Experimental Gerontology 180 (2023) 112259

Contents lists available at ScienceDirect

Experimental Gerontology

journal homepage: www.elsevier.com/locate/expgero

A prospective cohort study on the association between new falls and balancing ability among older adults over 80 years who are independent

Jian Zhou [a], Bo Liu [b,c,*], Hui Ye [a], Jin-Ping Duan [b]

[a] Department of Geriatrics, Beijing Tongren Hospital, China Capital Medical University, Beijing 100730, China
[b] Department of Otolaryngology Head and Neck Surgery, Beijing Tongren Hospital, China Capital Medical University, Beijing 100730, China
[c] Beijing Institute of Otolaryngology, Key Laboratory of Otolaryngology Head and Neck Surgery, Ministry of Education, Beijing 100730, China

ARTICLE INFO

Section editor: Christiaan Leeuwenburgh

Keywords:
Balance
Fall
Sensory integration test
Timed Up and Go Test (TUGT)
80 years and over

ABSTRACT

Objective: The purpose of this study was to prospectively investigate the relationship between new falls and the balancing ability of older adults aged ≥80 years who are independent and evaluate the validity of the assessment tools as a predictor of falls.
Methods: We enrolled a total of 160 participants (104 males and 56 females) aged 80 years or older. During the 12 months of observation, we investigated underlying diseases and drug use and performed a comprehensive geriatric assessment (including self-care ability, muscle strength, action ability, cognition, emotional state, and other aspects), as well as computerized dynamic posturography to assess balance and gait functions. We further analyzed the relationship between new falls and multiple internal risk factors.
Results: A total of 159 participants were included for statistical analysis, and there were 108 new falls among the 59 participants. Fall history and visual preference (PREF) scores on the sensory integration test showed a positive correlation with new falls. The composite equilibrium score (SOTcom), left total hip bone mineral density, left directional control, and end point deviation were all found to be negatively correlated with new falls ($P < 0.05$). The cut-off point of the timed "up and go" test (TUG) in predicting new falls in this cohort was >12.03 s, with a sensitivity of 78.0 %, a specificity of 51.5 %, and an AUC of 0.667 ($P < 0.001$, 95 % CI: 0.567–0.721). The cut-off point of SOTcom in predicting new falls was ≤52, with a sensitivity of 40.7 %, a specificity of 84.0 %, and an AUC of 0.606 ($P = 0.028$, 95 % CI: 0.525–0.682).
Conclusions: The decline of balance sensory input function (mainly vestibular and visual sense), skeletal muscle motor function, and related postural control ability constituted the main risk factors for new falls in older adults who were independent. The combined use of TUG and SOT was useful in further improving the accuracy of predicting new falls in this population and providing a direction for effective intervention and rehabilitation measures.

1. Introduction

Fall refers to an event that results in a person inadvertently resting on the ground or a lower plane due to sudden, involuntary, and unintentional changes in position, excluding those caused by violence, loss of consciousness, hemiplegia, or epileptic seizure (Gillespie et al., 2012). About 30 % of people aged ≥65 years and 50 % of people aged ≥80 years have at least one fall every year (WHO, 2021). Falls constitute an important cause of incapacitation, disability, shortened life span, and increased medical costs among older adults and can cause anxiety, depression, fear of falling, and social isolation, thereby foisting heavy care expenses and economic burden on families and society (GBD 2017

Abbreviations: SOTcom, composite equilibrium score; TUGT, timed up and go test; COPD, chronic obstructive pulmonary disease; ADL, activities of daily living; FTSST, Five Times Sit to Stand Test; UGS, usual gait speed; TUG, Timed Up and Go Test; FTS, full tandem stance; MoCA, Montreal cognitive assessment; SDS, Self-rating Depression Scale; FES-I, Falls Efficacy Scale International; CDP, computerized dynamic posturography; SOTcom, weight of composite equilibrium score; SOM, somatosensory; VIS, vision; VEST, vestibular; PREF, visual preference.

* Corresponding author at: Department of Otolaryngology Head and Neck Surgery, Beijing Tongren Hospital, China Capital Medical University, Beijing Institute of Otolaryngology, Key Laboratory of Otolaryngology Head and Neck Surgery, Ministry of Education, No.1 of Dong Jiao Min Xiang, Dongcheng District, Beijing 100730, China.

E-mail address: liubo6852@163.com (B. Liu).

https://doi.org/10.1016/j.exger.2023.112259
Received 6 May 2023; Received in revised form 13 July 2023; Accepted 14 July 2023
Available online 21 July 2023

Risk Factor Collaborators, 2018; Mekkodathil et al., 2020).

The annual fall rate of older adults in China ranges from 14.7 % to 34 % (median: 18 %), with 60 % to 75 % of reported fallers injuring themselves, with fractures accounting for 6 % to 8 % of all injuries (Kwan et al., 2011). The incidence of falls among older adults in China has increased by 79.2 % in the past 30 years, showing a significant upward trend with no gender, age, or regional disparities (Ye et al., 2021). Older adults who live independently are at greater risk of falling and being injured. As a result, early detection of fall risk and timely intervention are of great significance in prolonging the period of self-management for elderly people and minimizing the duration of their disability.

Previous studies have identified several risk factors for falls, including physiological decline, chronic diseases, psychological factors, and medications (National Institute for Health and Care Excellence, 2013). Among them, the ability to balance plays a major role, involving sensory input systems such as vision, vestibular sensation, proprioception, the central nervous system, and motor organs such as skeletal muscles. Balance and gait disorders are thought to be the leading causes of falls in older adults (Panel on Prevention of Falls in Older Persons, American Geriatrics Society and British Geriatrics Society, 2011). Vestibular dysfunction is regarded as a major risk factor for falls in older adults. Vestibular dysfunction refers to a malfunction of the vestibular system, which is responsible for perceiving body posture and movement, as well as perceptual issues with body orientation, motion, acceleration, and velocity. This dysfunction can affect body balance, making older adults more prone to falls, often accompanied by dizziness. Dizziness can cause hesitation, tension, and fear in older adults, thereby affecting their mobility and increasing the risk of falls. Nevertheless, the mechanism of balance disorders in older adults is still not well understood (Agrawal et al., 2020). Therefore, this study included multiple internal risk factors for falls in the elderly into a comprehensive analysis, covering underlying diseases, drug use, cognitive and psychological states, balance function, muscle strength, muscle function, bone mineral density, bone metabolism and vitamin D level, etc., to find out the correlation, explore the key risk factors for falls in this population, and analyze the mechanism. At the same time, effective tools for predicting fall risk suitable for this population are evaluated to provide direction for targeted intervention.

2. Materials and methods

2.1. Study design

This was a prospective cohort study with an observation period of 12 months.

2.2. Study participants

We enrolled a total of 160 elderly people aged 80 years or older who were treated in the geriatric outpatient department of the Beijing Tongren Hospital from April to October 2021, consisting of 104 males (65.0 %) and 56 females (35.0 %), with an average age of 84.9 ± 3.3 years (80–94 years). All of them were residents of Beijing.

Inclusion criteria: Those aged ≥80 years, able to live completely or moderately independently, and willing and able to cooperate to complete the relevant assessments. Exclusion criteria: Those with New York Heart Association (NYHA) grade III–IV cardiac function, chronic kidney disease stage 4–5, chronic obstructive pulmonary disease (COPD) stage 4, decompensated liver cirrhosis, and malignant tumors.

2.3. Data collection

2.3.1. Medical history and physical examination

We collected basic information and medical history details from our participants through interviews and a review of medical records. Data collected included age, gender, underlying diseases, history of falls within 12 months before enrollment, types of medications (≥ 5 medications were considered polypharmacy), and drugs acting on the central nervous system (sedative hypnotics, antipsychotics, antidepressants). We also measured their height, weight, and supine and orthostatic blood pressure. The outcome observed in this study, "new fall, "was defined as new falls that occurred within the 12 months from the start of the study.

2.3.2. Comprehensive geriatric assessment

A comprehensive assessment of older adults is an important tool for screening for geriatric syndromes. In this study, we used a common tool to assess the risk of falls, which covers activities of daily living, muscle strength, mobility, cognition, and emotional status. To reduce detection errors, a specially trained nurse performed the assessment in a standardized manner.

(1) The Barthel index of ADL was used to evaluate patients' ability to perform activities of daily living (ADL). A score of ≥75 points is classified as living moderately independently (Arli et al., 2020).
(2) We measured hand grip strength to evaluate grip strength. The hand grip strength of participants was measured using a hand-held dynamometer (both hands were tested twice, and the highest value of all four attempts was taken). Hand grip strength <32 kg in males and hand grip strength <20 kg in females was considered decreased muscle strength (Alley et al., 2014).
(3) We evaluated lower limb muscle strength using the Five Times Sit to Stand Test (FTSST): Using a chair (48 cm high), the participants were instructed to stand up and sit down 5 times as quickly as they could, without stopping in between, while keeping their arms folded across the chest. We recorded the time interval between the first time of sitting and the fifth time of contact with the chair. Taking >10 s or <5 times was considered high fall risk (Muñoz-Bermejo et al., 2021).
(4) We used the usual gait speed (UGS) to evaluate muscle function. The participant walked 6 m forward at their normal pace from the starting point. The timing began when the participant's toe crossed the starting line and ended when the toe reached the 6-meter finish line. The walking speed (m/s) was calculated. A gait speed of <0.8 m/s was considered reduced walking ability (Peel et al., 2013).
(5) We used the Timed Up and Go Test (TUG) to assess the dynamic balance function and mobility. Participants wore their regular footwear and could use a walking aid if needed. They were instructed to stand up from a chair with an armrest (seat height of 48 cm; armrest height of 68 cm), walk 3 m at their normal pace, and then turn, walk back, and sit down again. The time from start to sit down was recorded. TUG >12 s was considered to be a risk for falling (Chow et al., 2019).
(6) We used the full tandem stance (FTS) to evaluate the static balance function. The participant was instructed to stand with the heel against the toes for 10 s. They could move their arms or body to maintain balance, but not their feet. On observation, no displacement of both feet was counted as "0", while the foot being displaced was counted as "1" and indicated abnormal static balance.
(7) We used the Montreal cognitive assessment (MoCA) to evaluate cognitive function: Total score: 30 points (normal: ≥26 points; mild cognitive dysfunction: 18–25 points; moderate cognitive dysfunction: 11–17 points; and severe cognitive dysfunction: ≤10 points) (Jones et al., 2021).
(8) Participants filled up the Zung Self-rating Anxiety Scale (SAS), the Zung Self-rating Depression Scale (SDS), the Frail Scale, and the Falls Efficacy Scale International (FES—I) for the evaluation of anxiety, depression, asthenia, and fear of falling, respectively (Dunstan et al., 2017; Dong et al., 2017; Morgan et al., 2013).

2.3.3. Computerized dynamic posturography (CDP)

Computerized dynamic posturography (CDP) is a quantitative measurement of posture balance. We used the EquiTest dynamic balance table tester and the balance test board. Data were collected automatically, and calculations were done using the supporting computer information analysis and processing system (Harro and Garascia, 2019).

It consisted of the following components:

(1) Sensory Organization Test (SOT): This was used to examine the individual's ability to effectively use the three sensory systems (vestibular, visual, and somatosensory) for balance. The SOT was performed three times under six different conditions, with each test lasting 20 s. Participants were required to maintain body balance without moving their feet, and taking a step was considered falling. Condition 1: fixed surface and normal vision, with eyes open; Condition 2: fixed surface, with eyes closed; Condition 3: fixed surface and sway-referenced vision, with eyes open; Condition 4: sway-referenced surface and normal vision, with eyes open; Condition 5: sway-referenced surface, with eyes closed; and Condition 6: sway-referenced surface and vision, with eyes open. After completion of the test, the weightages of the composite equilibrium score (SOTcom), somatosensory (SOM), visual (VIS), vestibular (VEST), and visual preference (PREF) were calculated by the system according to the scores under each sensory input system.

(2) Limits of Stability Test (LOS): This was used to effectively evaluate the ability of participants to maintain balance using voluntary movement. Participants were instructed to stand barefoot on a support board, gaze forward, and maintain their center of gravity stable at the center of the testing area. Upon the appearance of a corresponding signal on the screen, they were asked to promptly shift their body weight toward the target area while ensuring that their center of gravity remained stable, and maintain this position for 10 s before shifting their weight back to the center of the testing area. Eight-tests were performed for different directions: forward (FW), backward (BW), right (RT), left (LT), forward-right (FWRT), forward-left (FWLT), backward-right (BWRT), and backward-left (BWLT). After the test, data were calculated by the system, and the following indices were obtained for the four directions of forward, backward, left, and right, as well as a comprehensive index.

Reaction Time (RT): The time between the signal to move and the initiation of the movement, expressed in seconds.

Movement Velocity (MVL): The average speed of the center of gravity (COG) movement in degrees per second.

Endpoint Excursion (EPE): The initial distance traveled by the center of gravity on the primary attempt to reach the target highlighted on the screen, expressed as a percentage of LOS. It represents the individual's perceived LOS.

Maximum Excursion (MXE): The farthest distance traveled from the COG during the trial, expressed as a percentage of the maximum LOS distance.

Movement Directional Control (DCL): The amount of movement in the intended direction (toward the target highlighted on the screen) minus the amount of extraneous movement (off axis), expressed as a percentage.

(3) Tandem Walk (TW): The participant was tested for the ability to maintain balance while walking on a narrow support plane. The participant was instructed to stand at the starting point of the balance board in a heel-to-toe manner. After the instrument gave a start signal, the participant had to immediately walk along the center line of the board in a heel-to-toe manner without spaces between the steps or with the distance between the two feet not >1 cm, with their arms crossed. When the instrument gave a stop signal, the participant had to immediately stop walking and maintain balance while standing. The step width, speed, and end sway were calculated.

2.3.4. Laboratory tests

Between 8:00 and 10:00 am, a fasting sample of 10 mL of venous blood from the median cubital vein was collected and immediately sent to the laboratory. Blood urea nitrogen (BUN), serum creatinine (Cr), albumin (ALB), calcium (II) ion (Ca^{2+}), inorganic phosphorus, total testosterone (T), estradiol (E2), type I procollagen N-terminal telopeptide (P1NP), type I procollagen C-terminal telopeptide (β-CTx), and 25-hydroxyvitamin D (25OHD) were detected. E*stimated glomerular filtration rate* (eGFR) levels were calculated according to the Modification of Diet in Renal Disease (MDRD) formula.

2.3.5. Bone mineral density (BMD) examination

We measured the bone mineral density (BMD) and T-score of the lumbar spine 1–4, the bilateral femoral neck, and the total hip using a Lunar Prodigy dual-energy X-ray absorptometer (DXA). Normal bone mass: T-score ≥ -1; low bone mass: $-2.5 <$ T-score < -1; osteoporosis: T-score ≤ -2.5. T-score = (measured value - peak bone density of normal young people of the same race and gender) / standard deviation of peak bone density of normal young people of the same race and gender (China Medical Association of Osteoporosis and Bone Mineral Research, 2017).

2.4. Observation

The participants were followed up monthly by telephone or during outpatient consultations for 12 months to check for new falls and injuries.

2.5. Statistical analysis

We used SPSS 19.0 software for statistical analysis. After the test for normality, the measurement data in line with normal distribution were expressed as mean ± standard deviation, and those of non-normal distribution that showed normal distribution after log transformation were described as mean (95 % confidence interval). An independent samples *t*-test was used to compare the means between the two groups. The data in non-normal distribution were expressed as the median (interquartile range) and analyzed using the Mann-Whitney *U* test. Categorical data were expressed as percentages, and the chi-square test was used for inter-group comparison; Spearman's correlation coefficient was used to describe the correlation degree of measurement data; binary logistic regression was used to analyze the related factors; and receiver operating characteristic (ROC) curve analysis was performed using MedCalc statistical software. $P < 0.05$ indicated that the difference was statistically significant.

3. Results

3.1. New falls

During the 12-month observation period, one of the 160 participants was lost to follow-up, and a total of 159 participants were included in the final statistical analysis. There were 108 new falls among 59 participants, with an incidence rate of 37.1 % (59/159 cases), including 54 falls outdoors (50 %) and 54 falls indoors (50 %). According to details provided by the faller, there were 49 falls due to tripping or slipping (45.4 %), 13 falls due to missing a seat or step (12.0 %), 17 falls when walking unsteadily, turning, standing up, or reaching for objects (15.7 %), 15 falls when standing unsteadily (13.9 %), and 14 falls due to lower limb weakness (13.0 %). There were 55 falls (50.9 %) resulting in injuries, including 11 fractures, accounting for 20 % (11/55 cases) (Table 1).

Table 1
The frequency and proportion of new falls.

Frequency of falls	Cases of patient	Proportion
1	32	54.2 %
2	15	25.4 %
3	7	11.9 %
4	3	5.1 %
6	1	1.7 %
7	1	1.7 %

3.2. Comparison of basic information between older adults with new falls (the new fall group) and those without falls (the non-fall group)

Compared with the non-fall group, older adults in the new fall group were older ($P = 0.036$), had a higher previous fall rate ($P = 0.000$) and β-CTx value ($P = 0.034$), and had a lower BMI ($P = 0.007$) and left total hip BMD ($P = 0.044$). There were no statistically significant differences between the two groups in terms of male/female ratio, prevalence of major chronic diseases, postural hypotension, polypharmacy, and the ratio of drugs acting on the central nervous system, serum calcium, phosphorus, estradiol, testosterone, 25OHD, P1NP, and BMD of the lumbar spine 1–4, bilateral femoral neck, and right total hip (all $P > 0.05$) (Table 2).

3.3. Comparison of comprehensive geriatric assessment data between older adults with new falls (the new fall group) and those without falls (the non-fall group)

Compared with the non-fall group, the ADL score ($P = 0.006$), hand grip strength ($P = 0.013$), and FTS completion rate ($P = 0.033$) were lower, and the TUG ($P = 0.002$) and FTSST time ($P = 0.002$) were longer in the new fall group, with the differences being statistically significant. There were no significant differences in asthenia, anxiety, depression, cognitive function, fall attention score, or walking speed between the two groups (all $P > 0.05$) (Table 3).

3.4. Comparison of balance function and gait function between older adults with new falls (the new fall group) and those without falls (the non-fall group)

SOT: Compared with the non-fall group, the new fall group had lower SOTcom ($P = 0.028$) and VEST ($P = 0.009$) and higher PREF ($P = 0.030$), with the differences being statistically significant. There were no statistically significant differences in SOM or VIS between the two groups (all $P > 0.05$) (Table 4).

LOS: When compared with the non-fall group, the new fall group had lesser control of the right ($P = 0.006$) and left directions ($P = 0.012$), and the left endpoint excursion ($P = 0.002$) and maximum excursion ($P = 0.007$) were reduced, with statistically significant differences. There were no statistically significant differences in reaction time or movement speed between the two groups (all $P > 0.05$) (Table 4).

TW: There were no statistically significant differences in the step width, gait speed, or end-point sway between the two groups (all $P > 0.05$) (Table 4).

3.5. Risk factors for new falls

Analysis of related factors showed that fall history within 12 months before enrollment [*OR (95 % CI)* = 13.344 (4.707–37.830), $P = 0.000$] and PREF [*OR (95 % CI)* = 1.065 (1.025–1.106), $P = 0.001$] were positively correlated with new falls. Left total hip BMD [*OR (95 % CI)* = 0.013 (0.000–0.352), $P = 0.010$], SOTcom [*OR (95 % CI)* = 0.965 (0.936–0.995), $P = 0.023$], left directional control [*OR (95 % CI)* = 0.947 (0.903–0.994), $P = 0.027$], and left endpoint excursion [*OR (95 % CI)* = 0.952 (0.919–0.985), $P = 0.005$] were negatively correlated with new falls ($P < 0.01$, $P < 0.05$) (Table 5).

Table 2
Comparison of Basic Information between the Elderly with New Falls and Those without Falls.

Index	Fall group (n = 59)	Non-fall group (n = 100)	*t , χ2 , z-value*	P-value
Age (years)	85.6 ± 3.8	84.5 ± 3.0	2.119*	0.036
Male [n(%)]	36(61.0 %)	68(68.0 %)	0.397#	0.621
BMI (kg/m2)	22.3 ± 3.2	23.7 ± 3.2	−2.739*	0.007
Coronary heart disease [n(%)]	24(40.7 %)	35(35.0 %)	0.513#	0.500
Hypertension [n (%)]	42(71.2 %)	68(68.0 %)	0.177#	0.725
Diabetes [n(%)]	16(27.1 %)	33(33.0 %)	0.602#	0.481
Cerebrovascular disease [n(%)]	21(35.6 %)	26(26.0 %)	1.640#	0.213
Stage 3 CKD [n(%)]	12(20.3 %)	19(19.0 %)	0.042#	0.839
Osteoporosis [n(%)]	13(22.0 %)	17(17.0 %)	0.614#	0.530
Postural hypotension [n (%)]	4(6.8 %)	6(6.0 %)	0.038#	0.845
Polypharmacy [n (%)]	55(93.2 %)	86(86.0 %)	1.927#	0.202
CNS medication [n (%)]	12(20.3 %)	21(21.0 %)	0.010#	1.000
Fall history [n(%)]	39(66.1 %)	20(20.0 %)	32.125#	0.000
History of fracture [n(%)]	9(15.3 %)	10(10.0 %)	0.974#	0.325
Serum calcium (mmol/L)	2.39 ± 0.12	2.38 ± 0.10	0.318*	0.751
Inorganic phosphorus (mmol/L)	1.12 ± 0.13	1.11 ± 0.14	0.682*	0.496
E2 (pg/ml)	26.13 ± 16.78	29.11 ± 17.70	−1.025*	0.307
T (ng/ml)	2.84 (0.37, 4.48)	3.23(1.37, 4.16)	−0.659@	0.510
eGFR (ml/min)	76.50 ± 16.06	71.51 ± 15.76	1.899*	0.059
25OHD (ng/ml)	25.12 ± 9.80	25.50 ± 10.79	−0.191*	0.828
P1NP(ng/ml)	36.51 (31.78–41.64)	31.46 (28.51–34.57)	1.792†	0.075
β-CTx(ng/ml)	0.27 (0.23–0.31)	0.22(0.19–0.25)	2.138†	0.034
L1–4BMD (g/cm2)	1.18 ± 0.25	1.25 ± 0.28	−1.404*	0.162
LnBMD (g/cm2)	0.78 ± 0.13	0.81 ± 0.13	−1.473*	0.143
RnBMD (g/cm2)	0.78 ± 0.16	0.82 ± 0.13	−1.413*	0.160
LtBMD (g/cm2)	0.86 ± 0.15	0.92 ± 0.18	−2.026*	0.044
RtBMD (g/cm2)	0.87 ± 0.14	0.90 ± 0.14	−1.355*	0.177

Note: BMI: body mass index; Stage 3 CKD: stage 3 chronic kidney disease; CNS medication: Central nervous system medication; Fall history: Fall within 12 months before enrollment; Fracture history: Previous history of fragility fracture; E2: estradiol; T: testosterone; eGFR: estimated glomerular filtration rate; 25OHD: 25 hydroxyvitamin D; P1NP: Type I procollagen N-terminal peptide; β-CTx: Type I procollagen carboxy terminal peptide; L1–4 BMD: mean BMD of lumbar spine 1–4; LnBMD: left femoral neck bone mineral density; RnBMD: right femoral neck bone mineral density; LtBMD: left total hip bone density; RtBMD: right total hip bone density; *, a two-sample *t*-test was used for statistical comparison; #, Chi-square test was used for statistical comparison; @, Non-parametric tests were used for statistical comparison; †, For non-normally distributed data that become normally distributed after log transformation, the mean (95 % confidence interval) is used to describe the data. Two independent sample *t*-tests are used for comparing the means between two groups.

3.6. Accuracy of TUG in predicting new falls and related factor analysis

The ROC curve was plotted to demonstrate the predictive accuracy of TUG (Fig. 1). The cut-off point of TUG was >12.03 s in older adults who could take care of themselves, with a sensitivity of 78.0 %, a specificity of 51.5 %, and an AUC of 0.667 ($P < 0.001$, 95 % CI: 0.567–0.721).

TUG showed a strong negative correlation with gait speed, a strong positive correlation with FTSST ($r_s = 0.703$, $P < 0.001$), a moderate negative correlation with ADL ($r_s = -0.492$, $P < 0.001$), MoCA ($r_s = -0.538$, $P < 0.001$), and MEX-C ($r_s = -0.487$, $P < 0.001$), a weak

Table 3
Comparison of comprehensive geriatric assessment data between the elderly with new falls and those without falls.

Index	Fall group (n = 59)	Non-fall group (n = 100)	*t* , *χ2* , *z-value*	*P-value*
ADL (points)	100 (90, 100)	100 (100,100)	−2.739@	0.006
Frail (points)	1 (0,2)	0 (0,1)	−1.705@	0.088
MoCA (points)	24.0 ± 4.1	25.3 ± 3.3	−1.931*	0.056
SDS (points)	31.3 (28.8, 38.3)	30.0 (26.3, 37.5)	−0.831@	0.406
SAS (points)	30.0 (28.8, 35.0)	30.0 (26.3, 35.0)	−1.168@	0.243
FES-I (points)	36.3 ± 11.8	36.2 ± 12.5	0.034*	0.973
Hand grip strength (kg)	21.94 ± 5.79	24.37 ± 5.95	−2.521*	0.013
UGS(m/s)	0.76 ± 0.26	0.83 ± 0.21	−1.923*	0.056
TUG(sec)	16.46 (14.60–18.25)	13.08 (12.25–13.92)	3.203†	0.002
FTSST (*sec*)	16.55 ± 5.29	13.98 ± 4.79	3.134*	0.002
FTS [n(%)]	37(62.7 %)	44 (44.0 %)	4.938#	0.033

Note: ADL: Activity of Daily Living Scale (Barthel Index); Frail: The Frail Scale; MoCA: Montreal Cognitive Assessment; SDS: Zung's Self-rating Depression Scale; SAS: Zung's Self-Rating Anxiety Scale; FES—I: Falls Efficacy Scale International; UGS: usual gait speed; TUG: timed up and go test; FTSST: five times sit to stand test; FTS: full tandem stance; *, a two-sample t-test was used for statistical comparison; #, Chi-square test was used for statistical comparison; @, Non-parametric tests were used for statistical comparison; †, For non-normally distributed data that become normally distributed after log transformation, the mean (95 % confidence interval) is used to describe the data. Two independent sample t-tests are used for comparing the means between two groups.

positive correlation with FRAIL score (r_s = 0.368, $P < 0.001$), and a weak negative correlation with SOTcom (r_s = −0.227, P = 0.004), VIS (r_s = −0.230, P = 0.003), EPE-C (r_s = −0.364, $P < 0.001$), and DCL-C (r_s = −0.332, $P < 0.001$).

3.7. Accuracy of SOT in predicting new falls and related factor analysis

The cut-off point of SOTcom in predicting new falls was ≤52 points, with a sensitivity of 40.7 %, a specificity of 84.0 %, and an AUC of 0.606 (P = 0.028, 95 % CI: 0.525–0.682). The ROC curve of SOTcom is shown in Fig. 2.

SOTcom showed a strong positive correlation with VEST (r_s = 0.879, $P < 0.001$), a moderate positive correlation with VIS (r_s = 0.649, $P < 0.001$), a weak positive correlation with ADL (r_s = 0.283, $P < 0.001$), gait speed (r_s = 0.203, P = 0.010), PREF (r_s = 0.267, P = 0.001), EPE-C (r_s = 0.251, P = 0.002), DCL-C (r_s = 0.241, P = 0.003), and a weak negative correlation with FRAIL (r_s = −0.257, P = 0.001), TUG (r_s = −0.227, P = 0.004), FTSST (r_s = −0.339, $P < 0.001$), RT-C (r_s = −0.300, $P < 0.001$), Step Width (r_s = −0.255, P = 0.002), and End Sway (r_s = −0.246, P = 0.004).

4. Discussion

Through in-depth analysis of multiple risk factors of new falls in elderly self-care population, it was found that balance function is the key factor leading to falls, but balance function was also associated with other risk factors to varying degrees. Balance refers to the posture of the body and the ability to automatically adjust and maintain the posture when doing exercise or being subjected to external forces. It can be divided into static balance and dynamic balance (Winter et al., 1990). Balance is related to three major human activities: 1) maintaining a specific posture, such as sitting or standing. 2) Voluntary movement, such as movement between different postures. 3) Response to external disturbances, such as tripping, slipping, or pushing (Pollock et al., 2000).

In a survey of older adults in China (Wu et al., 2021), it was found that postural stability and overall balancing ability began to decline significantly at the age of 65 years, static and dynamic balancing ability began to decline significantly at the age of 70 years, and overall balance performance and specific task performance declined significantly after the age of 80 years. There were no significant differences between males and females, but individual differences gradually increased with age, and the coefficient of variation began to increase significantly at the age of about 75 years.

Table 4
Comparison of balance function and gait function between the elderly with new falls and those without falls.

Index	Fall group (n = 59)	Non-fall group (n = 100)	t/χ^2/z-value	P-value
SOM(points)	98.0 (96.0, 100.0)	99.0 (97.0,101.0)	−1.515@	0.130
VIS(points)	77.0 (60.0, 83.0)	74.5 (69.0, 85.0)	−1.240@	0.215
VEST(points)	54.0 (2.0, 67.0)	62.0 (40.0, 74.0)	−2.622@	0.009
PREF(points)	100.0 (94.0, 106.0)	96.0 (89.0, 101.0)	−2.166@	0.030
SOTcom (points)	66.0 (45.0, 76.0)	69.0(59.3, 77.8)	−2.201@	0.028
RT-F (sec)	0.99 (0.89–1.12)	0.98 (0.93– 1.04)	−0.522†	0.603
RT-B (sec)	0.77(0.68–0.87)	0.78(0.72– 0.84)	−0.618†	0.538
RT-R (sec)	0.95 ± 0.40	1.01 ± 0.31	−1.045*	0.298
RT-L (sec)	0.99 ± 0.32	1.01 ± 0.38	−0.330*	0.742
RT-C (sec)	0.92 (0.86–0.99)	0.94(0.89– 0.99)	−0.665†	0.507
MVL-F(deg/s)	2.57 ± 0.71	2.59 ± 0.91	−0.157*	0.876
MVL-B(deg/s)	2.03 ± 0.83	1.77 ± 0.68	1.965*	0.052
MVL-R(deg/s)	3.00 ± 0.82	3.03 ± 0.91	−0.186*	0.852
MVL-L(deg/s)	2.90 ± 1.09	3.18 ± 1.26	−1.336*	0.184
MVL-C(deg/s)	2.64 ± 0.60	2.64 ± 0.73	−0.060*	0.952
DCL-F(%)	75.00(67.00, 81.00)	75.00(68.00, 81.00)	−0.401@	0.688
DCL-B(%)	43.19 ± 23.61	46.87 ± 20.96	−0.975*	0.331
DCL-R(%)	63.55 ± 13.72	69.45 ± 8.66	−2.828*	0.006
DCL-L(%)	65.38 ± 15.58	71.49 ± 10.16	−2.565*	0.012
DCL-C(%)	63.45(60.21–66.98)	66.15(64.17–67.93)	−1.590†	0.116
EPE-F(%)	42.58 ± 10.68	46.33 ± 13.37	−1.748*	0.083
EPE-B(%)	36.02 ± 14.71	33.89 ± 12.86	0.911*	0.364
EPE-R(%)	55.66 ± 15.77	60.39 ± 15.45	−1.764*	0.080
EPE-L(%)	49.23 ± 15.44	57.83 ± 16.53	−3.096*	0.002
EPE-C(%)	45.96 ± 9.05	49.38 ± 11.48	−1.860*	0.065
MEX-F(%)	62.81 ± 16.63	64.85 ± 15.66	−0.739*	0.461
MEX-B(%)	47.81 ± 21.88	44.85 ± 17.42	0.845*	0.401
MEX-R(%)	70.77 ± 17.27	76.17 ± 15.38	−1.949*	0.053
MEX-L(%)	63.17 ± 17.13	71.60 ± 18.14	−2.756*	0.007
MEX-C(%)	61.26 ± 12.23	63.94 ± 13.45	−1.192*	0.235
Step Width (cm)	15.42(13.33–17.85)	14.50(13.42–15.75)	0.401†	0.689
Speed(cm/s)	16.33 ± 8.99	17.25 ± 7.77	−0.631*	0.529
EndSway (deg/s)	8.25(7.26–9.25)	7.57(6.88– 8.29)	1.128†	0.261

Note: SOM: Somatosensory; VIS: Vision; VEST: Vestibular; PREF: Visual Preference; SOTcom: Composite Equilibrium Score, the weighted average score of sensory integration test under six test conditions; RT: Reaction Time; MVL: Movement Velocity; DCL: Directional Control; EPE: Endpoint Excursion; MXE: Maximum Excursion. F: forward; B: backward; R: right; L: left; C: comprehensive; *, a two-sample t-test was used for statistical comparison; #, Chi-square test was used for statistical comparison; @, Non-parametric tests were used for statistical comparison; †, For non-normally distributed data that become normally distributed after log transformation, the mean (95 % confidence interval) is used to describe the data. Two independent sample t-tests are used for comparing the means between two groups.

We found that the incidence of new falls in our study population was 37.1 %, highlighting the need for intervention measures to prevent falls among older adults. Among the 108 fall events, 73.1 % (15.7 % + 45.4 % + 12.0 %) of all falls were caused by a decline in the dynamic balancing ability, emphasizing the importance of interventions aimed at

Table 5
Risk factors for new falls.

Factor	*B*	*S.E.*	*Wald*	*P*	*OR(95%CI)*
Fall history	2.591	0.532	23.754	0.000	13.344(4.707–37.830)
LtBMD	−4.382	1.675	6.675	0.010	0.013(0.000–0.352)
SOTcom	−0.035	0.016	5.168	0.023	0.965(0.936–0.995)
PREF	0.063	0.019	10.531	0.001	1.065(1.025–1.106)
DCL-L	−0.054	0.024	4.877	0.027	0.947(0.903–0.994)
EPE-L	−0.050	0.018	8.047	0.005	0.952(0.919–0.985)
Constant	4.798	2.729	3.091	0.079	121.271

Note: Fall history: fall within 12 months before enrollment; LtBMD: left total hip bone density; SOTcom: total score for sensory integration test; PREF: visual preference; DCL-L: left directional control; EPE-L: left endpoint excursion.

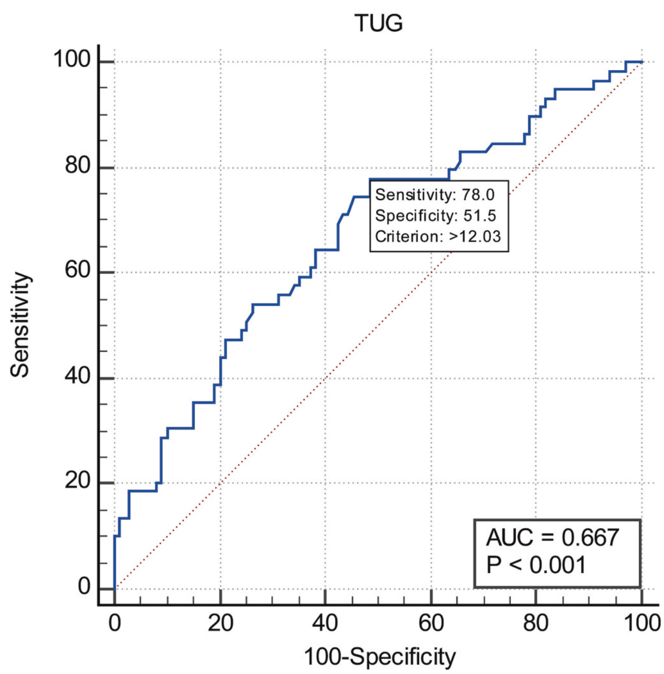

Fig. 1. ROC Curve of TUG in Predicting Falls.

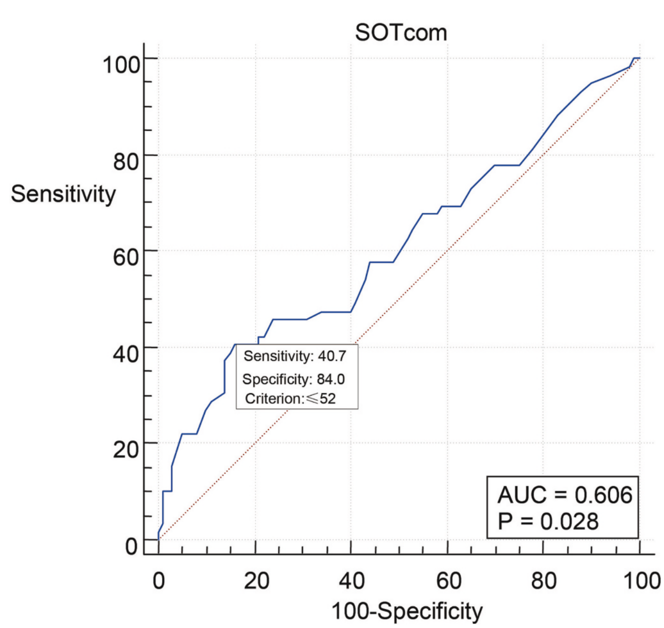

Fig. 2. ROC Curve of SOTcom in Predicting Falls.

improving this ability in this population as the most effective measure to prevent falls. We further found that 50.9 % of the falls resulted in injuries, of which a fifth were fractures, emphasizing the severity of falls and their impact on the health and quality of life of older adults. In sum, the results of this study highlight the urgent need for effective strategies to prevent falls among older adults, particularly those that address the decline of the dynamic balancing ability to move, change position, or respond to external disturbances.

According to the analysis of internal risk factors, there were no significant differences in frailty, anxiety, depression, cognition, fear of falling, postural hypotension, major chronic diseases, or medication factors between the new fall group and the non-fall group. Estrogen, androgen and vitamin D are all involved in bone and muscle metabolism, which are related to osteoporosis and sarcopenia. In this study, there were no statistically significant differences in P1NP(reflecting osteoblast activity), testosterone and 25OHD (reflecting vitamin D level) between the two groups. However, in the new fall group, age, previous fall history and β-CTx (which reflects osteoclast activity) were higher, which suggested that bone resorption was more clear in people who fell. While BMI, ADL score, hip BMD, hand grip strength, and FTS completion rate were lower, and FTSST and TUG time were longer ($P < 0.01$, $P < 0.05$), and the gait speed showed a slower trend ($P = 0.056$). In older adults who were able to live independently, in addition to age and previous fall history, muscle strength, muscle function, hip bone mineral density (BMD), and dynamic and static balancing ability were worse in the new fall group. As the organs responsible for maintaining balance, muscles and bones are regulated by various hormones and factors, and they develop and decrease synchronously, with simultaneous physical-mechanical sensing effects. Muscle loss is a risk factor for falls in community-dwelling older adults (Zhang et al., 2019), as well as a risk factor for osteoporosis. Patients with osteoporosis usually have muscle weakness, decreased gait speed, and postural balance disorders, making them more prone to falls and fractures (Hsu et al., 2014; Zhou et al., 2018).

The maintenance of balance is a complex process involving multiple systems. The information is transmitted to the central nervous system through the eyes, vestibular organs, and proprioceptors located in joints and muscles. After the information is selected and reorganized by the central nervous system, it is then transmitted to the motor system to regulate the center of gravity and support points of the body through muscle and bone movement so as to maintain body balance (Day et al., 2002). In this study, the scores of SOTcom and VEST were decreased, the control of right and left directions was weakened, and the left end point deviation and maximum deviation were decreased in the new-fall group ($P < 0.01, P < 0.05$). These results suggest that the balance sensory input function, especially the vestibular sense, and the postural control ability of the left and right directions were significantly decreased in those with new falls.

Vestibular dysfunction is an important contributor to imbalance and falls among older adults in the United States (Agrawal et al., 2009; Beylergil et al., 2019). The vestibular system maintains postural stability through vestibulo-ocular reflexes (VORs), vestibulo-spinal responses (VSRs), and vestibulo-autonomic responses (VARs). Vestibular dysfunction in older adults is considered to be a progressive, bilateral, and partial loss of vestibular function because the exposures associated with aging (e.g., cumulative toxicity, metabolism, ischemia, infection) are usually systemic (Agrawal et al., 2020). Vestibular dysfunction usually results in dizziness due to blurred or swaying vision, as the eyes are unable to compensate for head movements quickly enough (Minor, 1998), and the lack of postural stability during changes in head position and orientation or the lack of intracranial perfusion during changes in position can lead to dizziness, imbalance, or even falls (Murray et al., 2018; Jian et al., 1999).

Vestibular dysfunction also includes vestibular compensatory capacity, which is the process by which the system can compensate for the loss of vestibular inputs. Neurons receiving vestibular input may upregulate sensitivity to diminished vestibular input and/or increase signals from other more reliable sensory systems (e.g., the visual system) (Lacour et al., 2016; Peterka et al., 2011). In this study, the increase in PREF in the new fall group suggested that this group increasingly relied on visual signals during vestibular compensation. However, the impaired visual function reduced the ability to transmit correct visual signals, further increasing the risk of falls. Therefore, the testing and treatment of visual acuity and visual function in this population is also an important means to prevent falls.

Binary logistic regression analysis was conducted with newly occurring falls as the dependent variable and related factors with statistically significant differences as the independent variables. The result suggested that the risk factors for new falls included previous falls, decreased SOTcom, increased PREF, decreased left total hip BMD, direction control, and end point deviation ($P < 0.05$). Thus, although there are multiple internal risk factors for falls, the decline of balance sensory input function (mainly vestibular sense and visual sense), skeletal muscle motor function, and related postural control ability constitute the more prominent influencing factors in older adults who can take care of themselves.

Early screening and identification are the basis of effective intervention. TUG, a commonly used tool in screening for risk factors for falls, is a convenient method to test dynamic balance and gait and is suitable for large-scale rapid screening (Panel on Prevention of Falls in Older Persons, American Geriatrics Society and British Geriatrics Society, 2011; Algorithm for Fall Risk Screening, Assessment, and Intervention [webpage on the Internet], 2023). According to a meta-analysis conducted by Schoene et al., TUG showed a poor risk identification effect in healthy and functional people but a higher value in older adults with poor health and hypofunction (Schoene et al., 2013). Regarding the cut-off point for TUG in predicting falls, literature reports a broad range between 10 and 33 s (Barry et al., 2014). The significant discrepancies in cut-off points may be attributed to factors such as the geographical region, ethnicity, age, gender, health status of the study population, and research design. The Centers for Disease Control and Prevention (CDC) in the United States recommend a cut-off point of 12 s but do not specify the target population (Centers for Disease Control and Prevention, 2023). After following up with 300 self-managing elderly people aged $\geq$80 years for 12 months, our team found that the risk of new falls increased by 98 % in those with TUG time longer than 12 s (Zhou et al., 2021). In the current study, the cut-off point of TUG in predicting new falls was >12.03 s, with a sensitivity of 78.0 %, a specificity of 51.5 %, and an AUC of 0.667. TUG showed a strong negative correlation with gait speed, a strong positive correlation with FTSST, and a moderate negative correlation with ADL, MoCA, and MEX-C, indicating that TUG mainly reflected muscle function and lower limb muscle strength, and it was also associated with cognitive ability and partial postural control ability.

CDP has increasingly been used in assessing fall risk in older adults as an objective, quantitative, and accurate method for assessing balance function. However, there are no guidelines available for the population aged 80 and over. A small sample survey suggested that the SOTcom score was 69.9 $\pm$ 8.4 for subjects aged 80–84 years and 60.7 $\pm$ 10.3 for those aged 85–89 years (Perucca et al., 2021). However, the cut-off point of SOTcom for predicting fall risk in the population aged 80 and over who are able to live independently has not been reported yet.

In this study, the cut-off point of SOTcom in predicting new falls was $\leq$52 points, with a sensitivity of 40.7 % and a specificity of 84.0 %. SOTcom showed a strong positive correlation with vestibular sense and a moderate positive correlation with visual sense, suggesting that SOTcom mainly reflected vestibular and visual functions. SOTcom showed a weak negative correlation with TUG, and the accuracy of the two assessment methods in predicting new falls was moderately low when used separately. However, TUG (higher accuracy) and SOTcom (higher specificity) could reflect different aspects of the participants' balancing ability, and the combined application could be used to evaluate the participants' sensory input, motor output, and cognitive ability more comprehensively, thus further improving the prediction accuracy.

This study still has some limitations. During the recruitment process, we found that men were more willing to participate in the evaluations and follow-ups than women, with men accounting for 65 % of the sample. As a result, the representativeness of the data may be affected to some extent. The evaluation tools we used included a combination of a simple and quick screening tool and the CDP. The CDP requires specialized equipment, a long evaluation time, and high costs. It is mostly available in large hospitals and research institutions, which limits its wider usage. Moreover, it may be difficult to carry out large-scale screening and follow-up in hospitals. Therefore, it is necessary to establish a collaborative system between hospitals, communities, and primary medical institutions to jointly carry out scientific research and practice on fall prevention and control in the elderly population.

5. Conclusion

A fall is an unpredictable factor in the process of healthy aging, but it is preventable and controllable. As we found in this study, the decline in balancing ability is the key risk factor for new falls in older adults who can take care of themselves. The sequential use of comprehensive geriatric assessment and computerized dynamic posturography can aid in the early detection and refinement of fall risk, providing direction for targeted examination and intervention, such as individualized muscle strength training, vestibular rehabilitation, treatment of visual impairment, cognitive rehabilitation, and anti-osteoporosis treatment. This necessitates close multidisciplinary collaboration among teams comprising geriatrics, otolaryngology, ophthalmology, neurology, rehabilitation medicine, psychology, and nutrition.

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki(as was revised in 2013). The study was approved by Ethics Committee of the Beijing Tongren Hospital, China Capital Medical University. The written, informed consent was obtained from the participant for participating in this study.

Consent to publish

Not applicable.

CRediT authorship contribution statement

Jian Zhou, Bo Liu conceived the idea. Jian Zhou, Hui Ye, Jin-Ping Duan conceptualised the study. Jian Zhou, Bo Liu, Hui Ye, Jin-Ping Duan collected the data. Jian Zhou analyzed the data.Jian Zhou, Bo Liu drafted and reviewed the manuscript. All authors read and approved the final draft.

Funding

This study was funded by the Central Health Care Research Project (2020YB48).

Declaration of competing interest

The authors declare that they have no competing interests.

Data availability

All data generated or analyzed during this study are included in this article. Further enquiries can be directed to the corresponding author.

Acknowledgements

We are particularly grateful to all the people who have given us help on our article.

References

Agrawal, Y., Carey, J.P., Della Santina, C.C., Schubert, M.C., Minor, L.B., 2009. Disorders of balance and vestibular function in US adults: data from the National Health and Nutrition Examination Survey, 2001-2004 [published correction appears in Arch Intern Med. 2009 Aug 10;169(15):1419]. Arch. Intern. Med. 169 (10), 938–944. https://doi.org/10.1001/archinternmed.2009.66.

Agrawal, Y., Merfeld, D.M., Horak, F.B., et al., 2020. Aging, vestibular function, and balance: proceedings of a National Institute on Aging/National Institute on Deafness and Other Communication Disorders Workshop. J. Gerontol. A Biol. Sci. Med. Sci. 75 (12), 2471–2480. https://doi.org/10.1093/gerona/glaa097.

Algorithm for Fall Risk Screening, Assessment & Intervention [webpage on the Internet], 2023. Centers for Disease Control and Prevention [cited 2021 Sep 17]. Available from: https://www.cdc.gov/steadi/pdf/STEADI-Algorithm-508.pdf.

Alley, D.E., Shardell, M.D., Peters, K.W., et al., 2014. Grip strength cutpoints for the identification of clinically relevant weakness. J. Gerontol. A Biol. 69 (5), 559–566. https://doi.org/10.1093/gerona/glu011.

Arli, S., Yildiz, M., Bakan, A., 2020. Relationship between fall risks and activities of daily living in older individuals. Front. Nurs. 7 (3), 249–256. https://doi.org/10.2478/fon-2020-0022.

Barry, E., Galvin, R., Keogh, C., Horgan, F., Fahey, T., 2014. Is the Timed Up and Go test a useful predictor of risk of falls in community dwelling older adults: a systematic review and meta-analysis. BMC Geriatr. 14 (1), 14. https://doi.org/10.1186/1471-2318-14-14.

Beylergil, S.B., Karmali, F., Wang, W., Bermúdez Rey, M.C., Merfeld, D.M., 2019. Vestibular roll tilt thresholds partially mediate age-related effects on balance. Prog. Brain Res. 248, 249–267. https://doi.org/10.1016/bs.pbr.2019.04.019.

Centers for Disease Control and Prevention, 2023. National Center for Injury Prevention and Control, Division of Unintentional Injury Prevention. Available from. http://www.cdc.gov/homeandrecreationalsafety/Falls/steadi/index.html.

China Medical Association of Osteoporosis and Bone Mineral Research, 2017. Guidelines for diagnosis and treatment of primary osteoporosis (2017). Chin. J. Osteoporosis Bone Mineral Res. 10 (5), 413–444. Chinese. https://doi.org/10.3969/j.issn.1674-2591.2017.05.002.

Chow, R.B., Lee, A., Kane, B.G., Jacoby, J.L., Barraco, R.D., Dusza, S.W., Meyers, M.C., Greenberg, M.R., 2019. Effectiveness of the "Timed Up and Go" (TUG) and the chair test as screening tools for geriatric fall risk assessment in the ED. Am. J. Emerg. Med. 37 (3), 457–460. https://doi.org/10.1016/j.ajem.2018.06.015.

Day, B.L., Guerraz, M., Cole, J., 2002. Sensory interactions for human balance control revealed by galvanic vestibular stimulation. Adv. Exp. Med. Biol. 508, 129–137. https://doi.org/10.1007/978-1-4615-0713-0_16.

Dong, L., Qiao, X., Tian, X., et al., 2017. Cross-cultural adaptation and validation of the FRAIL scale in Chinese community-dwelling older adults. J. Am. Med. Dir. Assoc. 19 (1), 12–17. https://doi.org/10.1016/j.jamda.2017.06.011.

Dunstan, D.A., Scott, N., Todd, A.K., 2017. Screening for anxiety and depression: reassessing the utility of the Zung scales. BMC Psychiatry 17 (1), 329. https://doi.org/10.1186/s12888-017-1489-6.

GBD 2017 Risk Factor Collaborators, 2018. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet 392 (10159), 1923–1994. https://doi.org/10.1016/S0140-6736(18)32225-6.

Gillespie, L.D., Robertson, M.C., Gillespie, W.J., et al., 2012. Interventions for preventing falls in older people living in the community. Cochrane Database Syst. Rev. 9, CD007146 https://doi.org/10.1002/14651858.CD007146.pub3.

Harro, C.C., Garascia, C., 2019. Reliability and validity of computerized force platform measures of balance function in healthy older adults. J. Geriatr. Phys. Ther. 42 (3), E57–E66. https://doi.org/10.1519/JPT.0000000000000175.

Hsu, W.L., Chen, C.Y., Tsauo, J.Y., et al., 2014. Balance control in elderly people with osteoporosis. J. Formos. Med. Assoc. 113 (6), 334–339. https://doi.org/10.1016/j.jfma.2014.02.006.

Jian, B.J., Cotter, L.A., Emanuel, B.A., Cass, S.P., Yates, B.J., 1999. Effects of bilateral vestibular lesions on orthostatic tolerance in awake cats. J. Appl. Physiol. 86, 1552–1560. https://doi.org/10.1152/jappl.1999.86.5.1552.

Jones, M., Paulson, S., Gills, J., et al., 2021. The effects of mild cognitive impairment on fall severity in older adults. Innov. Aging 5 (Supple1), 698. https://doi.org/10.1093/geroni/igab046.2617.

Kwan, M.M., Close, J.C., Wong, A.K., Lord, S.R., 2011. Falls incidence, risk factors, and consequences in Chinese older people: a systematic review. J. Am. Geriatr. Soc. 59 (3), 536–543. https://doi.org/10.1111/j.1532-5415.2010.03286.x.

Lacour, M., Helmchen, C., Vidal, P.P., 2016. Vestibular compensation: the neuro-otologist's best friend. J. Neurol. 263 (Suppl. 1), S54–S64. https://doi.org/10.1007/s00415-015-7903-4.

Mekkodathil, A., El-Menyar, A., Kanbar, A., et al., 2020. Epidemiological and clinical characteristics of fall-related injuries: a retrospective study. BMC Public Health 20 (1), 1186. https://doi.org/10.1186/s12889-020-09268-2.

Minor, L.B., 1998. Gentamicin-induced bilateral vestibular hypofunction. JAMA. 279 (7), 541–544. https://doi.org/10.1001/jama.279.7.541.

Morgan, M.T., Friscia, L.A., Whitney, S.L., et al., 2013. Reliability and validity of the Falls Efficacy Scale-International (FES-I) in individuals with dizziness and imbalance. Otol. Neurotol. 34 (6), 1104–1108. https://doi.org/10.1097/MAO.0b013e318281df5d.

Muñoz-Bermejo, L., Adsuar, J.C., Mendoza-Muñoz, M., et al., 2021. Test-retest reliability of Five Times Sit to Stand Test (FTSST) in adults: a systematic review and meta-analysis. Biology (Basel) 10 (6), 510. https://doi.org/10.3390/biology10060510.

Murray, A.J., Croce, K., Belton, T., Akay, T., Jessell, T.M., 2018. Balance control mediated by vestibular circuits directing limb extension or antagonist muscle co-activation. Cell Rep. 22 (5), 1325–1338. https://doi.org/10.1016/j.celrep.2018.01.009.

National Institute for Health and Care Excellence, 2013. Falls: assessment and prevention off alls in older persons. In: NICE Clinical Guideline 161 [R]. Available at. http://www.nice.org.uk/CG161 (Accessed May 9, 2022).

Panel on Prevention of Falls in Older Persons, American Geriatrics Society and British Geriatrics Society, 2011. Summary of the updated American Geriatrics Society/British Geriatrics Society clinical practice guideline for prevention of falls in older persons. J. Am. Geriatr. Soc. 59 (1), 148–157. https://doi.org/10.1111/j.1532-5415.2010.03234.x.

Peel, N.M., Kuys, S.S., Klein, K., 2013. Gait speed as a measure in geriatric assessment in clinical settings: a systematic review. J. Gerontol. A Biol. Sci. Med. Sci. 68 (1), 39–46. https://doi.org/10.1093/gerona/gls174.

Perucca, L., Robecchi Majnardi, A., Frau, S., et al., 2021. Normative data for the NeuroCom® sensory organization test in subjects aged 80-89 years. Front. Hum. Neurosci. 15, 761262. https://doi.org/10.3389/fnhum.2021.761262.

Peterka, R.J., Statler, K.D., Wrisley, D.M., Horak, F.B., 2011. Postural compensation for unilateral vestibular loss. Front. Neurol. 2, 57. Published 2011 Sep 6. https://doi.org/10.3389/fneur.2011.00057. Published 2011 Sep 6.

Pollock, A.S., Durward, B.R., Rowe, P.J., Paul, J.P., 2000. What is balance? Clin. Rehabil. 14 (4), 402–406. https://doi.org/10.1191/0269215500cr342oa.

Schoene, D., Wu, S.M., Mikolaizak, A.S., et al., 2013. 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. 61 (2), 202–208. https://doi.org/10.1111/jgs.12106.

WHO, 2021. Step Safely: Strategies for Preventing and Managing Falls across the Life-course. World Health Organization, Geneva (Licence: CC BY-NC-SA 3.0 IGO).

Winter, D.A., Patla, A.E., Frank, J.S., 1990. Assessment of balance control in humans. Med. Prog. Technol. 16 (1–2), 31–51 (PMID: 2138696).

Wu, H., Wei, Y., Miao, X., et al., 2021. Characteristics of balance performance in the Chinese elderly by age and gender. BMC Geriatr. 21 (1), 596. https://doi.org/10.1186/s12877-021-02560-9.

Ye, P., Er, Y., Wang, H., et al., 2021. Burden of falls among people aged 60 years and older in mainland China, 1990-2019: findings from the Global Burden of Disease Study 2019. Lancet Public Health 6 (12), e907–e918. https://doi.org/10.1016/S2468-2667(21)00231-0.

Zhang, X., Huang, P., Dou, Q., et al., 2019. Falls among older adults with sarcopenia dwelling in nursing home or community: a meta-analysis. Clin. Nutr. 39 (1), 33–39. https://doi.org/10.1016/j.clnu.2019.01.002.

Zhou, X., Deng, H., Shen, X., et al., 2018. Effect of balance training on falls in patients with osteoporosis: a systematic review and meta-analysis[J]. J. Rehabil. Med. 50 (7), 577–581. https://doi.org/10.2340/16501977-2334.

Zhou, J., Liu, B., Qin, M.Z., Liu, J.P., 2021. A prospective cohort study of the risk factors for new falls and fragility fractures in self-caring elderly patients aged 80 years and over. BMC Geriatr. 21 (1), 116. Published 2021 Feb 10. https://doi.org/10.1186/s12877-021-02043-x. Published 2021 Feb 10.