Xie *et al. BMC Neurology* (2024) 24:336
https://doi.org/10.1186/s12883-024-03848-0

BMC Neurology

RESEARCH Open Access

Association of oral frailty and gait characteristics in patients with cerebral small vessel disease

Hong-yang Xie[1†], Jun-li Chen[2†], Cui-qiao Xia[1], Nan Zhang[1], Zhen-xi Xia[1], Hong-yi Zhao[1,3] and Yong-hua Huang[1*]

Abstract

Background The objectives of this study were twofold: (1) to compare gait characteristics between cerebral small vessel disease (CSVD) patients with low-risk oral frailty (OF) and high-risk OF, particularly during dual-task walking (DTW); (2) to investigate the association of OF, the gait characteristics of DTW, and falls among older adults patients with CSVD.

Methods A total of 126 hospitalized patients diagnosed with CSVD were recruited and classified into a low-risk group ($n = 90$) and a high-risk group ($n = 36$) based on OF status in our study. Comprehensive data pertaining to basic parameters (cadence, as well as stride time, velocity and length), variability, asymmetry, and coordination were gathered during both single-task walking (STW) and DTW. Additionally, the number of falls was calculated. Subsequently, t-test or chi-squared test was used for comparison between the two groups. Furthermore, linear regression analysis was employed to elucidate the association of the OF index-8 score and gait parameters during cognitive DTW. Also, logistic regression models were utilized to assess the independent association of OF risk and falls.

Results During cognitive DTW, the high-risk group demonstrated inferior performance in terms of basic parameters ($p < 0.01$), coefficient of variation (CV) of velocity and stride length ($p < 0.05$), as well as phase coordination index (PCI) when compared with the low-risk group ($p < 0.05$). Notably, differences in basic gait parameters were observed in cognitive DTW and STW conditions between the two groups ($p < 0.01$). However, only the high-risk group evinced significant variations in CV and PCI during cognitive DTW, as opposed to those during STW ($p < 0.05$). Furthermore, our findings also revealed the association of OF, the gait characteristics of cognitive DTW, ($p < 0.01$) and falls ($p < 0.05$).

Conclusion CSVD patients with a high risk of OF need to pay more attention to their gait variability or coordination. Also, they are recommended to undergo training involving dual-task activities while walking in daily life, thereby reducing the deterioration and mitigating the risk of falls. Besides, this study has confirmed an association of OF and DTW gait as well as falls in patients with CSVD.

Keywords Cerebral small vessel disease, Dual-task walking, Oral frailty, Gait

†Hong-yang Xie and Jun-li Chen contributed equally to this work as Co-first author.

*Correspondence:
Yong-hua Huang
huangyh@163.com

[1]Department of Neurology, The Seven Medical Center of PLA General Hospital, Dongsi Shitiao, Dongcheng District, Nanmencang, Beijing 100007, China
[2]Department of Hematology, The Fifth Medical Center of PLA General Hospital, Fengtai District, Beijing 100039, China
[3]Department of Neurology, Number 984 Hospital of the PLA, Haidian District, Beijing 100094, China

Introduction

In patients with cerebral small vessel disease (CSVD), the presence of structural abnormalities or dysfunction in cerebral microvessels often leads to clinical, imaging, or pathological alterations [1]. Additionally, movement disorders and cognitive impairment are prominent clinical symptoms of CSVD [2]. The prevalence of CSVD, serving as one of significant health challenges for aging society, exhibits a substantial rise in correlation with advancing age [3]. The European Stroke Organization has already recommended the dual-task walking (DTW) as a pivotal instrument for assessing covert CSVD [4]. In fact, DTW holds an important significance in daily life. For instance, it contributes to conversing, operating a mobile device, or observing traffic while walking. According to the description of previous research, undertaking two tasks concurrently might have an adverse impact on gait performance, regardless of whether subjects in a state of health or patients grappling with neurological disorders [1, 5]. Our preceding investigation further corroborated that patients afflicted with CSVD frequently exhibited notable deterioration in gait parameters during DTW assessments, particularly in the cognitive DTW [6].

Oral health plays a pivotal role in maintaining the dietary habits and the nutritional status of older patients [7]. The concept of oral frailty (OF), initially embraced in Japan, has swiftly gained prominence, illuminating its vital role in public oral health [8]. OF refers to the progressive deterioration of oral function, encompassing diminished oral motor abilities, impaired chewing capabilities, and disturbances in swallowing. According to an observational study, approximately 16% of older adults residing in the community exhibited signs of OF [9]. In addition, the association of OF with under-nutrition, fall or gait deterioration was also indeed affirmed [7, 9–11]. Numerous studies have documented an association between oral health and motor function. For example, a reduced number of teeth or insufficient posterior occlusal support leads to poor balance and gait abnormalities [12–14]. There are several plausible reasons for these associations. Firstly, occlusal interference and variations in mandibular position assume a pivotal role in governing the equilibrium of body posture and the dynamic prowess of muscles [12, 14]. Secondly, inadequate dietary intake resulting from masticatory and swallowing disorders can lead to impairment in muscle strength and gait performance [12, 15]. However, there is a dearth of studies on the gait characteristics and the prevalence of falls among CSVD patients with OF.

A cross-sectional investigation was performed in this research to elucidate the alterations in gait parameters among CSVD patients suffering from OF. The primary objective was to ascertain whether there was an association between OF and gait impairments. Furthermore, as we know, DTW is commonly employed in CSVD research. However, the specific gait alterations occurred in CSVD patients with OF during DTW remain inadequately understood. Consequently, our study would investigate the changes in gait parameters manifested in DTW condition. In addition, poor gait performance is recognized as a prominent contributing factor to the occurrence of falls. Looking for compelling evidence about association between OF and falls would contribute to exploring approaches to preventing falls among the older adults CSVD. Hence, an exploration was also performed on the association of OF and falls within the CSVD cohort. This research would help us grasp the highlight of OF, thereby elucidating the significance of oral health for motor functions.

Materials and methods

Participants

A cross-sectional study was designed, encompassing a cohort of 126 consecutive inpatients diagnosed with CSVD from the Department of Neurology. The participants were hospitalized between the period spanning January 1, 2022, and June 1, 2023. Ethical approval for this study was obtained from the academic ethics committee of the biological sciences division at the Seventh Medical Center in the Chinese PLA General Hospital (2022–098). Prior to their inclusion in this study, all participants provided their informed consent, demonstrating their commitment. All methodologies employed during the study adhered strictly to the requisite guidelines and regulations.

To ensure the selection of suitable participants, the inclusion criteria were as follows: (1) the ability to ambulate independently for a minimum of 30 steps, regardless of whether a tray was being carried or not; (2) the ability to understand and execute instructions effectively; and (3) the presence of at least one of the CSVD imaging manifestations, namely, white matter hyperintensities (WMHs), lacunar infarcts (LIs), or celebral microbleeds (CMBs) [16, 17]. Notably, patients with WMH grade of 1 and no other markers were required to have at least one vascular risk factor, such as hypertension, diabetes, or hyperlipemia. In addition, this study implemented rigorous exclusion criteria as follows: (1) deficiency in receptive language skills, impeding the understanding and adherence to commands; and (2) the presence of specific comorbidities, including acute cerebral ischemic or bleeding episodes, leukoencephalopathy with demyelinating or genetic origins, major psychiatric ailments, gait disorders attributed to musculoskeletal issues, dementia, and contraindications for undergoing magnetic resonance imaging (MRI) scans. The collected data encompassed essential demographic information such as age, gender, years of education, and the presence of comorbidities.

Magnetic resonance imaging

The participants' T1-weighted imaging sequences, T2-weighted imaging sequences, susceptibility-weighted imaging sequences, and fluid-attenuated inversion recovery were captured by a 3.0 T MRI scanner (Siemens AG, Munich, Germany).

The interpretations of the MRI image were conducted by two impartial neurologists. In the event of any discrepancies, a radiologist, acting as a neutral third party, intervened to provide resolution. Ultimately, a consensus was achieved with the guidance of the radiologist.

Experimental protocol

The gait characteristics of all participants were collected under following three conditions: (1) walking without any additional task; (2) walking while performing three serial subtractions from a randomly selected starting number (90, 95, 100, or 105 by drawing lots; cognitive DTW); and (3) walking while holding a tray with four empty glasses placed on the corners (motor DTW).

As previously mentioned, patients were instructed to perform both STW and DTW, each consisting of 30 strides. They were required to evenly distribute their attention between the two tasks, rather than favoring one over the other. To mitigate the impact of acceleration and deceleration, data from twenty-five strides in the middle phase of the study were collected.

Measurement methods and gait parameters

Firstly, participants wearing a gait analyzer were required to walk in a comfortable manner in a corridor of approximately 50 m in length, without any additional requirements to familiarize themselves with their surroundings, avoiding any distractions caused by site factors. Next, the rules of single-task walking (STW) and DTW were explained to the patient. The researcher gave a short demonstration, and the participant then completed approximately 5 strides of cognitive and motor DTW. One test was completed for each item after the start of the formal testing, and all parameters were averaged over the course of the walk. The MiniSun Intelligent Device for Energy Expenditure and Activity System (MiniSun, Fresno, CA, USA) was employed to gather all gait-related data. The basic gait parameters, including velocity (m/s), cadence (step/min), stride length (m), and stride time (s), were measured, recorded and averaged.

Furthermore, the measurement of interlimb bilateral coordination was conducted by the phase coordination index (PCI) [18]. To explain briefly, the gait cycle was conceptualized as a 360° circle, with each step (i.e., from heel strike to toe-off on the same foot) representing a specific phase (φ) within this cycle [19, 20]. By combining the coefficients of variation (φCoV) and absolute differences (φABS), the PCI (1) was derived. A lower PCI value signified a higher level of coordination [21].

The calculation of the PCI was as follows:

The measurement of gait variability (%) involved the calculation of the coefficient of variation (CV) [22]. Since the ratio between the bilateral legs was related, the CV for one side was computed using the following formula:

$$\text{stride } CV = \frac{\text{stdev}\,(stride)}{mean\,(stride)} \times\ 100\%$$

The determination of the gait asymmetry (GA) was achieved through the following operational formula [19]:

$$GA = |ln(\,R\_STP/\,L\_STP) \times\ 100|\%$$

Where R_STP or L_STP denoted the mean count of bilateral swing times individually.

An elevated GA or CV suggested diminished symmetry or increased variability.

Cognitive functional outcome measures

Additional cognitive evaluations encompassed the mini-mental state examination (MMSE), verbal fluency test (VEF), clock drawing test (CDT), and trail-making test part-B (TMT-B), whose findings were predominantly influenced by CSVD in prior research [23]. The VEF, which could be employed to gauge linguistic proficiency, involved tallying the number of animals mentioned within a span of one minute. The TMT-B, a measure of executive function, could assess the time taken to complete the trail-marking task B. A transformed score of the CDT, which appraised visuospatial abilities (lower scores indicating limited skills in this domain), was determined based on the accuracy of the clock dials drawn by participants [24].

The definition of oral frailty

The evaluation of OF was conducted by a questionnaire known as the OF index-8 (OFI-8). The OFI-8 was a comprehensive screening questionnaire consisting of eight items that inquired about oral health-related behaviors. The scoring system involved a maximum of 11 points [25]. The reported threshold for determining significance was a score of 4 or 3 points. Based on previous studies and data characteristics, the low-risk group was defined as having an OFI-8 score of 3 or less; while the high-risk group was defined as having an OFI-8 score higher than 4. The clinical features of each group were gathered [11, 25, 26].

Statistical analysis

We performed a post-hoc power analysis with the Gpower software that the sample size of this study contributed a enough power. The normality of statistical indicators was determined using the Shapiro-Wilk test. Normally distributed variables were expressed as mean ± SD, while skewed distributions were presented as median with interquartile range. Frequencies were used to present categorical variables. Besides, the t-test was employed for normally distributed data, while the nonparametric Mann-Whitney U test for skewed distributions. The chi-squared test was utilized to analyze categorical variable data. Generalized estimating equations (GEE) were used to detect differences in gait variance across different conditions (STW and DTW) and groups (Low- and High-risk OF states). In the event of an interaction between three conditions of walking task (STW, cognitive DTW, and motor DTW) and groups (Low- and High-risk OF), post-hoc comparisons were conducted, with Bonferroni's method used to correct for multiple comparisons. Linear regression analysis was employed to elucidate the association of the OFI-8 scores and gait parameters during cognitive DTW. Logistic regression models were also utilized to assess the independent association of OF risk and falls. The data were analyzed using SPSS version 22.0 (IBM Corp., Armonk, NY, USA), and statistical significance was defined as $p < 0.05$.

Table 1 Demographic and clinical characteristics of the study participants

Variables	Low-risk ($n = 90$)	High-risk ($n = 36$)	Testing value	*p*-value
Age, years, mean ± SD	64.8 ± 8.3	67.0 ± 9.4	1.915‡	0.169
Sex, n (%)			3.838*	0.050
Female	39 (43.3%)	9 (25%)		
Male	51 (56.7%)	27 (75%)		
Education, years, median (Q1, Q3)	12.0 (9.0,12.0)	12.0 (9.0,12.0)	-1.951†	0.051
MMSE, points, median (Q1, Q3)	29.0 (27.0,30.0)	29 (28.0,30.0)	-0.831†	0.406
Hypertension, n (%)	62 (68.9%)	27 (75%)	0.463*	0.496
Stenocardia, n (%)	9 (10%)	3 (8.3%)	0.083*	0.773
Myocardial infarct, n (%)	7 (7.8%)	4 (11.1%)	0.359*	0.549
Hyperlipidemia, n (%)	71 (78.9%)	27 (75%)	0.225*	0.635
Diabetes, n (%)	24 (26.7%)	14 (38.9%)	1.824*	0.177
VEF, number, mean ± SD	17.4 ± 3.7	15.9 ± 4.3	1.365†	0.245
CDT, points, median (Q1, Q3)	12.0 (11.0,13.0)	11.50 (10.0,12.8)	-2.025†	0.043
TMT-B, s, median (Q1, Q3)	76.0 (60.0,89.0)	87.5 (67.0,97.5)	-1.990‡	0.047
Fall, n (%)	19 (21.1%)	16 (44.4%)	6.978*	0.008

The data analysis was used the t-test or nonparametric Mann-Whitney U test or chi-squared test. CDT, clock drawing test; MMSE, mini-mental state examination; TMT-B, trail-making test-part B; VFT, verbal fluency test; $^{*}\chi^2$ value; †Z value; ‡t value

Results

Participants' characteristics

The demographic and clinical characteristics of the participants were outlined in Table 1. A total of 126 patients (including 38.1% of females) diagnosed with CSVD were enrolled in this study. The age of the participants range from 45 to 91 years, with an average age of 66.1 ± 8.3 years. Among the participants, 90 patients were categorized as low-risk of OF, with an average age of 64.8 ± 8.3 years and involving 43.3% of females. Additionally, 36 patients were classified as high-risk OF, with an average age of 67.0 ± 9.4 years and including 25.0% of females. Statistically significant differences were observed between the two groups in TMT-B ($p = 0.047$), CDT ($p = 0.043$) and falls ($p = 0.008$). No significant differences were found between the two groups in terms of age, gender, education, comorbidities, and VEF.

The gait characteristics of patients with oral frailty during single-task walking and dual-task walking

The direct parameters of the gait cycle for the different walking methods were presented in Table 2, and discrepancies between the OF (group) and walking methods (condition) were observed. Interactions between the groups and conditions were detected for all parameters. A post-hoc analysis of differences between the high- risk and low-risk groups revealed that, in the cognitive DTW condition, the high-risk group of OF exhibited poorer performance across all direct parameters compared to the low-risk group ($p < 0.05$). In the STW condition, only stride length showed a significant difference ($p < 0.05$); while there was no difference in motor DTW condition.

Subsequently, a post-hoc analysis was performed to identify differences between the three conditions of walking task (STW, cognitive DTW, and motor DTW) and groups (Low- and High-risk OF). Participants in the high-risk group of OF exhibited lower cadence, slower speed, longer stride time, and shorter stride length during cognitive DTW compared to STW ($p < 0.05$). A similar conclusion was reached for the low-risk group of OF ($p < 0.05$). No significant differences were found in the parameters between motor DTW and STW, regardless of the low-risk or high-risk group of OF.

The coefficient of variation of gait characteristics of patients with oral frailty during single-task walking and dual-task walking

Table 3 presented the CV of the gait parameters and the outcomes of the GEE analysis. The analysis outcomes revealed a significant interaction between condition and group for PCI, CV of velocity, and stride length.

Table 2 Summary of generalized estimation equations for direct gait parameters in single and dual-task conditions for the low-risk and high risk oral frailty groups

Variables	Group		Group		Condition		Interaction	
	Low-risk ($n=90$)	High-risk ($n=36$)	χ2	*p*	χ2	*p*	χ2	*p*
Stride length, mean ± SD, (m)			5.536	0.019	23.599	< 0.001	17.653	< 0.001
STW	0.987 ± 0.172	0.894 ± 0.179**						
Cognitive DTW	0.936 ± 0.171††	0.846 ± 0.141**/†						
Motor DTW	0.944 ± 0.171††	0.904 ± 0.185						
Stride time, mean ± SD, (s)			1.085	0.298	57.453	< 0.001	12.346	< 0.002
STW	1.129 ± 0.120	1.134 ± 0.129						
Cognitive DTW	1.190 ± 0.139††	1.278 ± 0.214*/††						
Motor DTW	1.142 ± 0.148	1.135 ± 0.138						
Candence, mean ± SD, (step/min)			0.171	0.679	67.362	< 0.001	17.126	< 0.001
STW	106.634 ± 11.514	107.512 ± 12.312						
Cognitive DTW	101.758 ± 11.688††	95.949 ± 15.276*/††						
Motor DTW	105.520 ± 12.871	107.553 ± 12.605						
Velocity, mean ± SD, (m/s)			4.491	0.034	84.316	< 0.001	20.688	< 0.001
STW	0.886 ± 0.205	0.820 ± 0.201						
Cognitive DTW	0.804 ± 0.198††	0.674 ± 0.155**/††						
Motor DTW	0.844 ± 0.210††	0.816 ± 0.206						

Generalized estimation equations (GEE) were used to detect differences in gait variance across different conditions (STW and DTW) and groups (Low- and High-risk of OF states). STW, single-task walking; DTW, dual-task walking. χ2 and *p*-values by variable (If there is interaction according to generalized estimation equations, post-hoc analysis would be performed)

Results of post-hoc analysis: Compare with Low risk group: *$p<0.05$, **$p<0.01$; Compare with STW: †$p<0.05$, ††$p<0.01$

Subsequently, a post-hoc analysis was conducted. The post-hoc analysis demonstrated that the high-risk group exhibited greater variability and higher PCI during cognitive DTW compared to the low-risk group ($p<0.05$). However, no significant differences were observed during motor DTW and STW. Furthermore, within the high-risk group of OF, there was higher variability in velocity and stride length, as well as higher PCI in cognitive DTW compared to STW ($p<0.05$). Among CSVD patients in low-risk group, no significant differences were detected in these parameters across the three walking conditions. It was noteworthy that the aforementioned conclusion remained robust after accounting for potential confounding factors, such as CDT and TMT-B.

The association between the gait parameters during dual-task walking and OFI-8 score

The gait parameters assessed by cognitive DTW demonstrated notable disparities between the two groups. Consequently, a linear regression analysis was conducted to explore the relationship between gait parameters during cognitive DTW (with the exclusion of CV of stride time and cadence) and the scores of OFI-8. The corresponding findings were outlined in Table 4. As anticipated, all parameters exhibited a significant association with the scores of OFI-8 in the initial model ($p<0.01$). Even after accounting for potential confounding factors, this correlation remained statistically significant in the adjusted model ($p<0.01$).

The association of oral frailty and falls in patients with cerebral small vessel disease

We observed a significant rise in the incidence of falls among patients in high-risk group of OF, as compared to those in low-risk group in Table 1. Therefore, a multivariate logistic regression analysis was further carried out. The analysis outcomes revealed that OF was independently associated with falls (odds ratio = 2.779, 95% confidence interval 1.193–6.475, $p=0.018$), even after adjusting for potential confounding factors such as CDT and TMT-B. The outcomes were shown in Table 5.

Discussion

Among patients with CSVD, the prevalence of OF was found to be 28.6% in this study, which was a little higher compared to previous research [10, 25, 27]. These CSVD patients endured the burdens of cognitive and motor disorders, which consequently restricted their capacity to prioritize oral health in their daily lives. Our study pinpointed out that individuals with a high risk of OF showed lower velocity or cadence, shorter stride length, longer stride time, particularly during cognitive DTW conditions in comparison to low-risk of OF. Furthermore, poor gait stability and coordination among those with OF was mirrored. A notable deteriorate in basic gait parameters, their CV, as well as the PCI during cognitive DTW in comparison to STW, among participants with a high risk of OF. Conversely, in patients with low-risk of OF, only the basic gait parameters displayed disparities

Table 3 Summary of coefficient of variation of parameters of gait in single and dual-task conditions for the low-risk and high risk oral frailty groups

Variables	Group		Group		Condition		Interaction	
	Low-risk (*n* = 90)	High-risk (*n* = 36)	χ2	*p*	χ2	*p*	χ2	*p*
Stride length CV, median (Q1, Q3), (%)			1.558	0.212	8.561	0.014	6.929	0.031
STW	5.800 (4.375,8.675)	7.800 (4.575,10.625)						
Cognitive DTW	7.069 (5.511,9.138)	8.435 (5.523,11.914)[*/†]						
Motor DTW	7.150 (5.215,8.835)	8.050 (5.277,9.040)						
Stride time CV, median (Q1, Q3), (%)			2.489	0.115	15.045	0.001	4.500	0.105
STW	2.632 (1.887,3.572)	2.871 (2.265,4.918)						
Cognitive DTW	3.600 (2.532,5.294)	3.491 (2.620,7.848)						
Motor DTW	2.971 (2.474,4.214)	2.985 (2.614,4.338)						
Candence CV, median (Q1, Q3), (%)			0.877	0.349	9.557	0.008	5.773	0.056
STW	3.952 (3.097,5.850)	4.252 (3.277,6.488)						
Cognitive DTW	4.985 (3.715,6.479)	6.400 (3.684,9.049)						
Motor DTW	4.392 (3.437,5.674)	3.957 (3.152,6.072)						
Velocity CV, median (Q1, Q3), (%)			11.143	0.001	11.341	0.003	22.177	< 0.001
STW	8.191 (5.872,13.056)	10.850 (7.036,15.405)						
Cognitive DTW	7.865 (6.250,12.125)	16.294 (10.813,21.976)[**/††]						
Motor DTW	9.549 (6.957,12.004)	10.792 (7.264,14.953)						
GA, median (Q1, Q3), (%)			1.871	0.171	2.867	0.238	0.460	0.795
STW	1.100 (0.000,2.228)	1.223 (0.960,3.199)						
Cognitive DTW	1.128 (0.929,2.687)	1.889 (0.987,3.344)						
Motor DTW	1.158 (0.940,2.738)	1.854 (1.028,3.364)						
PCI, median (Q1, Q3)			4.682	0.030	10.359	0.006	6.980	0.031
STW	4.221 (2.984,7.347)	5.346 (3.363,9.056)						
Cognitive DTW	5.468 (3.401,7.685)	6.959 (4.717,12.426)[**/†]						
Motor DTW	4.479 (3.158,7.609)	4.758 (3.922,8.525)						

Generalized estimation equations (GEE) were used to detect differences in gait variance across different conditions (STW and DTW) and groups (Low- and High-risk of OF states). STW, single-task walking; DTW, dual-task walking; CV, coefficient of variation; GA, gait asymmetry; PCI, phase coordination index. χ2 and *p*-values by variable (If there is interaction according to generalized estimation equations, post-hoc analysis would be performed)

Results of post-hoc analysis: Compare with Low risk group: [*]$p < 0.05$, [**]$p < 0.01$; Compare with STW: [†]$p < 0.05$, [††]$p < 0.01$

Table 4 Linear regression analysis showing the association between the parameters during DTW and the points of OFI-8

		Model 1				Model 2			
		B	*p*	95% Confidence interval		B	*p*	95% Confidence interval	
Value of OFI-8	Stride length (m)	-6.390	< 0.001	-9.587	-3.192	-6.165	< 0.001	-9.341	-2.988
	Stride time (s)	5.420	0.001	2.162	8.678	4.986	0.004	1.649	8.322
	Candence (step/min)	-0.065	0.003	-0.107	-0.022	-0.059	0.009	-0.103	-0.015
	Velocity (m/s)	-6.609	< 0.001	-9.277	-3.941	-6.276	< 0.001	-8.995	-3.558
	Stride length CV (%)	0.205	< 0.001	0.094	0.315	0.190	0.001	0.080	0.301
	Velocity CV (%)	0.222	< 0.001	0.161	0.283	0.218	< 0.001	0.157	0.280
	PCI	0.292	< 0.001	0.218	0.367	0.290	< 0.001	0.216	0.363

Linear regression analysis was employed to elucidate the association of the OFI-8 points and gait parameters during cognitive DTW. Model 2 was adjusted for all confounding factors, including CDT and TMT-B. PCI, phase coordination index; DTW, dual-task walking; CV, coefficient of variation; CDT, clock drawing test; TMT-B, trail-making test-part B

Table 5 Logistic regressions showing the association between the fall and the risk of oral frailty (as the dependent variable) in CSVD patients

	B	*p*	OR	95% CI	
Oral frailty	1.022	0.018	2.779	1.193	6.475
CDT	-0.032	0.904	0.968	0.574	1.635
TMT-B	0.008	0.662	1.008	0.974	1.042

CSVD, cerebral small vessel disease; CDT, clock drawing test; TMT-B, trail-making test-part B; OR, Odds ratio; CI, confidence interval. Logistic regression models were also employed to assess the independent association of OF risk and falls between cognitive DTW and STW scenarios. Moreover, a proportional association was observed between the progressive accumulation of oral health deficits and the extent of decline in gait performance, which verified by the fact that OFI-8 scores exhibited a linear correlation with all of gait parameters during cognitive DTW. As anticipated, we also discovered a significant and independent association between OF and falls. To the best of our knowledge, this study stood as the inaugural endeavor to illustrate the gait characteristics observed in the CSVD patients afflicted with suboptimal oral health. Our findings underscored the significance of appreciating the OF within patients diagnosed with CSVD. Notably, OFI-8 holds promise as a potent tool for identifying the heightened risk of falls in these patients.

A previous study revealed a notable correlation between inferior dentition status and reduced cadence [14]. Another study also showed an association of diminished occlusal force and deteriorated stability in a cohort of 87 older adults [28]. Moreover, a research published in 2019 unveiled that the absence of posterior occlusal support foretold the occurrence of diminished gait speed in 80-yearold Japanese adults [12]. Also, another research revealed that tooth loss would hasten the deterioration of gait speed [29]. Recently, there was several research to explore the association between gait characteristics and OF. For instance, Ryo Komatsu et al. confirmed that gait speed during STW, recognized as a subdomain of physical frailty, was linked to OF [30]. A study conducted on elderly patients within Japanese communities also discovered that there was a notable presence of diminished gait speed, reduced stride lengths, prolonged double support duration, and heightened variability when performing STW in participations with OF [10]. However, in our study, only the deterioration in stride length was detected during STW conditions in the patients with a high risk of OF compared with low-risk, possibly due to differences in the enrolled participants. Previous research has mainly focused on community-dwelling adults, whereas we largely focused on patients with CSVD. Patients with CSVD often exhibit a tendency to walk slowly, which is partly attributed to damage to the integrity of subcortical connections, particularly in the frontal cortex and basal ganglia [31]. However, the deterioration of gait characteristics in participation suffered from OF is minimal, making it challenging to detect using the STW method. Therefore, it is necessary to introduce DTW to detect gait disorders in CSVD patients with OF.

Walking without concurrently performing a secondary task is often considered a semi-automatic action that does not require additional cognitive resources from the brain [32]. In contrast, DTW is a complex task that necessitates intact cognitive functions. Therefore, a decline in performance during DTW indicates competition for attentional resources [32]. As a result, DTW can be used to detect subtle differences in gait. Due to the lack of sufficient attention given to the gait characteristics of CSVD patients with high-risk OF, the association between OF and DTW has yet to be identified. Currently, there is limited literature discussing this association. Our study first identified changes of gait parameters in DTW condition among these patients. In our study, there was no difference between the low-risk and high-risk groups when performing motor DTW. However, the high-risk group showed poor performance in PCI, cadence, stride time, as well as speed, stride length and their CV than the low-risk group during cognitive DTW conditions. Furthermore, patients in the high-risk group showed significant differences in variability and coordination during the cognitive DTW condition compared to STW. Consequently, in the future clinical research, variability and coordination need to be further studied to enhance the quality of management and mitigate fall risk in CSVD patients with a high risk of OF.

Indeed, prior epidemiological researches have revealed an association between poor oral health and elevated incidence of falls in older adult individuals [33] and dementia patients [34]. Recently, Naoto Kamide et al. further verified that the OF served as a risk factor for falls, regardless of the presence of sarcopenia and the time taken in the Timed Up and Go (TUG) test [11], which are recognized predictors for falls in the older adults [35, 36]. Our study yielded a similar finding, indicating that OF in CSVD patients had an independent association with falls, regardless of the TMT-B and CDT, which are considered as the cognitive domains most vulnerable to CSVD. Furthermore, past research has identified several parameters that serve as indicators of an elevated risk of falls among older patients, including decrease in gait speed, reduction in stride length, and increase in variability [37]. Although, no significant differences were observed in the STW in our study, these changes were detected in the cognitive DTW. Hence, we speculated that the association of OF and falls may be influenced by gait characters for CSVD patients, especially under the condition of cognitive DTW. However, the study employed a cross-sectional design, restricting the ability to discuss causation.

Limitation

Our study presented the inaugural evidence of the association of OF and quantitative gait detection as well as falls in patients diagnosed with CSVD. However, it is important to acknowledge the limitations of this research. Firstly, a cross-sectional design in this study limited the establishment of causality. Hence, additional investigations, such as a cohort study, are necessary to expand our understanding of the topic. Secondly, the neuroimaging findings were assessed using a semi-quantitative approach. In future studies, an automated system is recommended for measuring neuroimaging characteristics, which will offer a more objective and metric-based assessment.

Conclusion

To sum up, the gait variability or coordination of CSVD patients with a high risk of OF should obtain more attention, and it is necessary to train the patients dual task activities when they are walking in daily life. Our findings confirm an association between OF and locomotion gait in patients with CSVD, both in the condition of STW and DTW, with DTW being a more precise method for detecting this association. Furthermore, OF has been verified as an independent risk factor for the falls in CSVD individuals. Collectively, doctors should consider OF as a potentially modifiable risk factor for older patients with CSVD to reduce the deterioration and mitigate the risk of falls.

Acknowledgements
The authors thank Dr. Wei Wei and Jichao Ding for providing magnetic resonance imaging support. We also thank Miss Yu Ding for her assistance with data processing.

Author contributions
Hongyang Xie and Junli Chen were responsible for the data collection and manuscript writing. Nan Zhang and Cuiqiao Xia were responsible for data collection and processing. Zhenxi Xia, Hongyang Xie and Junli Chen was responsible for data analysis. Yonghua Huang and Hongyi Zhao were responsible for the study design and manuscript revision. All authors contributed to the article, reviewed, and approved the final version of the manuscript.

Funding
This study was supported by the Wu Jieping Medical Foundation (Grant No. 320.6750.18456).

Data availability
The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This clinical study was designed and performed in accordance with the Declaration of Helsinki and approved by the Academic Ethics Committee of the Biological Sciences Division of the Seventh Medical Center of the PLA General Hospital (Beijing, China) (2022-098). All the participants provided written informed consent.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 24 January 2024 / Accepted: 3 September 2024
Published online: 10 September 2024

References

1. Al-Yahya E, et al. Cognitive motor interference while walking: a systematic review and meta-analysis. Neurosci Biobehav Rev. 2011;35(3):715–28.
2. Wardlaw JM, et al. Neuroimaging standards for research into small vessel disease and its contribution to ageing and neurodegeneration. Lancet Neurol. 2013;12(8):822–38.
3. Hilal S, et al. Prevalence, risk factors and consequences of cerebral small vessel diseases: data from three Asian countries. J Neurol Neurosurg Psychiatry. 2017;88(8):669–74.
4. Wardlaw JM, et al. ESO Guideline on covert cerebral small vessel disease. Eur Stroke J. 2021;6(2):Cxi–clxii.
5. Chawla H, et al. Effect of type of secondary task on cued gait on people with idiopathic Parkinson's disease. J Neurosci Rural Pract. 2014;5(1):18–23.
6. Xia C, et al. Spatiotemporal gait characteristics during single- and dual-task walking are associated with the burden of cerebral small vessel disease. Front Neurol. 2023;14:1285947.
7. Iwasaki M, et al. Association between oral Frailty and Nutritional Status among Community-Dwelling older adults: the Takashimadaira Study. J Nutr Health Aging. 2020;24(9):1003–10.
8. Watanabe Y, et al. Oral health for achieving longevity. Geriatr Gerontol Int. 2020;20(6):526–38.
9. Tanaka T, et al. Oral Frailty as a risk factor for physical Frailty and Mortality in Community-Dwelling Elderly. J Gerontol Biol Sci Med Sci. 2018;73(12):1661–7.
10. Iwasaki M, et al. Oral frailty and gait performance in community-dwelling older adults: findings from the Takashimadaira study. J Prosthodont Res. 2021;65(4):467–73.
11. Kamide N, et al. The association of oral frailty with fall risk in community-dwelling older adults: a cross-sectional, observational study. Eur Geriatr Med; 2023.
12. Hatta K, et al. Lack of posterior occlusal support predicts the reduction in walking speed in 80-year-old Japanese adults: a 3-year prospective cohort study with propensity score analysis by the SONIC Study Group. Gerodontology. 2019;36(2):156–62.
13. Tsakos G, et al. Tooth loss associated with physical and cognitive decline in older adults. J Am Geriatr Soc. 2015;63(1):91–9.
14. Yamaga T, et al. Relationship between dental occlusion and physical fitness in an elderly population. J Gerontol Biol Sci Med Sci. 2002;57(9):M616–20.
15. Yoshihara A, et al. The relationship between dietary intake and the number of teeth in elderly Japanese subjects. Gerodontology. 2005;22(4):211–8.
16. Chen X, Wang J, Shan Y, et al. Cerebral small vessel disease: neuroimaging markers and clinical implication. J Neurol. 2019;266:2347–62.
17. van den Brink H, Doubal FN, Duering M. Advanced MRI in cerebral small vessel disease. Int J Stroke. 2023;18(1):28–35.
18. Plotnik M, Giladi N, Hausdorff JM. A new measure for quantifying the bilateral coordination of human gait: effects of aging and Parkinson's disease. Exp Brain Res. 2007;181(4):561–70.
19. Swanson CW, Fling BW. Associations between gait coordination, variability and motor cortex inhibition in young and older adults. Exp Gerontol. 2018;113:163–72.
20. Richmond SB, et al. A temporal analysis of bilateral gait coordination in people with multiple sclerosis. Mult Scler Relat Disord. 2020;45:102445.
21. Han SH, et al. Quantitative analysis of the bilateral coordination and gait asymmetry using inertial measurement unit-based gait analysis. PLoS ONE. 2019;14(10):e0222913.
22. Kalron A. Gait variability across the disability spectrum in people with multiple sclerosis. J Neurol Sci. 2016;361:1–6.
23. Zhào H, et al. Cognitive Frailty among Elderly Chinese patients with Cerebral Small Vessel Disease: a structural MRI study. Front Med (Lausanne). 2020;7:397.
24. Freedman M, et al. Clock drawing: a neuropsychological analysis. IE-WW NORTON; 1994.
25. Tanaka T, et al. Oral Frailty Index-8 in the risk assessment of new-onset oral frailty and functional disability among community-dwelling older adults. Arch Gerontol Geriatr. 2021;94:104340.
26. Iwasaki M et al. A two-year longitudinal study of the Association between oral Frailty and deteriorating Nutritional Status among Community-Dwelling older adults. Int J Environ Res Public Health, 2020. 18(1).
27. Minakuchi S, et al. Oral hypofunction in the older population: position paper of the Japanese society of Gerodontology in 2016. Gerodontology. 2018;35(4):317–24.
28. Song-Yu X, et al. Postural stability and occlusal status among Japanese elderly. Gerodontology. 2012;29(2):e988–97.

29. Welmer AK, et al. Impact of tooth loss on walking speed decline over time in older adults: a population-based cohort study. Aging Clin Exp Res. 2017;29(4):793–800.
30. Komatsu R et al. Association between Physical Frailty subdomains and oral Frailty in Community-Dwelling older adults. Int J Environ Res Public Health, 2021. 18(6).
31. Wardlaw JM, Smith C, Dichgans M. Small vessel disease: mechanisms and clinical implications. Lancet Neurol. 2019;18(7):684–96.
32. Clark DJ. Automaticity of walking: functional significance, mechanisms, measurement and rehabilitation strategies. Front Hum Neurosci. 2015;9:246.
33. Yamamoto T et al. Dental status and incident falls among older Japanese: a prospective cohort study. BMJ Open, 2012. 2(4).
34. Yoshida M, et al. Functional dental occlusion may prevent falls in elderly patients with dementia. J Am Geriatr Soc. 2005;53(9):1631–2.
35. Schoene D, et al. Discriminative ability and predictive validity of the timed up and go test in identifying older people who fall: systematic review and meta-analysis. J Am Geriatr Soc. 2013;61(2):202–8.
36. Beaudart C, et al. Health outcomes of Sarcopenia: a systematic review and Meta-analysis. PLoS ONE. 2017;12(1):e0169548.
37. Mortaza N, Abu Osman NA, Mehdikhani N. Are the spatio-temporal parameters of gait capable of distinguishing a faller from a non-faller elderly? Eur J Phys Rehabil Med. 2014;50(6):677–91.

Publisher's note