018). Lancet Reg Health West Pac. 2024;47:101106. Published 2024 May 29. https://doi.org/10.1016/j.lanwpc.2024.101106
4. Schrag A, Siddiqui UF, Anastasiou Z, et al. Clinical variables and biomarkers in prediction of cognitive impairment in patients with newly diagnosed Parkinson's disease: a cohort study. Lancet Neurol. 2017;16(1):66–75. https://doi.org/10.1016/S1474-4422(16)30328-3.
5. Petersen RC, Morris JC. Mild cognitive impairment as a clinical entity and treatment target. Arch Neurol. 2005;62(7):1160–7. https://doi.org/10.1001/archneur.62.7.1160.
6. Saito S, Ohi T, Murakami T, et al. Association between tooth loss and cognitive impairment in community-dwelling older Japanese adults: a 4-year prospective cohort study from the Ohasama study. BMC Oral Health. 2018;18(1):142. Published 2018 Aug 20. https://doi.org/10.1186/s12903-018-0602-7
7. Panza F, Lozupone M, Solfrizzi V, et al. Different Cognitive Frailty Models and Health- and Cognitive-related Outcomes in Older Age: From Epidemiology to Prevention. J Alzheimers Dis. 2018;62(3):993–1012. https://doi.org/10.3233/JAD-170963.
8. Peres MA, Macpherson LMD, Weyant RJ, et al. Oral diseases: a global public health challenge [published correction appears in Lancet. 2019 Sep 21;394(10203):1010. https://doi.org/10.1016/S0140-6736(19)32079-3]. Lancet. 2019;394(10194):249–260. https://doi.org/10.1016/S0140-6736(19)31146-8
9. Qi X, Zhu Z, Plassman BL, et al. Dose-Response Meta-Analysis on Tooth Loss With the Risk of Cognitive Impairment and Dementia. J Am Med Dir Assoc. 2021;22(10):2039–45. https://doi.org/10.1016/j.jamda.2021.05.009.
10. Weyant RJ, Pandav RS, Plowman JL, et al. Medical and cognitive correlates of denture wearing in older community-dwelling adults. J Am Geriatr

Soc. 2004;52(4):596–600. https://doi.org/10.1111/j.1532-5415.2004.52168.x.

11. Yang HL, Li FR, Chen PL, et al. Tooth Loss, Denture Use, and Cognitive Impairment in Chinese Older Adults: A Community Cohort Study. J Gerontol A Biol Sci Med Sci. 2022;77(1):180–7. https://doi.org/10.1093/gerona/glab056.
12. Jongsiriyanyong S, Limpawattana P. Mild Cognitive Impairment in Clinical Practice: A Review Article. Am J Alzheimers Dis Other Demen. 2018;33(8):500–7. https://doi.org/10.1177/1533317518791401.
13. Jayedi A, Rashidy-Pour A, Shab-Bidar S. Vitamin D status and risk of dementia and Alzheimer's disease: A meta-analysis of dose-response. Nutr Neurosci. 2019;22(11):750–9. https://doi.org/10.1080/1028415X.2018.1436639.
14. Li J, Ogrodnik M, Devine S, et al. Practical risk score for 5-, 10-, and 20-year prediction of dementia in elderly persons: Framingham Heart Study. Alzheimers Dement. 2018;14(1):35–42. https://doi.org/10.1016/j.jalz.2017.04.013.
15. Zhou S, Song S, Jin Y, et al. Prospective association between social engagement and cognitive impairment among middle-aged and older adults: evidence from the China Health and Retirement Longitudinal Study. BMJ Open. 2020;10(11):e040936. Published 2020 Nov 18. https://doi.org/10.1136/bmjopen-2020-040936
16. Dregan A, Stewart R, Gulliford MC. Cardiovascular risk factors and cognitive decline in adults aged 50 and over: a population-based cohort study. Age Ageing. 2013;42(3):338–45. https://doi.org/10.1093/ageing/afs166.
17. Ma Y, Liang L, Zheng F, et al. Association Between Sleep Duration and Cognitive Decline. JAMA Netw Open. 2020;3(9):e2013573. Published 2020 Sep 1. https://doi.org/10.1001/jamanetworkopen.2020.13573
18. Li H, Li C, Wang A, et al. Associations between social and intellectual activities with cognitive trajectories in Chinese middle-aged and older adults: a nationally representative cohort study. Alzheimers Res Ther. 2020;12(1):115. Published 2020 Sep 25. https://doi.org/10.1186/s13195-020-00691-6
19. Yuan Y, Peng C, Burr JA, et al. Frailty, cognitive impairment, and depressive symptoms in Chinese older adults: an eight-year multi-trajectory analysis. BMC Geriatr. 2023;23(1):843. Published 2023 Dec 12. https://doi.org/10.1186/s12877-023-04554-1
20. Zeng Y, Jr DP, Vlosky D, et al. Healthy longevity in China: demographic, socioeconomic, and psychological dimensions. 2008.
21. Herzog AR, Wallace RB. Measures of cognitive functioning in the AHEAD Study [published correction appears in J Gerontol B Psychol Sci Soc Sci 1997 Nov;52(6):203]. J Gerontol B Psychol Sci Soc Sci. 1997;52 Spec No:37–48. https://doi.org/10.1093/geronb/52b.special_issue.37
22. Zhang Z, Gu D, Hayward MD. Early life influences on cognitive impairment among oldest old Chinese. J Gerontol B Psychol Sci Soc Sci. 2008;63(1):S25–33. https://doi.org/10.1093/geronb/63.1.s25.
23. Jak AJ, Bondi MW, Delano-Wood L, et al. Quantification of five neuropsychological approaches to defining mild cognitive impairment. Am J Geriatr Psychiatry. 2009;17(5):368–75. https://doi.org/10.1097/JGP.0b013e31819431d5.
24. Jia Q, Duan Y, Gong R, et al. Living arrangements and depression of the older adults- evidence from the Chinese longitudinal healthy longevity survey. BMC Public Health. 2023;23(1):1870. Published 2023 Sep 27. https://doi.org/10.1186/s12889-023-16730-4
25. Linden A. Measuring diagnostic and predictive accuracy in disease management: an introduction to receiver operating characteristic (ROC) analysis. J Eval Clin Pract. 2006;12(2):132–9. https://doi.org/10.1111/j.1365-2753.2005.00598.x.
26. Ren C, McGrath C, Yang Y. Edentulism and associated factors among community-dwelling middle-aged and elderly adults in China. Gerodontology. 2017;34(2):195–207. https://doi.org/10.1111/ger.12249.
27. Patel J, Wallace J, Doshi M, et al. Oral health for healthy ageing. Lancet Healthy Longev. 2021;2(8):e521–7. https://doi.org/10.1016/S2666-7568(21)00142-2.
28. Chen H, Iinuma M, Onozuka M, et al. Chewing Maintains Hippocampus-Dependent Cognitive Function. Int J Med Sci. 2015;12(6):502–509. Published 2015 Jun 9. https://doi.org/10.7150/ijms.11911
29. Zhang Y, Ge M, Zhao W, et al. Association Between Number of Teeth, Denture Use and Frailty: Findings from the West China Health and Aging Trend Study. J Nutr Health Aging. 2020;24(4):423–8. https://doi.org/10.1007/s12603-020-1346-z.
30. Kim EK, Lee SK, Choi YH, et al. Relationship between chewing ability and cognitive impairment in the rural elderly. Arch Gerontol Geriatr. 2017;70:209–13. https://doi.org/10.1016/j.archger.2017.02.006.
31. Xu M, Cheng M, Gao X, et al. Factors associated with oral health service utilization among adults and older adults in China, 2015–2016. Community Dent Oral Epidemiol. 2020;48(1):32–41. https://doi.org/10.1111/cdoe.12497.
32. Sattler C, Toro P, Schönknecht P, et al. Cognitive activity, education and socioeconomic status as preventive factors for mild cognitive impairment and Alzheimer's disease. Psychiatry Res. 2012;196(1):90–5. https://doi.org/10.1016/j.psychres.2011.11.012.
33. Nakamura T, Zou K, Shibuya Y, et al. Oral dysfunctions and cognitive impairment/dementia. J Neurosci Res. 2021;99(2):518–28. https://doi.org/10.1002/jnr.24745.
34. Peltzer K, Hewlett S, Yawson AE, et al. Prevalence of loss of all teeth (edentulism) and associated factors in older adults in China, Ghana, India, Mexico, Russia and South Africa. Int J Environ Res Public Health. 2014;11(11):11308–11324. Published 2014 Oct 30. https://doi.org/10.3390/ijerph111111308
35. Kang J, Wu B, Bunce D, et al. Cognitive function and oral health among ageing adults. Community Dent Oral Epidemiol. 2019;47(3):259–66. https://doi.org/10.1111/cdoe.12452.
36. Iinuma T, Arai Y, Abe Y, et al. Denture wearing during sleep doubles the risk of pneumonia in the very elderly. J Dent Res. 2015;94(3 Suppl):28S-36S. https://doi.org/10.1177/0022034514552493.
37. Chen R, Irving M, Clive Wright FA, et al. An evaluation of health workforce models addressing oral health in residential aged care facilities: A systematic review of the literature. Gerodontology. 2020;37(3):222–32. https://doi.org/10.1111/ger.12475.
38. Yang Q, Zhang JH, Mao J, et al. Functional teeth and cognitive function among the Chinese elderly: The chain mediating effect of depressive symptoms and social participation. Geriatr Nurs. 2024;58:111–8. https://doi.org/10.1016/j.gerinurse.2024.05.009.
39. Jang YJ. Association between dentures use and prevalence of depression in elderly. Journal of Korean society of Dental Hygiene. 2020;20(6):843–53. https://doi.org/10.13065/jksdh.20200078.
40. Palomer T, Ramírez V, Ortuño D. Relationship between oral health and depression: data from the National Health Survey 2016–2017. BMC Oral Health. 2024;24(1):188. Published 2024 Feb 5. https://doi.org/10.1186/s12903-024-03950-2
41. Laudisio A, Milaneschi Y, Bandinelli S, et al. Chewing problems are associated with depression in the elderly: results from the In CHIANTI study. Int J Geriatr Psychiatry. 2014;29(3):236–44. https://doi.org/10.1002/gps.3995.
42. Shim J, Lee Y, Hong SJ, et al. Relationship between usage of removable denture and depression in Korean adults with loss of multiple teeth: A cross-sectional study using the seventh Korea national health and nutrition examination survey. The Journal of Korean Academy of Prosthodontics. 2021;59(1):1–10. https://doi.org/10.4047/jkap.2021.59.1.1.
43. Almeida OP, Hankey GJ, Yeap BB, et al. Depression as a risk factor for cognitive impairment in later life: the Health In Men cohort study. Int J Geriatr Psychiatry. 2016;31(4):412–20. https://doi.org/10.1002/gps.4347.
44. Barberger-Gateau P, Commenges D, Gagnon M, et al. Instrumental activities of daily living as a screening tool for cognitive impairment and dementia in elderly community dwellers. J Am Geriatr Soc. 1992;40(11):1129–34. https://doi.org/10.1111/j.1532-5415.1992.tb01802.x.
45. Cromwell DA, Eagar K, Poulos RG. The performance of instrumental activities of daily living scale in screening for cognitive impairment in elderly community residents. J Clin Epidemiol. 2003;56(2):131–7. https://doi.org/10.1016/s0895-4356(02)00599-1.
46. Bakker MH, Vissink A, Spoorenberg SLW, et al. Are Edentulousness, Oral Health Problems and Poor Health-Related Quality of Life Associated with Malnutrition in Community-Dwelling Elderly (Aged 75 Years and Over)? A Cross-Sectional Study. Nutrients. 2018;10(12):1965. Published 2018 Dec 12. https://doi.org/10.3390/nu10121965
47. Brennan LJ, Strauss J. Cognitive impairment in older adults and oral health considerations: treatment and management. Dent Clin North Am. 2014;58(4):815–28. https://doi.org/10.1016/j.cden.2014.07.001.

48. Aoki H, Kimoto K, Hori N, et al. Cell proliferation in the dentate gyrus of rat hippocampus is inhibited by soft diet feeding. Gerontology. 2005;51(6):369–74. https://doi.org/10.1159/000088700.
49. Watanabe K, Ozono S, Nishiyama K, et al. The molarless condition in aged SAMP8 mice attenuates hippocampal Fos induction linked to water maze performance. Behav Brain Res. 2002;128(1):19–25. https://doi.org/10.1016/s0166-4328(01)00268-6.

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