International Journal of Gerontology 15 (2021) 301–308
https://doi.org/10.6890/IJGE.202110_15(4).0002

International Journal of Gerontology

journal homepage: http://www.sgecm.org.tw/ijge/

Review Article

Equipment-Free Fall-Risk Assessments for the Functionally Independent Elderly: A Systematic Review and Meta-Analysis

Chen-Ju Fu [a], Wen-Chien Chen [b], Meng-Ling Lu [c], Chi-Chien Niu [b], Yi-Hsuan Lee [d], Chih-Hsiu Cheng [d] *

[a] *Division of Emergency and Critical Care Radiology, Chang Gung Memorial Hospital Linkou Main Branch, Taoyuan, Taiwan,* [b] *Department of Orthopedic Surgery, Chang Gung Memorial Hospital, Taoyuan, Taiwan,* [c] *Department of Orthopedic Surgery, Chang Gung Memorial Hospital Kaohsiung Branch, Kaohsiung, Taiwan,* [d] *School of Physical Therapy and Graduate Institute of Rehabilitation Science, Chang Gung University, Taoyuan, Taiwan*

ARTICLE INFO

Accepted 19 April 2021

Keywords:
accidental falls,
aged,
task performance and analysis,
geriatric assessment

SUMMARY

Falls are the leading causes of unintentional fatal injury occurring in the elderly worldwide. Various functional variables of instrumental tests have been used to evaluate the risks of falls. However, such tests are usually difficult to perform in the elderly and limited to environmental conditions. This study was to review whether the simple and equipment-free assessments could efficiently identify the functionally independent elderly to be fallers or non-fallers. PubMed and Scopus electronic databases systematically searched before March 2020 were included in this review. Studies were selected if they focused on the elderly aged over 65 years who can walk without assistance, adopted assessments without the need for equipment, and reported quantified assessment variables. The significance testing, sensitivity, specificity, receiver operating characteristics were evaluated. The quantitative data possible for meta-analyses were pooled to calculate the 95% confidence interval and heterogeneity among studies. Fifteen studies were selected for systematic review, of which nine were for meta-analysis. Ten assessment tests were identified. Seven of them revealed a significant difference (generally $p < 0.05$) between the fallers and non-fallers but did not come with high sensitivity or specificity. Three conclusive assessment tests to identify the fall risks through the meta-analysis were the alternate step, functional reach, and tandem stance tests. In conclusion, although most assessment tests demonstrated a significant difference between the fallers and non-fallers, the performance of tests for predicting fallers was less promising. The alternate step, functional reach, and tandem stance tests could be evidenced as reliably tests used in clinics or communities.

Copyright © 2021, Taiwan Society of Geriatric Emergency & Critical Care Medicine.

1. Introduction

Fall is one of the top leading causes of unintentional fatal injury occurring in the elderly persons worldwide.[1] The falls in the elderly usually attribute to the age-related decrease of control of postural stability and link to the deteriorated muscle strength or neuromuscular efficiency.[2] The guideline of full prevention from the orthopaedic surgeons panel suggested that not only intrinsic (subject-related) but also extrinsic (environment-related) and behavioral (activity-related) factors should be taken into consideration when identifying the risks of falls.[3] Nevertheless, there is still a lack of consensus to date regarding the choice of a convenient and inclusive evaluation tool to early detect the potential faller.

Functional variables from various instrumental tests have been used to evaluate the risks of falls in elderly, such as the posturographic performance during static/dynamic balance tests,[4] spatiotemporal and kinematic parameters during the gait evaluation,[5] and ground reaction force during the sit-to-stand tests.[6] However, performing instrumental tests requires dedicated equipment and limited to laboratory environment conditions that could expel possible applications in daily life. The laboratory equipments facilitate high-standard accurate measurements at the cost of poor accessibility and efficiency. On the contrary, various fall risk assessment batteries are easy to use in clinics or community, and are of great value as regular assessment tools to promote early intervention. Up to date, there is no thorough meta-analysis on the screening of fall risks in elderly based on the simple fall assessment batteries. The objective of this study was to conduct a systematic review and meta-analysis to assess the performance of equipment-free assessment tests to identify the elderly with fall risks, while taking the effect of clinical and environmental conditions into considerations.

* Corresponding author. School of Physical Therapy and Graduate Institute of Rehabilitation Science, College of Medicine, Chang Gung University, No. 259, Wen-Hwa 1st Rd., Kweishan, Taoyuan, Taiwan, R.O.C.
E-mail address: chcheng@mail.cgu.edu.tw (C.-H. Cheng)

2. Method

2.1. Search strategy and study selection

This study followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). Two electronic databases were systematically searched (i.e. PubMed and Scopus) and the relevant published papers before March 2020 were included in this review. The search terms were identified during primary independent literature review, including: FALL RISKS, FALLER, ASSESSMENT TOOLS, ELDERLY and AGE OVER 65. These terms were applied individually and then combined together with "and" and "or" Boolean operators.

Two independent reviewer (M.L.L. and C.C.N.) selected and assessed the studies for methodological validity and risk of bias prior to including in this systematic review. A consensus meeting was held to resolve any discrepancies on applicability and quality between the reviewers, and a third independent reviewer (W.C.C.) was consulted when the two reviewers could not reach agreement. The inclusion criteria were as follows,

(1) The subjects were the elderly over 65 years old and able to walk independently without assistance;
(2) The assessment is designed as a simple clinical screening tool with a minimum of training and not time consuming (generally less than 5 minutes).[7]
(3) The assessment is not performed with dedicated instruments;
(4) The assessment variables of fall risks can be quantified;

The exclusion criteria were as follows,

(1) Studies were not related to human subject or unavailable in English;
(2) The subjects had concomitant neurological diseases (e.g., dementia, Parkinson, cerebellar diseases, myelopathy, and peripheral neuropathy or impaired cognition);
(3) The age of subjects was not revealed.

Forward and backward citation searches were conducted to ensure if all the relevant studies were located. For the meta-analysis, the articles were selected if the same assessment test was included and the quantitative data can be pooled for further calculation.

2.2. Data extraction and methodological quality assessment

The following items were recorded from the selected papers: authors, year of publication, study design, subject selection criteria, age and gender distribution of subjects, follow-up duration, assessment tools, assessment protocols, environment conditions, and definition of fall risks. Achieved results including the significance testing, the cut-off point, sensitivity, specificity, like-hood ratio (LR), and inter/intra-rater reliability were obtained to identify the differences of the fallers and non-fallers and to evaluate the performance of screening for predicting fallers. The level of evidence based on the guidelines of the Oxford Centre for evidence-based medicine was also assessed.

2.3. Statistical analysis

Quantitative data were pooled for statistical meta-analysis using Review Manager (RevMan) version 5.3. An I^2 index was used to assess the heterogeneity among the reviewed studies, and I^2 values above 75% were considered as high heterogeneity. The pooled data were calculated and presented with 95% confidence intervals (CIs). The meta-analysis was carried out using either a fixed-effect model if no significant heterogeneity was observed ($p > 0.05$ and $I^2 < 50\%$), or a random-effect model if heterogeneity was detected ($p < 0.05$ and $I^2 \geq 50\%$).

3. Results

3.1. Selection and description of studies

An initial literature search resulted in a total of 4,144 studies. Three hundred and nine duplicate studies were removed. One thousand and thirty-seven studies were excluded because the subjects in those studies focused on the elderly with different diseases. Sixty-three studies were discarded because laboratory-based equipments were required. Furthermore, 2,661 studies were excluded as they investigated unrelated issues. Fifty-nine studies were still removed after thorough discussion to reach a consensus by all the reviewers. Finally, 15 studies were selected for the systematic review, and the data from 9 studies[8–16] showing one of the assessment tests was applied in more than two studies were pooled for the meta-analysis (Figure 1).

Table 1 summarized the characteristics of the study design of the 15 studies. One study combined the prospective and retrospective design.[11] Six were prospective studies,[7,8,16–19] and the other eight were cross-sectional studies.[9,10,12–15,20,21] The average age of the subjects in these selected studies was 65.7 to 80.6 years old. The percentage of the female subjects was generally higher than that of male ones, while three[12,13,20] out of the fifteen studies did not provide the gender distribution of the subjects or only recruited male or female subjects. Most subjects were from the local communities. The follow-up time ranged from 3 to 36 months. The fall was mainly defined as "unintentionally on the ground or lower surface, not as a major intrinsic event or an 21 overwhelming hazard". Some investigators simply asked the subjects whether they had ever slipped, stumbled or fallen in the recent years. The level of evidence of all 15 studies were 3B (Table 2).

3.2. Assessment of fall risk

Ten equipment-free assessment tests of fall risks were identified as follows: 5-time sit-to-stand test, alternate step test, one leg stance test, functional reach test, tandem stance test, stair ascent and stair descent test, ten-step test, minimal chair height standing test, half-turn test, and maximum step length test. The 5-time sit-to-stand test[22] is to measure the time taken to stand from a sitting position five times without using arms. The alternate step test[23] requires the subject to step alternately eight times with each leg on to

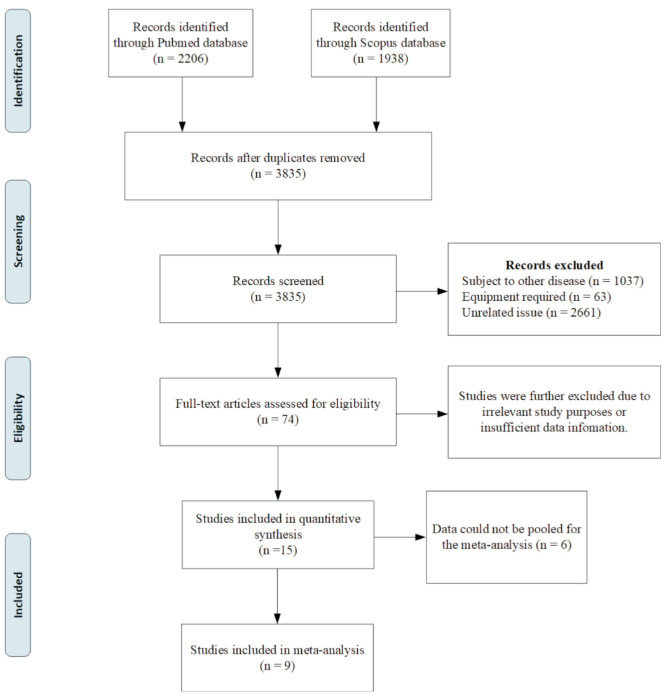

Figure 1. PRISMA flow diagram of study selection.

Table 1
Characteristics of the subjects and study design in the included studies.

Author/years	Design	Subject age (years old)	Gender distribution (% of female case)	Subject resource/ country	Follow-up duration	Definition of fall
Buatois 2008[17]	Prospective	70 ± 4	49.9%	Centre de Médecine Préventive/France	18-36 m	Self-questionnaire without details
Bongue 2011[7]	Prospective	F: 71.2 ± 5.0 Non-F: 70.5 ± 4.4	F: 66.4% Non-F: 43.7%	Health examination centers/France	12m	Unintentionally coming to rest on the ground, floor, or other lower level
Chang 2013[8]	Prospective	F: 72.5 ± 4.7 Non-F: 70.9 ± 4.9	F: 66.7% Non-F: 56.3%	No details/Taiwan	12m	No details
Cheng 2014[9]	Cross sectional	F: 77.5 ± 7.8 Non-F: 75.2 ± 6.4	F: 37% Non-F: 33%	No details	None	Unintentional coming to a lower level not caused by any external force or influence
Coqueiro 2014[20]	Cross sectional	73.4 ± 9.4	Male only	Local communities/ Brazil	None	Have you had any fall in the last 12 minths?
Ejupi 2015[10]	Cross sectional	79.7 ± 6.4	70%	Retirement village/ Austria	None	An unexpected event in which the person comes to rest on the ground, floor, or other lower level
Hirase 2014[11]	Prospective/ retrospective	77.2 ± 6.9	69.7%	Local communities/ Japan	3 m	Unintentionally coming to rest on the ground, floor, or other lower level in a manner that did not result from a major intrinsic event or an overwhelming hazard
Kim 2009[12]	Cross sectional	F: 75.8 ± 5.6 Non-F: 71.4 ± 5.0	Not available	Local communities/ Japan	None	In the past year, have you slipped or stumbled and then fallen down?
Kim 2017[13]	Cross sectional	F: 72.5 ± 5.9 Non-F: 72.8 ± 4.3	Female only	Social welfare centers/South Korea	None	An unexpected loss of balance resulting in coming to rest on the floor, the ground, or an object below the knee level
Kwan 2011[14]	Cross sectional	74.9 ± 6.4	42.9%	Villages/Taiwan	None	Inadvertently coming to rest on the ground or other lower level with or without loss of consciousness, and other than as a consequence of sudden onset of paralysis, epileptic seizure, excess alcohol intake, or overwhelming external force
Lindemann 2008[18]	Prospective	F: 68.8 ± 6.0 Non-F: 66.5 ± 5.8	F: 60% Non-F: 54%	Seniors meeting club/Germany	12 m	Any fall they had experienced in the past year
Makizako 2014[15]	Cross sectional	F: 73.2 ± 6.1 Non-F: 71.8 ± 5.4	F: 61.1% Non-F: 50.2%	No details/Japan	None	An unexpected event in which the person comes to rest on the ground, floor, or other lower level
Singh 2015[21]	Cross sectional	F: 68.3 ± 4.4 Non-F: 65.7 ± 4.5	F: 55.6% Non-F: 68.9%	Senior citizens club/ Malaysia	None	High and low risk of falls were defined as older adults who scored above and below the Physiological profile assessment score of 2
Tiedemann 2008[16]	Prospective	80.4 ± 4.5	65.8%	Database of a Health insurance company/ Australia	12 m	Events that resulted in a person coming to rest unintentionally on the ground or other lower level, not as the result of a major intrinsic event or an overwhelming hazard
Tiedemann 2010[19]	Prospective	75.3 ± 5.8	79%	Local communities/ Australia	12 m	Same as above

F: faller; Non-F: non-faller.

Table 2
Oxford Centre for evidence-based medicine levels of evidence of the included studies.

	Oxford Centre for evidence-based medicine									Level of evidence
	1.	2.	3.	4.	5.	6.	7.	8.	Total score	
Buatois 2008[17]	Yes	No	No	No	Yes	Yes	Yes	Yes	5/8	3B
Bongue 2011[7]	Yes	No	Yes	No	Yes	Yes	Yes	Yes	6/8	3B
Chang 2013[8]	Yes	No	Yes	No	Yes	Yes	Yes	Yes	6/8	3B
Cheng 2014[9]	Yes	No	Yes	No	Yes	Yes	Yes	Yes	6/8	3B
Coqueiro 2014[20]	Yes	No	No	No	Yes	Yes	Yes	Yes	5/8	3B
Ejupi 2015[10]	Yes	No	No	No	Yes	Yes	Yes	Yes	5/8	3B
Hirase 2014[11]	No	No	Yes	No	Yes	Yes	Yes	Yes	5/8	3B
Kim 2009[12]	Yes	No	No	No	Yes	Yes	Yes	Yes	5/8	3B
Kim 2017[13]	Yes	No	No	No	Yes	Yes	Yes	Yes	5/8	3B
Kwan 2011[14]	Yes	No	No	No	Yes	Yes	Yes	Yes	5/8	3B
Lindemann 2008[18]	Yes	No	No	No	Yes	Yes	Yes	Yes	5/8	3B
Makizako 2014[15]	Yes	No	No	No	Yes	Yes	Yes	Yes	5/8	3B
Singh 2015[21]	Yes	No	Yes	No	Yes	Yes	Yes	Yes	6/8	3B
Tiedemann 2008[16]	Yes	No	No	No	Yes	Yes	Yes	Yes	5/8	3B
Tiedemann 2010[19]	Yes	No	Yes	No	Yes	Yes	Yes	Yes	6/8	3B

the first step of stair and counts the number of steps. The one leg stance test[24] measures the time to stand on the preferred leg with eyes open for a maximum of 60 s. The functional reach test[25] requires the subject to stand firmly and flex the trunk forward to reach for the maximal distance beyond arm's length. The tandem stance test[26] requires the subject to stand with the heel of one foot directly in front of the toes of the other foot for a maximum of 30 s. The stair ascent and stair descent test[16] is to measure the time to climb eight steps of stairs, and then to descend the stairs and stop when completing the last step. The ten-step test[27] is to record the time to step up and down the first step of stair using alternate feet for ten repetitions. The minimal chair height standing test[28] is to determine the lowest height from which the subject could stand without arm support by lowing the seat until the subject could not stand from the seated position. The half-turn test[29] counts the number of steps taken to complete a 180° turn to face the opposite direction. The maximum step length test[30] requires the subject to step out maximally with the preferred leg and maintain the stance leg in the initial position, and the maximum valid step length between the toes of the stance leg and the toes of the stepping leg is measured while adjusted to the body height for inter-individual comparisons.

Table 3 summarized the studies reporting the outcome of the ten assessment tests in the fallers and non-fallers. Among those studies, one study[21] categorized the subjects into the "high risk fallers" and the "low risk fallers". Still one study[12] categorized the subjects into "no limitation" and "moderate limitation" according to their self-reported level of mobility limitation. To better extract the results, the no mobility limitation group and low falls risk group were treated as non-faller group, and the limited mobility group and high falls risk group were the faller group. Seven studies using the 5-time sit-to-stand test reported that the total time spent on the sit-to-stand task was greater in the faller group than the non-faller group, while two studies didn't conduct the statistical analysis[11,12] and the difference was not significant in one study.[14] Three studies using the alternate step test reported that the total stepping time was significantly higher in the faller group, while one study didn't show the results of statistical analysis.[12] The measures of the stair ascent and stair descent, ten-step, and minimal chair height standing tests were significantly higher in the faller group. In contrary, the measures of the one leg stance, functional reach, and maximum step length tests were significantly lower in the faller group. The stair ascent and stair descent, ten-step, minimal chair height standing, half-turn, and maximum step length tests were only used in single study. There were no significant differences between the groups in the measures of the tandem stance, stair ascent, and half-turn tests.

Eight out of the ten tests reports the cutoff values and the performance of the screening ability for the faller and non-faller (Table 4). The cut-off point of the 5-time sit-to-stand and the alternate step tests were mostly around 12 and 10 seconds respectively. The cut-off point value in Kim's study[12] was notably smaller (6.7 seconds and 4.41 seconds respectively) than those in the other studies. The 5-time sit-to-stand and the alternate step tests generally showed a moderate sensitivity (50–73%) and specificity (50–66%) and the area under the AUC ranged from 0.57 to 0.75. Two studies provided cut-off point of the one leg stance test as 12.7 and 18.6 seconds. The sensitivity and specificity of the one leg stance test ranged from 51% to 63%. The cut-off point of the functional reach test was around 24.2 cm and 27 cm with sensitivity and specificity around 57–63% and AUC around 0.65. Inconsistent cut-off points of the tandem stance test were observed in two studies (30 seconds and 10 seconds) with good specificity (69–81%) and fair AUC (0.57–0.62). The stair ascent and stair descent, half-turn, and maximum step length tests showed acceptable sensitivity and specificity except for the specificity of the half-turn test (28%). Most assessment tests showed good reliability.

3.3. Meta-analysis

Five meta-analyses including the 5-time sit-to-stand, alternate step, one leg stance, functional reach, and tandem stance tests

Table 3
Differences of the fallers and non-fallers on the performance in different assessment tests.

Assessment test	Study	Number of subjects	Faller	Non-faller	*p*-value
5-time-sit-to-stand test (sec)	Cheng 2014	F: 35/Non-F: 35	19.82 ± 4.46	15.65 ± 3.30	< 0.01
	Ejupi 2015	F: 29/Non-F: 65	15.33 ± 5.45	13.12 ± 4.06	0.034
	Hirase 2014	F: 292/Non-F: 1871	13.80 ± 7.50	11.30 ± 5.80	-
	Kim 2009	F: 96/Non-F: 259	8.55 ± 2.8	6.42 ± 1.6	-
	Kwan 2011	F: 81/Non-F: 199	13.3 ± 5.6	13.2 ± 4.8	> 0.05
	Makizako 2014	F: 645/Non-F: 3836	9.3 ± 3.4	8.6 ± 2.8	< 0.001
	Tiedemann 2008	F: 80/Non-F: 282	14.8 ± 6.2	12.5 ± 4.8	< 0.001
Alternate step test (sec)	Kim 2009	F: 96/Non-F: 259	5.51 ± 1.9	4.36 ± 0.8	-
	Kwan 2011	F: 81/Non-F: 199	13.1 ± 6.9	11.4 ± 4.3	< 0.05
	Tiedemann 2008	F: 74/Non-F: 265	12.2 ± 4.6	10.8 ± 3.8	0.007
One leg stance test (sec)	Chang 2013	F: 15/Non-F: 15	13.91 ± 4.92	17.58 ± 3.40	0.087
	Kim 2009	F: 96/Non-F: 259	20.9 ± 20.2	33.2 ± 21.9	-
	Kwan 2011	F: 81/Non-F: 199	11.6 ± 10.3	15.6 ± 11.1	< 0.05
Functional reach test (cm)	Kim 2009	F: 96/Non-F: 259	25.3 ± 5.4	28.7 ± 5.5	-
	Kim 2017	F: 30/Non-F: 30	22.27 ± 5.35	25.91 ± 5.93	0.016
Tandem stance test (sec)	Kim 2009	F: 96/Non-F: 259	23.7 ± 9.4	27.9 ± 5.2	-
	Kwan 2011	F: 81/Non-F: 199	17.1 ± 12.0	20.1 ± 10.8	> 0.05
Stair ascent and descent test (sec)	Tiedemann 2008	F: 80/Non-F: 282	Stair ascent: 5.9 ± 2.7	Stair ascent: 5.5 ± 2.6	0.055
			Stair descent: 6.6 ± 3.5	Stair descent: 5.7 ± 3.3	0.001
Ten-step test (sec)	Singh 2015	F: 18/Non-F: 122	17.84	7.14	0.003
Minimal chair height standing test (cm)	Kwan 2011	F: 81/Non-F: 199	29.7 ± 9.0	25.0 ± 9.2	< 0.001
Half-tum test (steps)	Tiedemann 2008	F: 80/Non-F: 282	Median: 4	Median: 4.5	0.080
			Inter-quartile range: 3–5	Inter-quartile range: 4–5	
Maximum step length test (% of body height)	Lindemann 2008	F: 30/Non-F: 26	62 ± 9	68 ± 7	0.027

F: faller; Non-F: non-faller.

Table 4
Performance of screening for predicting fallers in different assessment tests.

Assessment test	Study	Number of subjects	Cutoff point	Sensitivity (%)	Specificity (%)	LR+	LR-	AUC	ICC
5-time-sit-to-stand test (sec)	Buatois 2008	1958	15	55	65	1.57	0.69	-	-
	Coqueiro 2014	143	12	68	60	1.70	0.53	0.67	-
	Kim 2009	355	6.7	72	65	2.05	0.43	0.75	0.80
	Tiedemann 2008	362	12	66	55	1.46	0.61	-	0.89
	Tiedemann 2010	287	12	64	50	1.28	0.72	0.57	0.89
Alternate step test (sec)	Kim 2009	355	4.41	73	64	2.02	0.42	0.73	0.80
	Tiedemann 2008	339	10	69	56	1.56	0.55	-	0.78
	Tiedemann 2010	287	10	50	66	1.47	0.75	0.58	-
One leg stance test (sec)	Bongue 2011	1759	12.7	61	51	1.24	0.76	0.55	-
	Kim 2009	355	18.6	65	63	1.75	0.55	0.67	0.80
Functional reach test (cm)	Kim 2009	355	27	57	59	1.39	0.72	0.65	0.80
	Kim 2017	60	24.2	63	63	1.70	0.57	0.63	-
Tandem stance test (sec)	Kim 2009	355	30	41	81	2.15	0.72	0.62	0.80
	Tiedemann 2010	287	10	46	69	1.48	0.78	0.57	0.52
Stair ascent and descent test (sec)	Tiedemann 2008	362	5	54/63	58/55	1.28/1.40	0.58/0.67	-	0.84/0.86
Half-tum test (steps)	Tiedemann 2008	362	4	78	28	1.08	0.78	-	0.75
Maximum step length test (% of body height)	Lindemann 2008	56	66	70	69	2.3	0.4	-	-

LR: like-hood ratio; AUC: area under the receiver operating characteristic curve; ICC: intra-class correlation coefficients.

showed in the forest plot (Figure 2). Seven studies[9–12,14–16] including 7,805 subjects revealed significant difference in the complete time of the 5-time sit-to-stand test between the two groups (mean difference [faller – non-faller] = 1.90 seconds [95% CI: 0.98–2.82], $p <$ 0.001, Figure 2a). However, inconsistent results with high heterogeneity (I^2 = 87%) was also detected amongst the included studies, with only one study didn't favor the non-faller group.[14] The complete time of the alternate step test was found to significantly favor the non-faller group (1.20 seconds [0.84–1.56], $p < 0.001$, Figure 2b) with low heterogeneity (I^2 = 0%) among the three studies.[12,14,16] The maximal standing time of the one leg stance test was identified with high heterogeneity (I^2 = 80%) and significant group difference (-6.21 seconds [-10.60–-1.82], p = 0.006, Figure 2c) from the three studies[8,12,14] including 662 subjects. The maximal forward reaching distance of the functional reach test showed the low heterogeneity (I^2 = 0%) and significant group difference (-3.44 cm [-4.60–-2.28], $p <$ 0.001, Figure 2d) between the two studies.[12,13] The maximal standing time of the tandem stance test was reported with low heterogeneity (I^2 = 0%) and significant group difference (-3.84 seconds [-5.49–-2.18], $p < 0.001$, Figure 2e) between the two studies.[12,14]

4. Discussion

The objective of this study was to investigate the equipment-free assessment tests to identify the fall risks for the functionally independent elderly. Fifteen studies met the criteria were selected. Though the selected studies showed heterogeneous characteristics of subjects and inconsistent definitions of fall, the analysis results showed: (1) The most commonly studied equipment-free assessment test to identify the faller is the 5-time sit-to-stand test. (2) The included assessment tests in this study show significant difference between the fallers and the non-fallers except for the tandem stance, stair ascend, and the half-turn tests. (3) All assessment tests do not show good sensitivity or specificity. (4) The alternate step, functional reach, and tandem stance tests could be evidenced as the equipment-free assessment tests to identify the faller and non-faller.

The present study is a diagnostic systematic review, aiming at assessing the performance of the equipment-free screening tests to identify the elderly with fall risks. The level of evidence for all selected 15 studies was 3B (Table 2), which is the highest level for the case control study. Among the eight main questions to evaluate the level of evidence, the selected studies mostly failed to meet the requirement of the second and fourth criteria that required the study to be blind compared to a gold standard of diagnosis. Many of the current studies focused on the comparisons between the faller and non-faller but not on the assessment tool itself. This study summarized the statistical significance, sensitivity/specificity, and efficiency in differentiating the group difference as below, while high quality diagnostic studies with consistently applied reference standard and blinding are still needed to further reveal the usefulness of those equipment-free assessment tools.

The elderly with fall risks has presumably performed poorer than the ones without in the function-related assessment tests, especially the ones involving dynamic balance and activity level. The examined tests in this study are function-oriented and basically designed to assess the coordination of the trunk and lower extremities. Seven out of the fifteen selected studies used the 5-time sit-to-stand test, which is the most commonly used technique, and only one study showed insignificant difference between the fallers and non-fallers. The reason why the 5-time sit-to-stand test was mostly applied tests may because it can be used to evaluate the muscle strength of lower extremity for the elderly or for the patients with movement deficit resulted from the lumbar stenosis.[6] The sit-to-stand test is especially associated with the muscle strength of the knee extensors/flexors/ankle flexors, joint motion, balance, proprioception, reaction time and tactile sensation.[31] The decrease in muscle mass and muscle strength are signs of elderly frailty and associated with lower functional activities and fall risks. Generally speaking, the assessment tests included in this study used the time, length, or repetitions as the main measurements of fall risks, and thus were easy to conduct and suitable to be applied in clinical practice.

Only few sensitivity and specificity results from the selected studies reach the acceptable values as over 70%. The cutoff point of the 5-time sit-to-stand test for greater than 12 s was reported in three studies and could tell 64–68% faller.[16,19,20] Kim et al.[12] adopted a harder cutoff point at 6.7s and showed that the sensitivity could be increased to 72% with greater predictive discrimination and reliability. The cutoff point of the alternate step test for greater than 10 s could at least tell 50% faller.[16,19] Kim et al.[12] again reported a much challenging cutoff point set at 4.41s and showed that the sensitivity could be increased to 73% with greater predictive discrimination

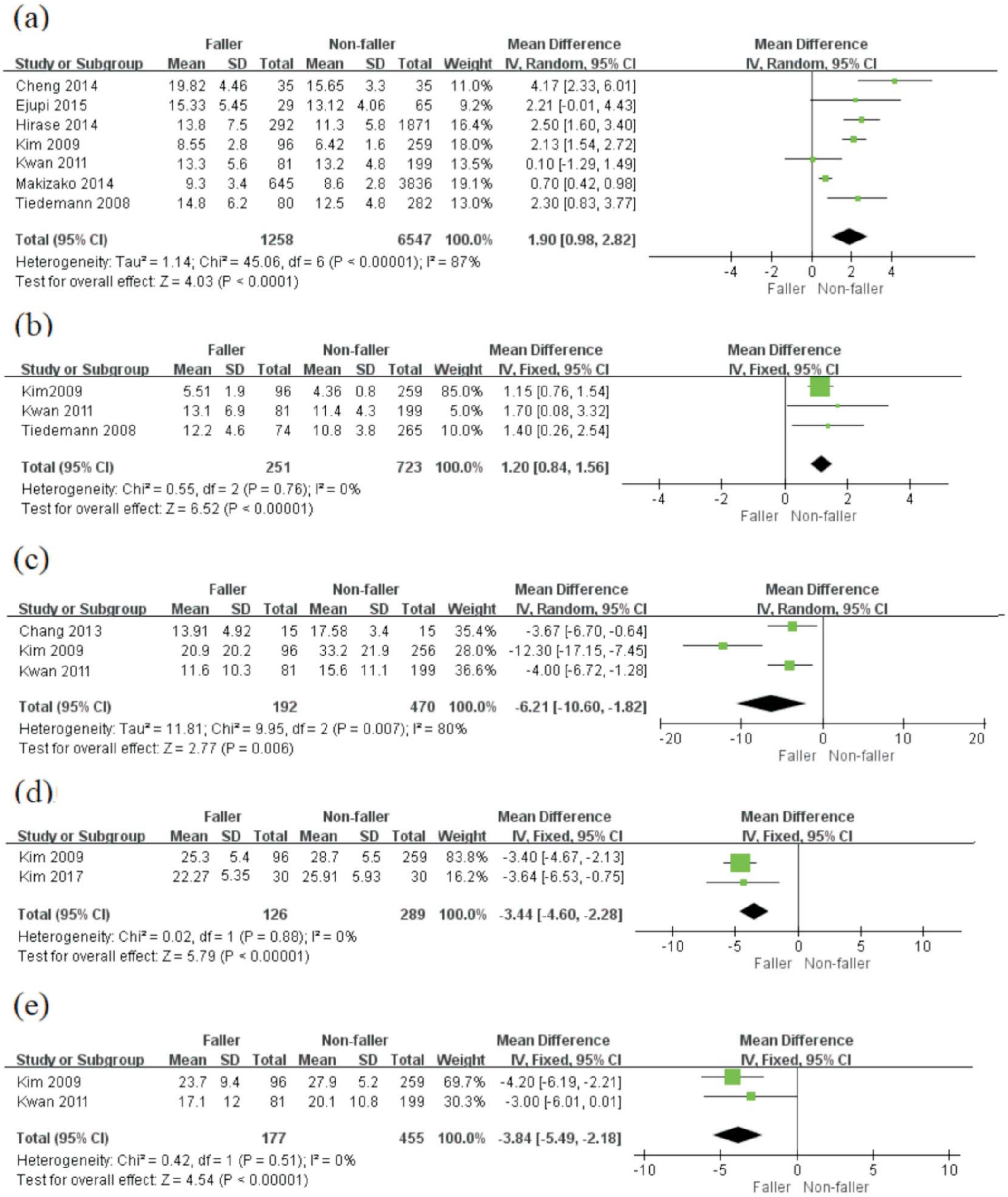

Figure 2. Forest plots of the screening assessment tests: (a) 5-time sit-to-stand test; (b) Alternate step test; (c) One leg stance test; (d) Functional reach test; (e) Tandem stance test.

(AUC was 0.73) and reliability (ICC was 0.8). The cutoff point of the one leg stance test smaller than 18.6s could tell 65% faller,[12] and the cutoff point decreased to 12.7 s reported by Bongue et al. can still screen out 61.0% of the elderly with fall risks.[7] Bongue et al. further showed that the screening assessment rate would increase to 70.2% when considering five additional fall risk factors, including the gender, living alone, psychoactive drug use, osteoarthritis, and previous falls.[7] In terms of the functional reach test, two studies reported similar cutoff point to be 27 cm[12] and 24.2 cm[13] and found that the sensitivity were 57% and 63% respectively. Russell et al.[32] showed that when the functional reach test combined with a survey of 13 fall risks, the screening assessment rate of the elderly with fall risks can increase to 71.3%. The cutoff point of the tandem stance test reported by Kim et al.[12] and Tiedemann et al.[19] were quite different to be 30 s and 10 s respectively with only 41% and 46% sensitivity. It could because Tiedemann et al. adopted a modified tandem stand test which the subject's feet were separated laterally and anteroposteriorly by 2.5 cm. The stair ascend and stair descend test did not show promised discrimination ability since the sensibility and specificity were around 54–63%. The half-turn test showed great ability to tell the faller (sensibility was 78%) but poor ability to differentiate the non-faller (specificity was 28%). The maximum step length test showed the potential to be both sound in the sensibility and specificity. However, the stair ascent and stair descent, half-turn, and maximum step length tests were only used in single study. Further study is suggested to consider the combination of tests reflecting different aspects of ability and to find out if this could help to improve the performance for predicting fallers.

Nine out of the selected fifteen studies were pooled for the meta-analysis on the five assessment tests (Figure 2a–e). The weights of the seven studies investigating the time to accomplish the 5-time sit-to-stand test was evenly matched (9.2%–19.1%) and did not prefer any studies. Though most studies showed longer complete time of the 5-time sit-to-stand test in fallers than the non-fallers, the confidence interval from the Ejupi et al.[10] and Kwan et al.[14] studies included zero and showed an effect not statistically significant which resulted in great heterogeneity (I^2 = 80%) among the included studies. Similarly, the one leg stance test also came with great confidence interval and great heterogeneity. The problem with the use of the 5-time sit-to-stand and the one leg stance test is therefore the varied effects among the included studies, making it difficult to ascertain the meaningful combined evidence and undermining their significance testing. Overall, results from the present meta-analysis suggested that the faller can accordantly showed longer complete time during the alternate step test, smaller maximal forward reaching distance of the functional reach test, and shorter maximal standing time of the tandem stance test compared to the non-faller. However, it must be noted that the weight remarkably skewed towards the Kim's study[12] which was 85.0%, 83.8%, and 69.7% for the alternate step, functional reach, and tandem stance tests respectively. Further large population study could still be encouraged to provide balanced evidence supporting the use of those assessment tests.

4.1. Limitations

Several study limitations should be addressed. First, there was no identical definition to identify the fallers in the selected studies. The question as the unintentional or unexpected falling event in the past year was commonly used in cross sectional studies. One study did not provide any definition,[8] and one study used the Physiological profile assessment score[21] referring to mobility limitation level of subjects. Different definition of falls could affect the accuracy of the comprehensive results. Second, the results in the included studies could be varied based on the different life style and region. For example, in terms of the 5-time sit-to-stand test, Asian population[11,12,14,15] showed a better performance compared to the Western one. Third, the performance in Kim's study[12] was superior to that of other studies in terms of the 5-time sit-to-stand, alternate step, one leg stance, functional reach, and tandem stance tests. Kim' study was also the only one focused on the female subjects such that the potential effects of the gender difference on the physical function and the performance of the assessment tests should be noted. Finally, given the high heterogeneity among the studies applying the 5-time sit-to-stand test (I^2 = 87%) and the one leg stance test (I^2 = 80%), a series of subgroup analyses and the publication bias analysis may be considered. However, it is unlikely that an investigation of heterogeneity will produce useful findings unless there are at least 10 studies included in the meta-analysis according to the guidance provided by the Cochrane Handbook for Systematic Reviews of Interventions.[33] Since the mostly used assessment test (i.e., the 5-time sit-to-stand test) was only included in seven studies, it is suggested that more future studies in this field are needed to come to a definite clarification about the confounding factors and to identify the best assessment test for clinical applications.

5. Conclusion

This study was to identify the equipment-free assessment tests which are handy and capable to distinguish the fall risks of elderly. It was concluded that the 5-time sit-to-stand test was mostly used to assess the risk of falling in elderly. Although most assessment tests demonstrated significant difference between the fallers and non-fallers, the performance of those tests for identifying fallers were less promising. The alternate step, functional reach, and tandem stance tests could be indicated as effective and reliable equipment-free tests to monitor the fall risks in the functionally independent elderly in clinics or communities.

Acknowledgements

We gratefully acknowledge supports of the Ministry of Science and Technology of the Republic of China, Healthy Aging Research Center, Chang Gung Memorial Hospital Research Program, to this research under the grants 110-2221-E-182-019-, EMRPD1L0411, CMRPD1J0152, and CRRPG3H0062 respectively.

Declaration of conflicts of interest

The authors declare that there is no conflict of interest.

References

1. Murray CJ, Vos T, Lozano R, et al. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet.* 2012;380(9859): 2197–2223.
2. Miszko TA, Cress ME, Slade JM, et al. Effect of strength and power training on physical function in community-dwelling older adults. *J Gerontol A Biol Sci Med Sci.* 2003;58(2):171–175.
3. Guideline for the prevention of falls in older persons. American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on falls prevention. *J Am Geriatr Soc.* 2001;49(5):664–672.
4. Maranesi E, Merlo A, Fioretti S, et al. A statistical approach to discriminate between non-fallers, rare fallers and frequent fallers in older adults based on posturographic data. *Clin Biomech (Bristol, Avon).* 2016;32:8–13.
5. Svoboda Z, Bizovska L, Janura M, et al. Variability of spatial temporal gait parameters and center of pressure displacements during gait in elderly fallers and nonfallers: A 6-month prospective study. *PLoS One.* 2017; 12(2):e0171997.
6. Chorin F, Cornu C, Beaune B, et al. Sit to stand in elderly fallers vs non-fallers: new insights from force platform and electromyography data. *Aging Clin Exp Res.* 2016;28(5):871–879.
7. Bongue B, Dupré C, Beauchet O, et al. A screening tool with five risk factors was developed for fall-risk prediction in community-dwelling elderly. *J Clin Epidemiol.* 2011;64(10):1152–1160.
8. Chang CJ, Chang YS, Yang SW. Using single leg standing time to predict the fall risk in elderly. *Annu Int Conf IEEE Eng Med Biol Soc.* 2013;2013:7456–7458.
9. Cheng YY, Wei SH, Chen PY, et al. Can sit-to-stand lower limb muscle power predict fall status? *Gait Posture.* 2014;40(3):403–407.
10. Ejupi A, Brodie M, Gschwind YJ, et al. Kinect-based five-times-sit-to-stand test for clinical and in-home assessment of fall risk in older people. *Gerontology.* 2015;62(1):118–124.
11. Hirase T, Inokuchi S, Matsusaka N, et al. A modified fall risk assessment tool that is specific to physical function predicts falls in community-dwelling elderly people. *J Geriatr Phys Ther.* 2014;37(4):159–165.
12. Kim MJ, Seino S, Kim MK, et al. Validation of lower extremity performance tests for determining the mobility limitation levels in community-dwelling older women. *Aging Clin Exp Res.* 2009;21(6):437–444.
13. Kim T, Xiong S. Comparison of seven fall risk assessment tools in community-dwelling Korean older women. *Ergonomics.* 2017;60(3):421–429.
14. Kwan MM, Lin SI, Chen CH, et al. Minimal chair height standing ability is independently associated with falls in Taiwanese older people. *Arch Phys Med Rehabil.* 2011;92(7):1080–1085.
15. Makizako H, Shimada H, Doi T, et al. The combined status of physical performance and depressive symptoms is strongly associated with a history of falling in community-dwelling elderly: cross-sectional findings from the Obu Study of Health Promotion for the Elderly (OSHPE). *Arch Gerontol Geriatr.* 2014;58(3):327–331.
16. Tiedemann A, Shimada H, Sherrington C, et al. The comparative ability of eight functional mobility tests for predicting falls in community-dwelling older people. *Age Ageing.* 2008;37(4):430–435.
17. Buatois S, Miljkovic D, Manckoundia P, et al. Five times sit to stand test is a predictor of recurrent falls in healthy community-living subjects aged

65 and older. *J Am Geriatr Soc.* 2008;56(8):1575–1577.

18. Lindemann U, Lundin-Olsson L, Hauer K, et al. Maximum step length as a potential screening tool for falls in non-disabled older adults living in the community. *Aging Clin Exp Res.* 2008;20(5):394–399.
19. Tiedemann A, Lord SR, Sherrington C. The development and validation of a brief performance-based fall risk assessment tool for use in primary care. *J Gerontol A Biol Sci Med Sci.* 2010;65(8):896–903.
20. Coqueiro R, Santos K, Schettino L, et al. "Chair stand" test as predictor of Brazilian elderly men fallers. *Maced J Med Sci.* 2014 2(2):316–318.
21. Singh DK, Pillai SG, Tan ST, et al. Association between physiological falls risk and physical performance tests among community-dwelling older adults. *Clin Interv Aging.* 2015;10:1319–1326.
22. Guralnik JM, Simonsick EM, Ferrucci L, et al. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *J Gerontol.* 1994;49(2):M85–M94.
23. Menz HB, Lord SR. The contribution of foot problems to mobility impairment and falls in community-dwelling older people. *J Am Geriatr Soc.* 2001;49(12):1651–1656.
24. Rikli R, Busch S. Motor performance of women as a function of age and physical activity level. *J Gerontol.* 1986;41(5):645–649.
25. Duncan PW, Studenski S, Chandler J, et al. Functional reach: predictive validity in a sample of elderly male veterans. *J Gerontol.* 1992;47(3): M93–M98.
26. Rossiter-Fornoff JE, Wolf SL, Wolfson LI, et al. A cross-sectional validation study of the FICSIT common data base static balance measures. Frailty and Injuries: Cooperative Studies of Intervention Techniques. *J Gerontol A Biol Sci Med Sci.* 1995;50(6):M291–M297.
27. Miyamoto K, Takebayashi H, Takimoto K, et al. A new simple performance test focused on agility in elderly people: The ten step test. *Gerontology.* 2008;54(6):365–372.
28. Schurr K, Ho G, Sherrington C, et al. Measurement of the ability to stand up from the lowest possible chair height: procedure and interrater reliability. Australian Physiotherapy Association Conference; 2002 May 25–28.
29. Berg K, Wood-Dauphinee S, Williams JI, et al. Measuring balance in the elderly: preliminary development of an instrument. *Physiother Can.* 1989;41(6):304–311.
30. Medell JL, Alexander NB. A clinical measure of maximal and rapid stepping in older women. *J Gerontol A Biol Sci Med Sci.* 2000;55(8):M429–M433.
31. Papa E, Cappozzo A. Sit-to-stand motor strategies investigated in able-bodied young and elderly subjects. *J Biomech.* 2000;33(9):1113–1122.
32. Russell MA, Hill KD, Day LM, et al. Development of the falls risk for older people in the community (FROP-Com) screening tool. *Age Ageing.* 2009; 38(1):40–46.
33. Higgins JPT, Green S. *Cochrane handbook for systematic reviews of interventions.* London, UK: The Cochrane Collaboration; 2011.