Heart & Lung 49 (2020) 458–462

Contents lists available at ScienceDirect

Heart & Lung

journal homepage: www.heartandlung.com

# Balance performance in patients with heart failure

Aylin Tanriverdi[a,*], Buse Ozcan Kahraman[b], Ismail Ozsoy[c], Serap Acar[b], Bihter Senturk[d], Ebru Ozpelit[d], Bahri Akdeniz[d], Sema Savci[b]

[a] Graduate School of Health Sciences, School of Physical Therapy and Rehabilitation, Dokuz Eylül University, Izmir, Turkey
[b] School of Physical Therapy and Rehabilitation, Dokuz Eylül University, Izmir, Turkey
[c] School of Physical Therapy and Rehabilitation, Ahi Evran University, Kirsehir, Turkey
[d] Department of Cardiology, Faculty of Medicine, Dokuz Eylül University, Izmir, Turkey

ARTICLE INFO

*Article History:*
Received 30 January 2020
Revised 1 April 2020
Accepted 7 April 2020
Available online 18 May 2020

*Keywords:*
Balance
Heart failure
Cardiac rehabilitation

ABSTRACT

*Background:* It has been suggested that patients with heart failure (HF) have an increased fall rate. Although balance is one of the most important risk factors for fall, there is not sufficient information about balance in HF.
*Objective:* To compare static, dynamic and functional balance between patients with HF and healthy controls.
*Methods:* Twenty-seven patients with HF and 22 healthy controls were recruited in this study. The Unilateral Stance (US) and Limits of Stability (LOS) tests were used to measure static and dynamic balance, respectively. Functional balance was assessed with Berg Balance Scale.
*Results:* There was no significant difference in age, gender and body mass index between the groups ($p > 0.05$). There was a significant difference in US with open eyes between the groups ($p < 0.05$). Reaction time (backward and left), endpoint excursion (backward), maximum excursion (forward and backward) and directional control (forward and right) variables of LOS were significantly different between the groups ($p < 0.05$).
*Conclusions:* Patients with HF have impaired static, dynamic and functional balance. Considering the balance impairment, a comprehensive balance assessment performed and balance training should be included in the management of HF as a part of the cardiac rehabilitation program.



## Introduction

Heart Failure (HF) is defined as a complex clinical syndrome caused by a structural and/or functional cardiac abnormality, resulting in reduced cardiac output and/or elevated intracardiac pressures at rest or during stress.[1,2] Decreased cardiac performance is one of the major causes of exercise intolerance.[3] Additionally, changes in skeletal muscle mass, density, fiber type, oxidative metabolism and mitochondrial function lead to muscle dysfunction in HF.[4] Functional difficulties mentioned above have been reported to increase the likelihood of falling in HF.[5] Falls have significant adverse consequences for elderly people including increased prevalence of health problems, health care costs and decreased quality of life.[6] Fall rate in patients with HF is higher than fall rate in elderly people, 43% and 30%, respectively.[7,8] Risk factors for fall include a previous fall, polypharmacy, mobility limitations, dizziness or orthosis and cognitive impairments in HF.[9] Furthermore, balance impairment is one of the most important risk factors for fall in elderly people.[10] Balance is negatively affected by any damage to the vestibular system, visual system or somatosensory system, which brings about the risk of falling.[11] Although the risk factors of fall are similar in the elderly people[12] and patients with HF,[9] there is not sufficient information about the balance performance in HF. Balance impairment, also, is reported in cardiopulmonary disease[13,14] and balance training added in pulmonary rehabilitation programs in COPD is supported as feasible and effective.[15] Therefore, it will be important to define the presence of balance impairment to develop fall preventive approaches and appropriate treatment programs in patients with HF. The aim of this study was to compare static, dynamic and functional balance in patients with HF compared with healthy controls.

## Methods

This observational, cross-sectional study was performed between May 2019 and December 2019. Patients with HF were recruited from

*Abbreviations:* BBS, Berg Balance Scale; COPD, chronic obstructive pulmonary disease; DC, directional control; EXE, endpoint excursion; m-EXE, maximal endpoint excursion; HF, heart failure; LOS, limits of stability; MVL, movement velocity; NYHA, New York Heart Association; RT, reaction time; US, unilateral stance; 6MWT, 6-min walk test

* Corresponding author.
*E-mail address:* aylin.tanriverdi@deu.edu.tr (A. Tanriverdi).

https://doi.org/10.1016/j.hrtlng.2020.04.004
0147-9563/

the Department of Cardiology at Dokuz Eylül University Hospital. The study included patients with HF who met the following inclusion criteria: diagnosis of HF according to 2016 ESC Heart Failure Guidelines,[2] clinically stable with symptoms consistent with New York Heart Association (NYHA) functional class I-II-III and volunteer to participate in the study. NYHA functional classification is a valid measurement of functional status.[16] Patients who have cognitive disorders, vertigo or impaired vision, neurologic and musculoskeletal problems that restricted mobility, were excluded from the study. Also, age and sex-matched healthy volunteers who did not have any cardiorespiratory disease and health problems that restrict mobility were selected from relatives of patients and university staff for healthy controls. All measurements of participants were carried out in School of Physical Therapy and Rehabilitation, Dokuz Eylül University, Izmir, Turkey.

To the best of our knowledge, there was no study which investigated the balance in patients with HF, therefore, we used the results of a study investigating the balance in patients with COPD.[13] In that study, the Berg Balance Scale score, which is a mutual outcome measure with our study, was significantly different between the patients with COPD and healthy controls with an effect size of 1.40 ($p < 0.001$).[13] Alpha error probability and power was set as 0.05 and 0.95, respectively. Since the population was different, we decided to set power as higher. A-priori sample size was calculated as 30 participants, 15 per each group, using the G*Power Software (Version 3.1.9.2, Düsseldorf University, Düsseldorf, Germany).

The study protocol was approved by the Dokuz Eylül University Institutional Non-invasive Research Ethics Board (No:2019/13-27 Date:22.05.2019). Written informed consent was obtained from all individual participants included in the study.

### Measurements

The demographic characteristics of participants were recorded. Clinical information of patients with HF including etiology of disease, ejection fraction, and hospitalization within the last years was obtained from clinical records. Participants were questioned about stories of falls within the last year. In addition, the participants were asked whether the fall was caused by syncope or dizziness. All participants underwent balance, quadriceps muscle strength and functional capacity assessments.

NeuroCom Balance Master System (Version 8.1, NeuroCom® 2003, USA) was used to evaluate static and dynamic balance. NeuroCom Balance Master System has been shown to have moderate to high test-retest reliability (intraclass correlation coefficient, > 0.84) in evaluating balance impairment in community-dwelling older adults and clinical groups.[17,18] This study used to unilateral stance (US) test for the static balance and limits of stability (LOS) for the dynamic balance assessment. US test measures postural sway velocity during the individual's standing position on one feet with eyes open and then eyes closed. Each of the four conditions consists of three 10-s trials.[19] The LOS assesses the ability of the individual to voluntarily sway to eight targets which divided by an angle of 45°. During the test, the participant shifts the weight to forward, forward-right, right, backward-right, backward, backward-left, left, forward-left side by controlling the center of gravity. Reaction time (RT), movement velocity (MVL), endpoint excursion (EXE), maximal endpoint excursion (m-EXE) and directional control (DC) were obtained from LOS. The time between the signal on the computer screen and the start of the motion is RT. The average of movement expressed as degrees per second is MVL. The distance traveled the first attempt to reach the target is EXE. The longest distance to reach the target is m-EXE. The comparison of the amount of motion towards the target to the amount of away from target is DC. EXE, m-EXE and DC were expressed as a percent. Scores from eight targets in LOS were reunited by the computer software program to provide four main directions.[20] Illustrations of NeuroCom Balance Master System assessments are presented in Fig. 1.

Berg Balance Scale (BBS) was used to assess functional balance. The scale consists of 14 items that evaluate activities of daily living such as sitting, standing without support, reaching, turning around, looking back, one leg stance. Items are graded from 0 (unable) to 4 points (independent). The highest score is 56 and indicates a good functional balance. The Turkish version of the BBS scale has been found to be reliable (intraclass correlation coefficient, > 0.97) and valid in older adults.[21]

Quadriceps muscle strength was measured using handheld dynamometer (Lafayette, Indiana, USA). Handheld dynamometer has been indicated to be reliable (intraclass correlation coefficient, ≥ 0.80) and valid for quadriceps muscle strength assessment in older adults. Test was performed seated position with hip and knee at 90° flexion. Dynamometer was situated on anterior surface of ankle joint and then the participant was asked to push as hard as against the dynamometer for 4–5 s.[22]

Functional exercise capacity was evaluated with the 6-min walk test (6MWT). 6MWT has been shown to be reliable (intraclass correlation coefficient = 0.90) and valid in mild to moderate HF.[23] 6MWT was performed according to American Thoracic Society recommendation.[24] The participants were asked to walk as fast as and standardized phrases were used to avoid encouragement during testing. After the test, the walking distance was recorded. Percent of predicted 6MWT distance was calculated using Enright and Sherrill reference equations.[25]

### Statistical analysis

All data were analyzed using IBM SPSS software (Version 23.0, IBM Corp., Armonk, NY, USA). Shapiro-Wilk test and histograms were used to check the normality of distribution. Multivariate analysis of variance (MANOVA) with a Bonferroni adjustment was performed to examine the differences in the dependent variables between the patients with HF and healthy controls. Continuous variables were presented as mean and standard deviation, while categorical variables were presented as number and percent. Statistical significance was determined as $p < 0.05$.

## Results

Twenty-seven participants with HF and 22 healthy controls were included in this study. Comparisons of characteristics of participants with HF and healthy controls are presented in Table 1. There were no significant differences in age, gender and body mass index between the groups. There were 7 patients with HF (25.8%) in NYHA class I, 12 patients (44.4%) in class II and 8 patients (29.6%) in class III. The etiology of patients with HF was ischemic heart disease. The rate of HF with reduced ejection fraction and with preserved ejection fraction was 81.5% and 18.5%, respectively. History of hospitalization for patients with HF was 48% in the last year. None of the participants reported falls due to syncope or dizziness. The presence of falls and number of falls during last year were higher in patients with HF than healthy controls ($p < 0.05$). Quadriceps muscle strength, 6MWT distance and percent of predicted 6MWT distance were significantly different between the groups ($p < 0.05$). BBS were lower in patients with HF than healthy controls and the difference was statistically significant ($p < 0.05$).

Comparison of static and dynamic balance of participants with HF and healthy controls is shown in Table 2. There was a significant difference in US with eyes open ($p < 0.05$) but there was no significant difference in US with eyes closed between the two groups ($p > 0.05$). RT in the backward and left directions were longer in patients with HF and the differences were statistically significant ($p < 0.05$). There was no significant difference in MV between the groups ($p > 0.05$).

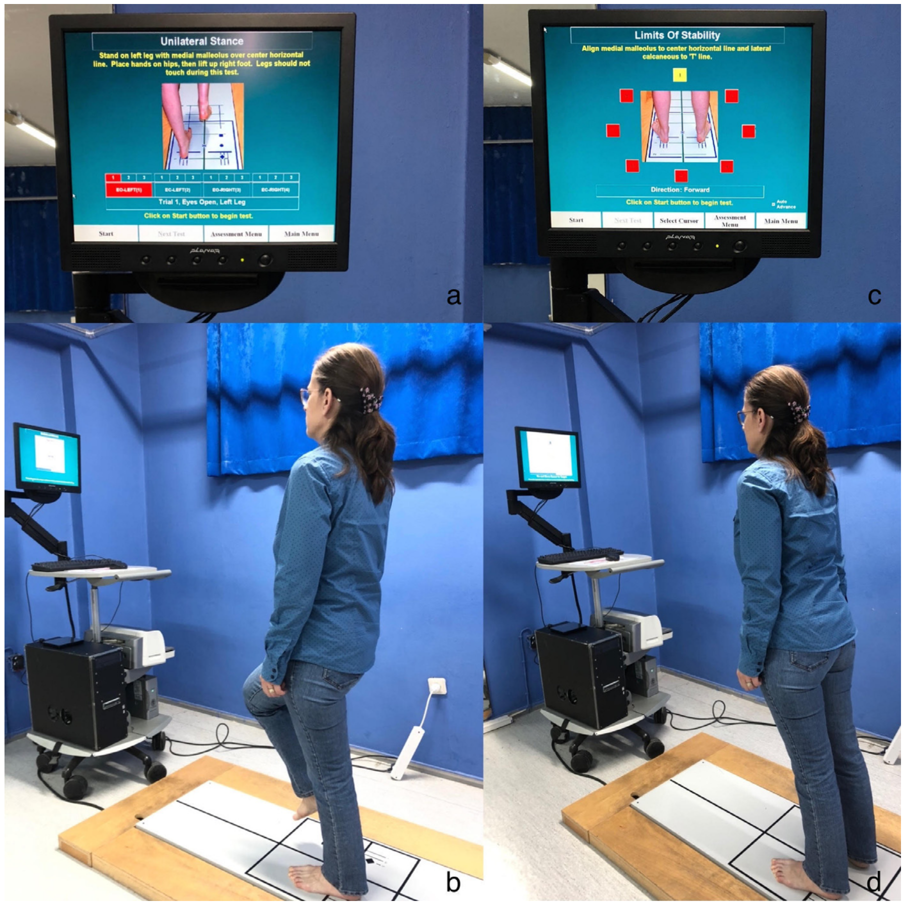


**Fig. 1.** Illustrations of Balance Master System assessments. a. instruction for unilateral stance test, b. application of unilateral stance test with participant, c. instruction for limits of stability test, d. application of limits of stability test with participant.

**Table 1**
Characteristics features of participants with HF and healthy controls.

| | HF ($n = 27$) | Healthy controls ($n = 22$) | *P* value |
|---|---|---|---|
| Age (y) | 66.22 ± 10.37 | 64.13 ± 9.58 | 0.473 |
| Gender (male) | 22 (81.5) | 14 (63.6) | 0.159 |
| BMI (kg/m$^2$) | 28.27 ± 3.80 | 27.26 ± 3.60 | 0.349 |
| NYHA class | | | |
| I | 7 (25.9) | – | N/A |
| II | 12 (44.4) | – | N/A |
| III | 8 (29.6) | – | N/A |
| EF (%) | 33.00 ± 11.72 | – | N/A |
| Fallers | 10 (37.0) | 2 (9.1) | 0.023* |
| Number of falls (within the last year) | 0.48 ± 0.84 | 0.09 ± 0.29 | 0.045* |
| Quadriceps Strength (kg) | 18.25 ± 5.93 | 35.05 ± 7.67 | < 0.001* |
| 6MWT distance (m) | 423.75 ± 68.20 | 478.12 ± 79.36 | 0.013* |
| Percent of predicted 6MWD (%) | 82.84 ± 13.98 | 92.52 ± 10.91 | 0.011* |
| BBS | 52.90 ± 2.50 | 54.49 ± 2.46 | 0.040* |

HF, heart failure; BMI, body mass index; NYHA, New York Heart Association; N/A, not applicable; EF, ejection fraction; 6MWT, 6 min walk test; BBS, Berg Balance Scale. Data were expressed as mean± SD or number (percentage). *Statistically significant difference ($p < 0.05$).

EXE in the backward direction and m-EXE in the forward and backward directions were significantly shorter in patients with HF ($p < 0.05$). DC in the forward and right directions was significantly worse in patients with HF ($p < 0.05$). Other variables of EXE, m-EXE and DC were lower in the patients with HF but differences between the groups were not statistically significant ($p > 0.05$).

**Table 2**
Static and dynamic balance of participants with HF and healthy controls.

| | HF ($n = 27$) | Healthy controls ($n = 22$) | *P* value |
|---|---|---|---|
| Unilateral Stand, °/s | | | |
| Right-side eye open | 1.85 ± 1.03 | 1.23 ± 0.37 | 0.010* |
| Left-side eye open | 2.01 ± 1.02 | 1.49 ± 0.74 | 0.040* |
| Right-side eye closed | 3.69 ± 2.08 | 3.07 ± 1.03 | 0.207 |
| Left-side eye closed | 3.80 ± 2.03 | 3.60 ± 2.14 | 0.747 |
| Reaction time, s | | | |
| Forward | 1.47 ± 0.45 | 1.05 ± 1.19 | 0.101 |
| Backward | 1.40 ± 1.59 | 0.71 ± 0.39 | 0.043* |
| Right | 1.41 ± 0.46 | 1.08 ± 0.78 | 0.074 |
| Left | 1.19 ± 0.61 | 0.60 ± 0.45 | < 0.001* |
| Movement velocity, °/s | | | |
| Forward | 2.07 ± 0.85 | 2.44 ± 1.08 | 0.168 |
| Backward | 2.05 ± 0.85 | 2.44 ± 0.93 | 0.136 |
| Right | 3.54 ± 1.66 | 3.70 ± 1.38 | 0.718 |
| Left | 3.20 ± 1.34 | 3.40 ± 1.18 | 0.580 |
| Endpoint excursion, % | | | |
| Forward | 37.92 ± 18.8 | 46.52 ± 23.34 | 0.160 |
| Backward | 43.62 ± 21.61 | 59.57 ± 23.67 | 0.010* |
| Right | 59.51 ± 20.23 | 62.85 ± 16.40 | 0.536 |
| Left | 56.11 ± 19.54 | 67.14 ± 18.80 | 0.051 |
| Maximum excursion, % | | | |
| Forward | 49.70 ± 21.79 | 64.00 ± 19.00 | 0.020* |
| Backward | 58.74 ± 27.00 | 76.95 ± 23.65 | 0.010* |
| Right | 77.77 ± 21.79 | 82.14 ± 16.54 | 0.443 |
| Left | 72.81 ± 20.14 | 76.95 ± 17.23 | 0.450 |
| Directional control, % | | | |
| Forward | 60.03 ± 21.05 | 76.19 ± 12.97 | 0.003* |
| Backward | 49.73 ± 24.27 | 60.42 ± 20.31 | 0.106 |
| Right | 63.03 ± 14.93 | 74.09 ± 13.58 | 0.010* |
| Left | 65.76 ± 14.90 | 71.75 ± 11.24 | 0.120 |

HF, heart failure. Data were expressed as mean ± SD. * Statistically significant difference ($p < 0.05$).

## Discussion

Based on our knowledge, this is the first study investigating static, dynamic and functional balance in patients with HF compared with healthy controls. The novel findings of this study have indicated that static, dynamic and functional balance was impaired in patients with HF compared with healthy controls. In addition, fall history was significantly higher in patients with HF.

Performing daily living activities relies on the successful maintenance of balance or postural control. Static balance is defined as the body's ability to maintain the center of gravity within the base of support for one stable position.[26] In our study, static balance was assessed with US which is known to be an important predictor of injurious falls in elderly individuals.[27] This study showed that there was a significant difference in postural sway with eyes open but no significant difference in postural sway with eyes closed. The increased postural sway with eyes open may result from decreased peripheral muscle strength observed in our patients.[28] Also, increase in postural sway in both groups when eyes are closed can be explained by eliminating visual input and giving more weight to somatosensory and vestibular systems.[29]

Dynamic balance is defined as maintaining the center of gravity within the base of support during movements such as walking or functional reach.[26] In our study dynamic balance was assessed with LOS test that gives information with regard to RT, MV, EXE, m-EXE and DC. Our study demonstrated that RT to backward and left directions has increased in patients with HF. The RT increases with aging and task difficulty.[30] An imaging study in patients with HF has reported structural alterations in brain regions including limbic, basal ganglia, thalamus, frontal, and cerebellum, in which some of those are important areas for maintaining motor control and balance.[31] Although in our study, there was no significant age difference and performed tasks were the same between the patients with HF and healthy controls, the increased RT in patients with HF may be due to these structural alterations of brain regions. In addition, EXE to the backward direction, m-EXE to the forward and backward directions, DC to the forward and right directions was decreased in patients with HF. These findings suggest that patients with HF had impaired dynamic balance on the predominantly forward and backward directions. Based on the previous study, balance impairment in the forward and backward directions may be attributed to inadequate torque at the ankle.[32] Another possible explanation for inability to shift the body in patients with HF is peripheral muscle weakness or disruption of perceived distance.[14]

The hypoxic-ischemic process in HF is presumably linked with impaired axonal integrity and myelin breakdown, as well as gray matter damage and those axonal and myelin alterations occur many brain regions especially related to motor control.[33] Cerebellar tissue damage in HF is reported predominantly in the vermis, which responsible for motor and tonus regulation contributed to balance control.[31] The balance impairments in HF observed in our study support the reflection of all these global and regional brain changes to physical function.

Berg Balance Scale (BBS) is proposed as one of two tests for core balance outcome set by the expert consensus.[34] In our study, the mean BBS score in patients with HF was consistent with the previous study conducting by using BBS to measure balance change after intervention in patients with HF.[35]

In this study, the presence of fall during the last year was higher in patients with HF than healthy controls. Falls in patients with HF may be affected by many factors such as ejection fraction, functional exercise capacity and balance.

There are some limitations to consider when interpreting the results of this study. First, because of the cross-sectional design of this study, the causality of these results cannot be explained. Second, most of our patients had higher functional class including NYHA class I and II, which may reduce the generalizability of our results to all HF patients. Therefore, research is warranted to investigate balance in patients with HF with reduced and preserved ejection fraction including different NYHA classes. Lastly, although the sample size of this study was sufficient to determine differences between patients with HF and healthy controls in most balance variables, further larger studies need to clarify the causality between balance and related factors in HF. Moreover, as many systems contributed to balance, each of these systems should be investigated to explain the underlying mechanism of balance impairment in HF.

This study provided insight into the impairments in balance performance. In this direction, we think that balance assessment, treatment and fall prevention strategies should be the main focus of fall preventive approaches and rehabilitation programs for patients with HF. Therefore, the assessment of patients with HF should also comprise static, dynamic and functional balance. Moreover, there is a clear need for future research on the effects of well-structured balance training protocols as a part of the cardiac rehabilitation program on balance performance and fall risk in patients with HF. Also, innovative interventions such as video-gaming based exercise (exergaming) combined with well-structured balance training protocols may provide supplementary benefits in this population.

## Conclusion

This study demonstrates that compared with healthy controls, patients with HF have impaired static, dynamic and functional balance. In the light of these findings, considering the balance impairment, a comprehensive balance assessment performed, and balance training should be included in the management of HF as a part of cardiac rehabilitation program.


## Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.


## Ethical approval

Ethical approval was obtained from the Dokuz Eylül University Institutional Non-invasive Research Ethics Board (No:2019/13-27 Date:22.05.2019) in according to the Declaration of Helsinki. Written informed consent was obtained from all individual participants included in the study.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.


## Acknowledgments

None.


## References


1. Yancy CW, Jessup M, Bozkurt B, et al. ACCF/AHA guideline for the management of heart failure: executive summary: a report of the American College of Cardiology Foundation/American Heart Association Task Force on practice guidelines. *Circulation*. 2013;128(16):1810–1852. https://doi.org/10.1161/CIR.0b013e31829e8807.
2. Ponikowski P, Voors AA, Anker SD, et al. ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure: the task force for the diagnosis and treatment of acute and chronic heart failure of the European Society of Cardiology (ESC). Developed with the special contribution of the Heart Failure Association (HFA) of the ESC. *Eur Heart J*. 2016;18(8):891–975. https://doi.org/10.1093/eurheartj/ehw128.

3. McCoy J, Bates M, Eggett C, et al. Pathophysiology of exercise intolerance in chronic diseases: the role of diminished cardiac performance in mitochondrial and heart failure patients. *Open Heart*. 2017;4:(2) e000632. https://doi.org/10.1136/openhrt-2017-000632.
4. Georgiadou P, Adamopoulos S. Skeletal muscle abnormalities in chronic heart failure. *Curr Heart Fail Rep*. 2012;9(2):128–132. https://doi.org/10.1007/s11897-012-0090-z.
5. Lee K, Davis MA, Marcotte JE, et al. Falls in community-dwelling older adults with heart failure: a retrospective cohort study. *Heart Lung*. 2020. https://doi.org/10.1016/j.hrtlng.2019.12.005. S0147-9563(19)30559-X.
6. Van Dieen JH, Pijnappels M. Falls in older people. *J Electromyogr Kinesiol*. 2008;18. https://doi.org/10.1016/j.jelekin.2007.06.001.
7. Tromp A, Pluijm S, Smit J, Deeg D, Bouter L, Lips P. Fall-risk screening test: a prospective study on predictors for falls in community-dwelling elderly. *J Clin Epidemiol*. 2001;54(8):837–844. https://doi.org/10.1016/s0895-4356(01)00349-3.
8. Lee PG, Cigolle C, Blaum C. The co−occurrence of chronic diseases and geriatric syndromes: the health and retirement study. *J Am Geriatr Soc*. 2009;57(3):511–516. https://doi.org/10.1111/j.1532-5415.2008.02150.x.
9. Lee K, Pressler SJ, Titler M. Falls in patients with heart failure: a systematic review. *J Cardiovasc Nurs*. 2016;31(6):555–561. https://doi.org/10.1097/JCN.0000000000000292.
10. Rubenstein LZ, Josephson KR. Falls and their prevention in elderly people: what does the evidence show? *Med Clin*. 2006;90(5):807–824. https://doi.org/10.1016/j.mcna.2006.05.013.
11. Horak FB. Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? *Age Ageing*. 2006;35(suppl_2):ii7–ii11. https://doi.org/10.1093/ageing/afl077.
12. O'Loughlin JL, Robitaille Y, Boivin JF, Suissa S. Incidence of and risk factors for falls and injurious falls among the community-dwelling elderly. *Am J Epidemiol*. 1993;137(3):342–354. 1doi: 10.1093/oxfordjournals.aje.a116681.
13. Beauchamp MK, Sibley KM, Lakhani B, et al. Impairments in systems underlying control of balance in COPD. *Chest*. 2012;141(6):1496–1503. https://doi.org/10.1378/chest.11-1708.
14. Kahraman BO, Ozsoy I, Savci S, et al. Static and Dynamic balance performance and balance confidence in individuals with and without pulmonary arterial hypertension. *J Cardiopulm Rehabil Prev*. 2018;38(4):259–263. https://doi.org/10.1097/HCR.0000000000000299.
15. Beauchamp MK, Janaudis-Ferreira T, Parreira V, et al. A randomized controlled trial of balance training during pulmonary rehabilitation for individuals with COPD. *Chest*. 2013;144(6):1803–1810. https://doi.org/10.1378/chest.13-1093.
16. Bennett JA, Riegel B, Bittner V, Nichols J. Validity and reliability of the NYHA classes for measuring research outcomes in patients with cardiac disease. *Heart Lung*. 2002;31(4):262–270. https://doi.org/10.1067/mhl.2002.124554.
17. Clark S, Rose DJ, Fujimoto K. Generalizability of the limits of stability test in the evaluation of dynamic balance among older adults. *Arch Phys Med Rehabil*. 1997;78(10):1078–1084. https://doi.org/10.1016/s0003-9993(97)90131-3.
18. Liston RA, Brauwer BJ. Realibility and validity of measures obtained from stroke patients using the Balance Master. *Arch Phys Med Rehabil*. 1996;77:425–430.
19. Weirich G, Bemben DA, Bemben MG. Predictors of balance in young, middle-aged, and late middle-aged women. *J Geriatr Phys Ther*. 2010;33(3):110–117. https://doi.org/10.1097/JPT.0b013e3181eda25b.
20. Geldhof E, Cardon G, De Bourdeaudhuij I, et al. Static and dynamic standing balance: test-retest reliability and reference values in 9 to 10 year old children. *Eur J Pediatr*. 2006;165(11):779–786. 10.1007/s00431-006-0173.5.
21. Sahin F, Yilmaz F, Ozmaden A, Kotevoglu N, Sahin T, Kuran B. Reliability and validity of the Turkish version of the Berg Balance Scale. *J Geriatr Phys Ther*. 2008;31(1):32–37.
22. Arnold CM, Warkentin KD, Chilibeck PD, Magnus CR. The reliability and validity of handheld dynamometry for the measurement of lower extremity muscle strength in older adults. *J Strength Cond Res*. 2010;24(3):815–824. https://doi.org/10.1519/JSC.0b013e3181aa36b8. Mar.
23. Uszko-Lencer NHMK, Mesquita R, Janssen E, et al. Reliability, construct validity and determinants of 6-minute walk test performance in patients with chronic heart failure. *Int J Cardiol*. 2017;240:285–290. https://doi.org/10.1016/j.ijcard.2017.02.109. Aug 1.
24. ATS. Committee on proficiency standards for clinical pulmonary function laboratories, ATS statement: guidelines for the six-minute walk test. *Am J Respir Crit Care Med*. 2002;166:111–117. https://doi.org/10.1164/ajrccm.166.1.at1102.
25. Enright PL, Sherrill DL. Reference equations for the six-minute walk in healthy adults. *Am J Respir Crit Care Med*. 1998;158(5):1384–1387. https://doi.org/10.1164/ajrccm.158.5.9710086.
26. Davlin CD. Dynamic balance in high level athletes. *Percept Motor Skill*. 2004;98(3_suppl):1171–1176. https://doi.org/10.2466/pms.98.3c.1171-1176.
27. Vellas BJ, Wayne SJ, Romero L, Baumgartner RN, Rubenstein LZ, Garry PJ. One−leg balance is an important predictor of injurious falls in older persons. *J Am Geriatr Soc*. 1997;45(6):735–738. https://doi.org/10.1111/j.1532-5415.1997.tb01479.x.
28. Orr R. Contribution of muscle weakness to postural instability in the elderly. A systematic review. *Eur J Phys Rehabil Med*. 2010;46(2):183–220.
29. Horak FB, Shupert CL, Mirka A. Components of postural dyscontrol in the elderly: a review. *Neurobiol Aging*. 1989;10(6):727–738. https://doi.org/10.1016/0197-4580(89)90010-9.
30. Fozard JL, Vercruyssen M, Reynolds SL, Hancock P, Quilter RE. Age differences and changes in reaction time: the Baltimore longitudinal study of aging. *J Gerontol*. 1994;49(4):P179–P189. https://doi.org/10.1093/geronj/49.4.p179.
31. Woo MA, Palomares JA, Macey PM, Fonarow GC, Harper RM, Kumar R. Global and regional brain mean diffusivity changes in patients with heart failure. *J Neurosci Res*. 2015;93(4):678–685. https://doi.org/10.1002/jnr.23525.
32. Winter DA, Prince F, Stergiou P, Powell C. Medial-lateral and anterior-posterior motor responses associated with centre of pressure changes in quiet standing. *Neurosci Res Commun*. 1993;12:141–148.
33. Kumar R, Woo MA, Macey PM, Fonarow GC, Hamilton MA, Harper RM. Brain axonal and myelin evaluation in heart failure. *J Neurol Sci*. 2011;307(1−2):106–113. https://doi.org/10.1016/j.jns.2011.04.028.
34. Sibley KM, Howe T, Lamb SE, et al. Recommendations for a core outcome set for measuring standing balance in adult populations: a consensus-based approach. *PLoS One*. 2015;10:(3) e0120568. https://doi.org/10.1371/journal.pone.0120568.
35. Bosnak-Guclu M, Arikan H, Savci S, et al. Effects of inspiratory muscle training in patients with heart failure. *Respir Med*. 2011;105(11):1671–1681. https://doi.org/10.1016/j.rmed.2011.05.001.