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Featured Article

# Balance performance measured by posturography in mild-moderate Alzheimer's Disease: An undervalued assessment

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ABSTRACT

*Purpose:* The aim of the study was to compare balance performance in mild-moderate stage Alzheimer's disease (AD) patients and healthy peers using clinical balance tests and computerized posturography.
*Methods:* We recruited 95 patients and divided them into two groups; 51 patients (62 % (n=32) female) in AD group and 44 patients in healthy controls group (50 % (n=22) female). Berg Balance Scale (BBS) and Timed Up & Go (TUG) test were performed. Computerized posturography was performed.
*Results:* The mean age was 77.2±5.5 years in the AD group and 73.8±4.4 years in the control group ($p<0.001$). Sensory organization test composite equilibrium score (60[30-81], $p<0.001$), step quick turn-sway velocity (69.2 [38.2-95.8], $p<0.001$) and step quick turn-time (3.8 [1.6-8.4], $p<0.001$) were significantly impaired in mild-moderate stage AD patients. Berg Balance Scale (50 [32-56], $p<0.001$) and TUG test (13.0 [7.0-25.7], $p<0.001$) results were worse in AD.
*Conclusions:* Computerized posturography measures were impaired in mild-moderate AD patients. The results highlight importance of early screening for balance and fall risk in AD patients. The study provides multi-dimensional and holistic assessment of balance performance in early-stage AD patients. Alzheimer's disease patients at earlier stages are prone to fall risk and should be evaluated accordingly.
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## Introduction

Alzheimer's disease (AD), the most common type of dementia, presents with an insidious onset and progressive deterioration of memory.[1] Since the age of population all over the world is increasing, the prevalence of AD is also increasing. In US, 11.3 % of people aged 65 years and over has AD by 2021.[2] In the future, clinicians and other healthcare professionals will engage in management of AD patients more often than now. As the disease progresses, impairments in other cognitive functions such as executive function, visuospatial ability, language, problem solving, and judgement are seen more commonly. These impairments affect activities of daily living and result in dependence. In advanced stages, behavioral changes, impaired mobility, hallucinations and seizures may be seen.[1] Independence is essential to fulfill activities in daily life and frequently based on good balance control.[3]

Falls are mostly seen in older people and may cause an increase in morbidity and mortality.[4] Each year, approximately 28-42% of people aged 65 years and older experience a fall and the prevalence increase with age.[5] Older people with dementia are more prone to falls and have higher adverse outcomes than their healthy peers. In one study including community sample of mild to moderate AD patients, 42% of the participants have experienced a fall in one year.[6]

Balance and cognitive impairments are major risk factors for falls in older people.[7,8] Balance is a complex issue resulting from interaction between cognition, motor, and sensory systems.[9,10] In the previous studies, it was shown that AD patients have worse balance performance than healthy controls.[11,12] Balance impairment becomes more common with advanced stages of AD.[13]

In the literature, there is growing data showing balance dysfunction in AD patients. Most of these studies evaluated the balance with clinical tests such as Berg Balance Scale (BBS), Timed Up & Go (TUG) test and single leg stance. However, balance which is a multidimensional

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complex issue has been evaluated by a single test or two tests in these studies.[11,14,15] More complex and comprehensive assessment of balance in these patients can give us more precise evidence regarding this relationship. Laboratory measurements called as computerized posturography use transducers to measure postural sway and weight transfer evaluate balance control in various conditions. There are a few studies using laboratory measurements for balance assessment. These studies demonstrated that balance dysfunction may be seen in early stages of cognitive dysfunction.[12,16] However, although these studies included older patients, researchers did not apply comprehensive geriatric assessment (CGA) to participants. Comprehensive geriatric assessment is a multi-dimensional context which describes general health condition of older patient including mental, psychological, physical, and nutritional status. It provides a holistic perspective to clinicians in managing the problems of older patients.[17] Comprehensive geriatric assessment gives an idea about balance performance to clinicians.

The main study aim was to investigate balance performance with clinical and laboratory measurements using both clinical assessment scales and more comprehensive posturography measurements in patients with early-stage AD and to compare these results with cognitively intact patients. We hypothesized that both of the clinical and laboratory balance assessments were impaired in early stage AD patients.

## Methods

### *Study design and population*

Participants of this case-control study were recruited from a geriatric medicine outpatient clinic of a university hospital. The study was approved by ethical committee (Project number: GO 17/150, Date: 07.02.2017). An informed consent was obtained from all participants (patients and their guardians). Patients with AD who were diagnosed by a geriatrician according to diagnostic and statistical manual of mental disorders 5 (DSM-5) criteria for dementia were included in the study if they had independent mobility. The exclusion criteria were having an orthopedic (recent surgery or severe arthritis of lower limb) or a neurologic (Parkinson's disease, stroke etc.) disease causing immobilization.

Serum 25-OH vitamin D3 and vitamin B12 levels of participants were obtained from medical records in the last month, as they interfere with gait and balance. Falls in the previous year were asked to patients or their caregivers and recorded.

### *Comprehensive geriatric assessment*

All patients admitted to the geriatric medicine outpatient clinic undergo CGA by a geriatrician. The comprehensive geriatric assessment includes an assessment of cognitive, functional, nutritional, and emotional states. The Mini-Mental State Examination (MMSE) scale for the screening of cognitive function, Mini-Nutritional Assessment Short Form (MNA-SF) for the screening of nutritional status, Katz Basic Activities of Daily Living Scale (BADLs) and Lawton Brody Instrumental Activities of Daily Living Scale (IADLs) for the screening of functional status, and Yesavage Geriatric Depression Scale (Yesevage GDS) for the screening of depression were performed within this framework.[18-26] All screening tests are based on question-answer method and easily applicable in the outpatient setting.

Cognitive assessment was conducted through clinical assessment and screening tests. Patients had to meet the DSM-5 criteria for a dementia diagnosis. After the diagnosis of AD, the Global Deterioration Scale (GDS) was applied,[27] and patients at Stage 4 and 5 according to the GDS were included in the study.

### *Clinical balance tests*

Berg Balance Scale was used for assessment of balance and fall risk. It contains 14-items including static and dynamic activities. Each item score ranges from 0-4, maximum score is 56 points. Higher scores demonstrate good balance performance.[28,29]

Timed Up & Go test is used to determine fall risk of older patients. The patient seated on a chair, stands up with command, walks three meters and turns back, walks to the chair, and sits down. The time starts from therapist's command to stand up. If the time lasts 13.5 seconds or longer, patient is accepted as high fall risk category.[30]

### *Grip strength*

Low grip strength is associated with adverse outcomes such as functional limitations, increased length of hospital stays, poor quality of life, and death.[31] In this study, grip strength is measured with a manual Takei handgrip dynamometer (Takei model 5101 TKK, digital, non-static handle, Japan) with the elbow flexed at 90° and the forearm at neutral position. Results lower than 16 kg in females and 27 kg in males are accepted as low handgrip strength.[32]

### *Laboratory balance tests: Computerized posturography*

Laboratory balance assessments were performed using computerized posturography. We conducted the Sensory Organization Test (SOT), Sit-to-Stand, Walk Across, Tandem Walk, and Step Quick Turn tests. The Smart Balance Master System was utilized for the SOT, while the Balance Master System (Neuro-Com International Inc., Clackamas, OR) with a short force platform was used for the sit-to-stand, walk across, tandem walk, and step quick turn tests. Individual who is tested stands on a force plate which is connected to a computer system and does test instructions such as walking, sitting, and standing, two steps forward and turning right or left, etc. The computer measures body sway, velocity and time needed for the activity, etc. Each test was repeated 3 times. Mean of three results was calculated and used in analysis. To prevent any tiredness, the tests were applied in two separate days. Laboratory balance tests are based on computerized measurements. They are more objective and sensitive than clinical balance tests which are based on subjective assessment.[33]

### *Computerized dynamic posturography-sensory organization test*

The computerized dynamic posturography-sensory organization test (CDP-SOT) evaluates balance performance by incorporating inputs from the visual, vestibular, and somatosensory systems. The test was conducted using the Smart Balance Master System, which consists of a pressure-monitored force platform and a dynamic visual surround. The force platform detects body sway based on the participant's center of mass displacement. Participants were barefoot and wore a harness on the 46 × 46 cm-sized force platform. The test was administered with an appropriate step width based on participants' height while in a standing position.

The computerized dynamic posturography-sensory organization test consists of six different conditions. The force plate remains fixed in the first three conditions. In the first condition, participants have their eyes open and experience a normal visual environment. The second condition involves participants closing their eyes. The third condition presents participants with an open-eyed visual environment that sways. The force plate becomes unstable in the last three conditions. In the fourth condition, participants have their eyes open with a normal visual environment. The fifth condition involves participants closing their eyes while maintaining a normal visual environment. In the sixth condition, participants have their eyes open

with a swaying visual environment. The objective is to maintain balance in each condition.

The equilibrium score reflects the subject's stability, with a score of 100 indicating no sway. Scores closer to 0 indicate higher levels of sway, while a score of 0 suggests a fall. The composite score is the mean of all equilibrium scores from the six conditions. Scores below 38 are associated with an increased risk of falls.

The sensory analysis component of CDP-SOT includes SOM (Somatosensory), which evaluates sway in the absence of visual input (when eyes are closed); VIS (Visual), which assesses sway in the presence of incorrect somatosensory input; VEST (Vestibular), which evaluates sway in the absence of visual input and the presence of incorrect somatosensory input; and PREF (Preferential), which examines sway in the absence of visual input compared to the presence of incorrect somatosensory input.

In the result graphic, green-colored columns represent normal results, while red-colored columns indicate pathologic findings.[34,35,36]

*Balance master system tests*

*Sit to stand test*

This test is used to determine balance ability of patient while standing from a seated surface to the force plate. Patients are instructed to stand up quickly without using their arms or hands and keep standing position for 5 seconds. Key component is shifting the body center of gravity from initial seating position to the standing over the feet position. Weight transfer time, rising index (force consumed to rise) and weight center sway velocity are evaluated via sit to stand test.

*Walk across test*

The test evaluates gait characteristics of patient while walking across the length of the force plate. Step width (the distance between the outer margins of two sequential steps, measured from outer margin of left foot to outer margin of right foot), step length (the distance between two sequential steps, measured from the start point of the left heel to start point of the right heel) and walking speed are measured.

*Tandem walk test*

This test is used to evaluate movement of head, body, and pelvis gravity center when patient walks heel to toe across the length of force plate. Step width, speed, and endpoint sway velocity are evaluated.

*Step quick turn test*

Turn performance is evaluated with this test. The patient takes two steps forward (one step for each leg), turns 180 degrees right or left and comes back to the start point on the force plate. The test is performed for each of the left and right directions. The turn direction with worst performance is used in analysis. Turn time and turn sway are measured in this test.

*Statistical analyses*

SPSS 22.0 version was used for statistical analyses. Descriptive statistics were performed to determine the population profile. Kolmogorov-Smirnov test was used for data distribution. Data in normal distributions were compared with independent samples t test. Nonparametric variables were compared with Mann Whitney U test. Categorical variables were compared with chi-square test. Pearson and Spearman correlation analyses were used for continuous variables, where appropriate. Logistic regression analyses were performed to show independent variables associated with AD. Hosmer-Lemeshow goodness of fit statistics were used to test model fit.

## Results

We recruited 51 patients with AD and 44 healthy controls. Results of comprehensive geriatric assessment, clinical balance tests, grip strength, and laboratory measurements are compared and presented in Table 1. Thirty-seven (72.5 %) of AD patients were at GDS stage 4 and remaining 14 (27.5 %) AD patients were at GDS stage 5. Mean age was 77.2±5.5 in the AD group and 73.8±4.4 in the control group ($p<0.001$). Thirty-two of AD and 22 of healthy controls were female. Seven (13.7%) of 51 AD patients and 7 (15.9 %) of 44 healthy controls were living alone, remaining participants were living with spouse, a

**Table 1**
Comparison of general characteristics and laboratory results between groups

| Parameters | Patients (n=51) | | Controls (n=44) | P value |
|---|---|---|---|---|
| Age (years) | 77.2±5.5 | | 73.8±4.4 | <0.001 |
| Sex | Female | 32 (62.7 %) | 22 (50 %) | 0.20 |
| | Male | 19 (37.3 %) | 22 (50 %) | |
| MMSE | 20 (0-30) | | 29 (19-30) | <0.001 |
| Katz ADLs | 6 (1-6) | | 6 (5-6) | <0.001 |
| Lawton-Brody IADLs | 5 (0-8) | | 8 (7-8) | <0.001 |
| Yesevage GDS | 3 (0-10) | | 5 (0-8) | 0.050 |
| MNA-SF | 12 (6-13) | | 14 (12-14) | <0.001 |
| Berg Balance Scale | 50 (32-56) | | 55 (45-56) | <0.001 |
| Timed Up & Go Test (seconds) | 13.0 (7.0-25.7) | | 7.2 (4.0-20.0) | <0.001 |
| Serum hemoglobin levels (g/dl) | 13.2±1.5 | | 13.7±1.6 | 0.070 |
| Serum calcium levels (mg/dl) | 9.6 (8.5-9.8) | | 9.3 (8.4-10.4) | 0.070 |
| Serum albumin (g/dl) | 4.2 (3.1-4.8) | | 4.2 (2.67-4.74) | 0.390 |
| Serum Vitamin B12 (pg/ml | 380 (110-1500) | | 269 (147-1209) | 0.100 |
| 25-OH Vitamin D3 (ng/ml) | 19.7 (5.3-84) | | 21 (5-43.4) | 0.840 |
| Handgrip strength (kg) | Female | 16.4±3.2 | 20±3.9 | <0.001 |
| | Male | 26.3±6.2 | 31.4±7.3 | 0.020 |
| Number of Drugs | 5 (0-15) | | 4 (0-14) | 0.100 |
| Falls | 17 (33.3 %) | | 2 (4.7 %) | <0.001 |
| Diabetes Mellitus | 19 (37.3 %) | | 12 (27.9 %) | 0.33 |
| Hypertension | 34 (66.7 %) | | 27 (62.8 %) | 0.69 |
| Coronary Artery Disease | 8 (15.7 %) | | 13 (30.2 %) | 0.092 |

*The results were presented as mean±standard deviation or median (minimum-maximum). MMSE: Mini Mental State Examination, KATZ ADLs: KATZ Activities of Daily Living, Lawton-brody IADLs: Lawton-Brody Intermediate Activities of Daily Living, Yesevage GDS: Yesevage Geriatric Depression Scale, MNA-SF: Mini Nutritional Assessment-Short Form

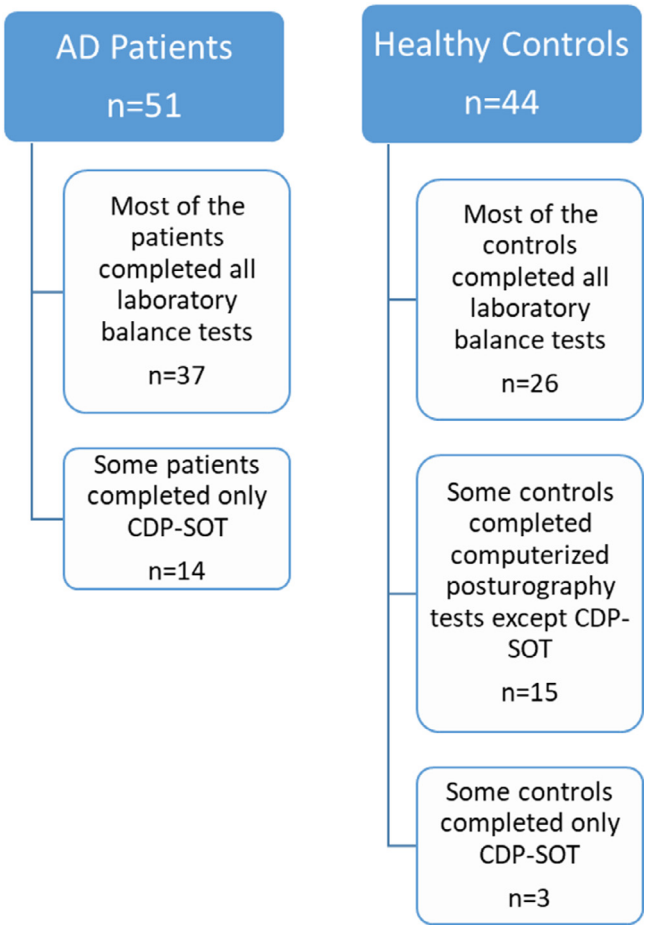



**Figure 1.** How many patients were able to complete each balance test?

family member, or a caregiver (p=0.76). Twenty-two (43.2%) of 51 AD patients and 4 (9.1 %) of 44 healthy controls did not attend any school, remaining 29 (56.8 %) of AD patients and 40 (90.9 %) of healthy controls attended to school for at least 5 years (p=0.01) (Fig. 1).

Depression rate was higher in AD group than in controls (41.2 % vs. 18.6 %, respectively) (p=0.018). Sex, all other comorbid diseases, and laboratory parameters were similar between groups. Berg Balance Scale (p<0.001), TUG (p<0.001) and handgrip strength (p<0.001 for female, p=0.02 for male) were significantly impaired in the AD group.

Computerized posturography results are shown in Table 2 and Table 3, respectively. Walk across speed (p<0.001), walk across step length (p<0.001), sit to stand rising index (p=0.02), tandem walk speed (p<0.001), step quick turn-turn sway velocity (p<0.001), and step quick turn-turn time (p<0.001) were impaired in the AD group (Table 2). Results of sensory organization test were significantly impaired in the AD group (Table 3).

Most of the posturography parameters were significantly correlated with comprehensive geriatric assessment tests except for Yesevage GDS, showing the impact of functionality, nutrition, and cognition on balance performance (Table 4).

Logistic regression analyses were performed putting the significant parameters, age, sex, and posturography parameters into equation to find the independent factors associated with AD (Table 5). Three different models were analyzed. Age, sex, walk across width, walk across speed, sit to stand rising index, sit to stand sway velocity, step quick turn-turn time, and tandem speed were put into equation in Model 1. Step quick turn-turn time (OR=4.7, 95%CI=2.3-9.8, p<0.001) and sit to stand sway velocity (OR=2.2, 95%CI=1.22-4.17, p=0.009) were significantly related with AD, independent from other parameters. Age, sex, SOT composite score, SOM, VIS, VEST, and PREF were put into equation in Model 2. SOT composite score (OR=0.9, 95%CI=0.88-0.97, p=0.0010) was independently related with AD, independent from other parameters. Finally, we have created Model 3 by putting age, MNA-SF vitamin B12 levels, BBS, TUG, and handgrip strength into equation. There was no significant relationship between the parameters and AD in Model 3. Results of the regression analyses are given in Table 5.

## Discussion

The findings of this study indicate that patients with AD experience frequent falls, exhibit lower handgrip strength, perform worse in BBS and TUG, and have significantly impaired parameters in computerized posturography. These results highlight the presence of significant gait and balance impairments in patients with mild to moderate stage AD, leading to mobility issues and an increased risk of falls.

The study results showed that balance was impaired in mild-moderate stages of AD. Composite equilibrium score and other scores from six different conditions showed a decline in AD patients. Although composite equilibrium score was not below 38 points which is the cutoff for increased fall risk, it was significantly decreased in AD. According to sensory analysis results, the balance of AD patients was more prone to impairment with unstable force plate and incorrect inputs than healthy controls. In previous studies, it was demonstrated that balance was impaired in mild moderate AD patients. Some studies showed that in the absence of visual input,

**Table 2**
Comparisons of Posturography Results Between Groups

| Posturography Parameters | Patient (n=37) | Control (n=41) | P value |
|---|---|---|---|
| Walk across step width (cm) | 19.4±3.6 | 17.8±4.2 | 0.080 |
| Walk across Speed (cm/sec) | 48.7±20.9 | 63.5±19.8 | <0.001 |
| Walk across Step length (cm) | 39.5 (17.7-87) | 45.3 (25.2-104.4) | <0.001 |
| Sit to stand COG-Sway velocity (°/sec) | 3.7±1 | 3.3±1 | 0.13 |
| Sit to stand Weight transfer time (sec) | 0.43 (0.23-2.2) | 0.43 (0.18-1.6) | 0.46 |
| Sit to stand Rising index (% body weight) | 10.6 (4.3-35) | 16.3 (3-36.6) | 0.020 |
| Tandem walk Step width (cm) | 11.3 (0-30) | 10.6 (7.7-20.5) | 0.91 |
| Tandem Walk Speed (cm/sec) | 12.9 (0.34) | 16.9 (5.8-32.8) | <0.001 |
| Tandem walk End sway (°/sec) | 7.2 (0-24.9) | 6.5 (3.3-13.8) | 0.79 |
| Step quick turn Turn sway velocity (%) | 69.2 (38.2-95.8) | 51.8 (31.9-146.8) | <0.001 |
| Step quick turn Turn time (sec) | 3.8 (1.6-8.4) | 2.4 (1.3-6.2) | <0.001 |

*The data were presented as mean±standard deviation or median (minimum-maximum). COG: Center of Gravity

**Table 3**
Comparison of Computerized Dynamic Posturography Results Between Groups

| Dynamic posturography measures | Patients with Alzheimer's Disease (n=51) | Healthy controls (n=29) | P value |
|---|---|---|---|
| SOT composite score | 60 (30-81) | 72 (48-88) | <0.001 |
| SOT1 (Condition 1) | 92.0 (76.6-96.0) | 93.3 (88.0-95.6) | <0.001 |
| SOT2 (Condition 2) | 90.0 (46.3-95.6) | 91.6 (72.0-95.6) | 0.020 |
| SOT3 (Condition 3) | 86.6 (41.3-94) | 89.6 (79.0-93.6) | 0.010 |
| SOT4 (Condition 4) | 63 (0-85) | 72 (43-91) | <0.001 |
| SOT5 (Condition 5) | 51.3 (0-76) | 61.6 (0.0-85.6) | 0.010 |
| SOT6 (Condition 6) | 43.3 (0-76.3) | 58.3 (0.0-86.3) | 0.020 |
| SOM | 2.0 % (1) | 6.9 % (2) | <0.001 |
| VIS | 64.7 % (33) | 55.1 % (16) | <0.001 |
| VEST | 47.1 % (24) | 31.0 % (9) | <0.001 |
| PREF | 19.6 % (10) | 6.9 % (2) | <0.001 |

*The data were presented as median (minimum-maximum) and percent (number). SOT: Sensory Organization Test, Condition 1: Stable forceplate, eyes are open, visual environment is normal, Condition 2: Stable forceplate, eyes are closed, visual environment is normal, Condition 3: Stable forceplate, eyes are open, visual environment is swaying, Condition 4: Unstable forceplate, eyes are open, visual environment is normal, Condition 5: Unstable forceplate, eyes are closed, visual environment is normal, Condition 6: Unstable forceplate, eyes are open, visual environment is swaying. SOM: The increased sway in the absence of visual input. VIS: The increased sway in the presence of incorrect somatosensory input. VEST: The increased sway in the absence of visual input and presence of incorrect somatosensory input. PREF: The increased sway in the absence of visual input compared with presence of incorrect visual input.

balance was more impaired in patients with AD.[12,37] However, in one study, postural stability was increased in AD patients in the absence of visual input.[38] Another study showed that postural stability was decreased in mild stage AD patients while increased in moderate stage AD patients.[39] In this present study, postural stability was increased in AD patients in the removal of visual input. This may be a result of pathologic changes in primary visual cortex in AD.[40] Chong et al discussed this finding as removal of visual input may ease the sensory processing load for the AD patients.[38] Further studies are needed to clarify this point.

There were a few studies demonstrating impaired balance which means postural instability during dynamic tasks in mild-moderate stage AD patients. These studies evaluated only balance with some tests such as functional reach, step test, TUG, and posturography measures.[12,37,38] In this present study, in addition to balance tests; functional, emotional, and nutritional status of participants were also evaluated. In other words, CGA was applied to all participants. This is the highlight of our study. Most of computerized posturography tests were significantly impaired in AD patients in our study. Furthermore, most of these tests were correlated with CGA tests except for Yesevage GDS. This shows that balance performance is in relation with cognition, nutrition, and functionality. Although Yesevage GDS score was not correlated with posturography results, its score is not diagnostic in dementia patients. Yesevage GDS is based on patients' thoughts, and it is performed as question-answer style. Alzheimer's disease patients may not answer these questions correctly, and it is known that Yesevage GDS can be misleading in dementia patients. Therefore, clinical assessment is more important in depression analyses of dementia patients. Demonstrating these nutritional and functional relationships of balance performance tests is a differentiating aspect of our study.

Within posturography tests, sit to stand sway velocity and step turn time were significant and independently affected in AD. In the walk across test, speed was decreased, and step length was shortened in mild-moderate stage AD patients. Alzheimer's Disease patients may prefer slow walking and shorter steps to stabilize balance rather than walking with wider steps. This is a parameter which leads to increased risk for falls. Walking speed was also decreased in the tandem walk test of AD patients. The sway velocity and time to turn was increased in patients with mild-moderate stage AD during step quick turn test. These findings were like previous studies[12,41] and may predict postural instability and consequently falls during dynamic tasks.

The Timed Up & Go test and the BBS are clinical balance tests that assess an individual's balance control. Time to complete TUG was significantly increased in patients with mild-moderate AD in our study showing impairment in walking speed. A result of the test time above 13.5 seconds is interpreted as increased risk for falls.[30] While mean test time was 13 seconds in AD patients, it was 7.2 seconds in healthy

**Table 4**
Correlation of Posturography Parameters with Comprehensive Geriatric Assessment Tests

| Posturography Tests | MNA-SF | KATZ ADLs | Lawton-Brody IADLs | Yesevage GDS | MMSE |
|---|---|---|---|---|---|
| SOT composite score | r=0.32 | r=0.31 | r=0.24 | r=-0.04 | r=0.354 |
| | p=0.0030 | p=0.0040 | p=0.029 | p=0.68 | p=0.0010 |
| Tandem speed (cm/sec) | r=0.31 | r=0.34 | r=0.45 | r=-0.22 | r=0.376 |
| | p=0.0050 | p=0.0030 | p<0.001 | p=0.051 | p=0.0010 |
| Walk across width (cm) | r=-0.04 | r=-0.09 | r=-0.13 | r=0.004 | r=-0.133 |
| | p=0.73 | p=0.39 | p=0.23 | p=0.90 | p=0.24 |
| Walk across length (cm) | r=0.27 | r=0.37 | r=0.40 | r=-0.18 | r=0.361 |
| | p=0.014 | p=0.0010 | p<0.001 | p=0.090 | p=0.0010 |
| Walk across speed (cm/sec) | r=0.28 | r=0.42 | r=0.48 | r=-0.12 | r=0.402 |
| | p=0.012 | p<0.001 | p<0.001 | p=0.28 | p<0.001 |
| Sit to stand rising index (% body weight) | r=0.27 | r=0.23 | r=0.35 | r=-0.22 | r=0.325 |
| | p=0.016 | p=0.040 | p=0.0010 | p=0.052 | p=0.0040 |
| Step quick turn Turn time (sec) | r=-0.47 | r=-0.37 | r=-0.46 | r=0.13 | r=-0.525 |
| | p<0.001 | p=0.0010 | p<0.001 | p=0.22 | p<0.001 |
| Step quick turn Turn sway (%) | r=-0.34 | r=-0.11 | r=-0.23 | r=0.06 | r=-0.307 |
| | p=0.0020 | p=0.30 | p=0.035 | p=0.57 | p=0.0060 |

*MNA-SF: Mini Nutritional Assessment short form, ADLs=Acivities of Daily Living, IADLs= Instrumental Activities of Daily Living, GDS=Geriatric Depression Scale

**Table 5**
Independent Factors Associated with Alzheimer's Disease

| Independent Factors | Odds Ratio | Confidence Interval | P value |
|---|---|---|---|
| Step quick turn Turn time (sec) Model 1 * | 4.7 | 2.30-9.83 | <0.001 |
| Sit to stand COG-sway velocity (°/sec) Model 1 * | 2.2 | 1.22-4.17 | 0.009 |
| SOT composite score Model 2 ** | 0.9 | 0.88-0.97 | 0.0010 |

* Model 1: Age, sex, walk across width, walk across length, walk across speed, sit to stand rising index, sit to stand sway velocity, step quick turn-turn time, tandem speed was put into model.

** Model 2: Age, sex, SOT composite score, SOM, VIS, VEST, PREF were put into model.COG: Center of Gravity, SOT: Sensory Organization Test.

controls. Meanwhile, Berg Balance Scale was significantly decreased in AD patients, however, it was in the range of no fall risk.[32] When history of falls was examined, mild-moderate stage AD patients were found to experience significantly more falls than healthy controls.

Grip strength was decreased in both sex of AD patients. Low grip strength is associated with functional limitations. It is also a screening tool for sarcopenia which is a predisposing factor for falls.[42] Number of medications, serum 25-OH vitamin D3, vitamin B12, calcium, hemoglobin, and albumin levels were similar in both groups. Since these parameters may affect balance and fall,[43] similarity of groups in the context of these parameters supplies more accurate evaluation. Furthermore, regression analyses have put forward that the examined balance parameters were affected in AD patients independent from other parameters. This shows that AD patients at earlier stages show increased risk for falls independent from other fall risk factors.

According to the regression analysis results, both the step quick turn - turn time and sit-to-stand - center of gravity sway velocity tests and the composite equilibrium score were found to be affected in AD patients, regardless of age or sex. Regression analyses further showed that age, clinical balance tests, nutritional status, handgrip test, and vitamin B12 levels were not independently related with AD. We can state that balance performance was impaired and independently affected in mild-moderate stage AD patients.

Our study has some limitations. Since the posturography is time consuming and has many instructions which may be difficult to follow, number of both AD patients and healthy controls who could not complete the tests was higher than expected. Therefore, the number of subjects analyzed in the study remains relatively small. These missing subjects created gaps in the comparison of data. We measured grip strength which is a predictor of sarcopenia and functional impairment, but we did not evaluate sarcopenia, a predisposing factor for falls.[44] Defining sarcopenic ones may provide more detailed comparison for balance impairment. Age was not matched between groups; healthy controls were younger than AD patients with a mean age of 73 years vs. 77 years. However, regression analyses showed that the impairment in balance tests was independent from age. Therefore, this is not actually considered as a limitation. Future studies with larger samples may give more clear evidence regarding this issue.

## Conclusions

Computerized posturography measurements were found to be impaired in mild to moderate AD patients. Specifically, walking speed, step length, and turn performance were significantly affected in the early stages of AD. The results of the BBS and TUG test also indicated better performance in healthy controls. A comprehensive geriatric assessment revealed that healthy controls exhibited better functionality and nutritional status. There was a correlation observed between balance performance and the results of the comprehensive geriatric assessment. This study offers a multidimensional and holistic assessment of balance performance in early-stage AD patients, highlighting their increased risk of falls. Clinicians should remain vigilant in evaluating and managing AD patients in relation to fall risk.

## Ethical Approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of XXX Medical School (Project number:GO 17/150, Date: 07.02.2017).

## 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.

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## References

1. Lane CA, Hardy J, Schott JM. Alzheimer's disease. *Eur J Neurol*. 2018 Jan;25(1):59–70. https://doi.org/10.1111/ene.13439.
2. Rajan KB, Weuve J, Barnes LL, et al. Population estimate of people with clinical Alzheimer's disease and mild cognitive impairment in the United States (2020-2060). *Alzheimer's Dement*. 2021:1–10. https://doi.org/10.1002/alz.12362.
3. Webber SC, Porter MM, Menec VH. Mobility in Older Adults: A Comprehensive Framework. *The Gerontologist*. August 2010;50(4):443–450. https://doi.org/10.1093/geront/gnq013.
4. Russell MA, Hill KD, Blackberry I, et al. Falls risk and functional decline in older fallers discharged directly from emergency departments. *J Gerontol*. 2006;61A:1090Y5. https://doi.org/10.1093/gerona/61.10.1090.
5. Sharif SI, Al-Harbi AB, Al-Shihabi AM, et al. Falls in the elderly: assessment of prevalence and risk factors. *Pharmacy Practice*. 2018 Jul-Sep;16(3):1206. https://doi.org/10.18549/PharmPract.2018.03.1206.
6. Horikawa E, Matsui T, Arai H, et al. Risk of falls in Alzheimer's disease: A prospective study. *Intern Med*. 2005;44. https://doi.org/10.2169/internalmedicine.44.717. 717Y21.
7. Muir SW, Gopaul K, Montero Odasso MM. The role of cognitive impairment in fall risk among older adults: a systematic review and meta-analysis. *Age Ageing*. 2012;41:299–308. https://doi.org/10.1093/ageing/afs012.
8. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. *N Engl J Med*. 1988;319:1701–1707. https://doi.org/10.1056/NEJM198812293192604.
9. Woollacott MH, Shumway-Cook A. Changes in posture control across the life span: a systems approach. *Phys Ther*. 1990;70:799–807. https://doi.org/10.1093/ptj/70.12.799.
10. Huxham FE, Goldie PA, Patla AE. Theoretical considerations in balance assessment. *Aust J Physiother*. 2001;47:89–100. https://doi.org/10.1016/s0004-9514(14)60300-7.
11. Pettersson AF, Olsson E, Wahlund LO. Motor function in subjects with mild cognitive impairment and early Alzheimer's disease. *Dement Geriatr Cogn Disord*. 2005;19:299–304. https://doi.org/10.1159/000084555.
12. Suttanon P, Hill KD, Said CM, et al. Balance and mobility dysfunction and falls risk in older people with mild to moderate Alzheimer disease. *Am J Phys Med Rehabil*. 2012 Jan;91(1):12–23. https://doi.org/10.1097/PHM.0b013e31823caeea.
13. Mazoteras Mun~oz V, van Abellan KG, Cantet C, et al. Gait and balance impairments in Alzheimer disease patients. *Alzheimer Dis Assoc Disord*. 2010;24:79–84. https://doi.org/10.1097/WAD.0b013e3181c78a20.
14. Pettersson AF, Engardt M, Wahlund LO. Activity level and balance in subjects with mild Alzheimer's disease. *Dement Geriatr Cogn Disord*. 2002;13. https://doi.org/10.1159/000057699. 213Y6.
15. Rolland Y, van Kan GA, Nourhashemi F, et al. An abnormal 'one-leg balance test' predicts cognitive decline during Alzheimer's disease. *J Alzheimers Dis*. 2009;16. https://doi.org/10.3233/JAD-2009-0987. 525Y31.
16. Tangen GG, Engedal K, Bergland A, et al. Relationships between balance and cognition in patients with subjective cognitive impairment, mild cognitive impairment, and Alzheimer disease. *Phys Ther*. 2014 Aug;94(8):1123–1134. https://doi.org/10.2522/ptj.20130298.
17. Garrard JW, Cox NJ, Dodds RM, et al. Comprehensive geriatric assessment in primary care: a systematic review. *Aging Clin Exp Res*. 2019. https://doi.org/10.1007/s40520-019-01183-w.
18. Folstein MF, Folstein SE, McHugh PR. Mini mental state: a practical method for grading the cognitive state of patients for the clinicians. *J Psychiatr Res*. 1975;12:189–198. https://doi.org/10.1016/0022-3956(75)90026-6.

19. Gungen C, Ertan T, Eker E, et al. Reliability and validity of the standardized Mini Mental State Examination in the diagnosis of mild dementia in Turkish population. *Turk Psikiyatri Derg*. 2002;13:273–281.
20. Kaiser MJ, Bauer JM, Ramsch C, et al. MNA-International Group. Validation of the Mini Nutritional Assessment short-form (MNA-SF): a practical tool for identification of nutritional status. *J Nutr Health Aging*. 2009;13(9):782–788. https://doi.org/10.1007/s12603-009-0214-7.
21. Sarikaya D, Halil M, Kuyumcu ME, et al. Mini nutritional assessment test long and short form are valid screening tools in Turkish older adults. *Arch Gerontol Geriatr*. 2015;61:56–60. https://doi.org/10.1016/j.archger.2015.04.006.
22. Katz S, Ford AB, Moskowitz RW, et al. Studies of illness in the aged. The index of BADL; a standardized measure of biological and psychological functions. *JAMA*. 1963;185:94. https://doi.org/10.1001/jama.1963.03060120024016.
23. Arik G, Varan HD, Yavuz BB, et al. Validation of Katz index of independence in activities of daily living in Turkish older adults. *Archiv Gerontol Geriatrics*. 2015;61:344–350.
24. Lawton MP, Brody EM. Assessment of older people: self-maintaining and instrumental activities of daily living. *Gerontologist*. 1969;9:179–186. https://doi.org/10.1016/j.archger.2015.08.019.
25. Yesavage JA, Sheikh JI. Geriatric depression scale (GDS) recent evidence and development of a shorter version. *Clin Gerontol*. 2008:165–173. https://doi.org/10.1300/J018v05n01_09.
26. Durmaz B, Soysal P, Ellidokuz H, Isik AT. Validity and reliability of geriatric depression scale−15 (Short form) in Turkish older adults. *North Clin Istanb*. 2018;5:216–220. https://doi.org/10.14744/nci.2017.85047.
27. Reisberg B, Ferris SH, de Leon MJ, Crook T. The global deterioration scale for assessment of primary degenerative dementia. *Am J Psychiatry*. 1982 Sep;139(9):1136–1139. https://doi.org/10.1176/ajp.139.9.1136.
28. Berg K, Wood-Dauphinee S, Williams JI, Maki B. Measuring balance in the elderly: validation of an instrument. *Can. J. Pub. Health*. 1992:S7–11. July/August supplement 2.
29. Sahin F, Yilmaz F, Ozmaden A, et al. Reliability and validity of the turkish version of the berg balance scale. *J Geriatr Phys Ther*. 2008;31(1):32–37. https://doi.org/10.1519/00139143-200831010-00006.
30. Shunway-Cook A, Brauer S, Woollacott M. Predicting the probability for falls in community-dwelling older adults using the Timed up & Go Test. *Phys Ther*. 2000;80(9):896–903.
31. Leong DP, Teo KK, Rangarajan S, et al. Prospective Urban Rural Epidemiology (PURE) Study investigators. Prognostic value of grip strength: findings from the Prospective Urban Rural Epidemiology (PURE) study. *Lancet*. 2015;386:266–273. https://doi.org/10.1016/S0140-6736(14)62000-6.
32. Cruz-Jentoft AJ, Bahat G, Bauer J, et al. Sarcopenia: revised European consensus on definition and diagnosis. *Age and Ageing*. 2019;48(1):16–31. https://doi.org/10.1093/ageing/afy169.
33. Visser JE, Carpenter MG, van der Kooij H, Bloem BR. The clinical utility of posturography. *Clin Neurophysiol*. 2008;119(11):2424–2436. https://doi.org/10.1016/j.clinph.2008.07.220. NovEpub 2008 Sep 12. PMID: 18789756.
34. Gribble PA, Hertel J. Considerations for normalizing measures of the star excursion balance test. *Measur Phys Educ Exer Sci*. 2003;7(2):89–100. https://doi.org/10.1207/S15327841MPEE0702_3.
35. Winter DA, Patla AE, Frank JS. Assessment of balance control in humans. *Med Prog Technol*. 1990;16(1-2):31–51.
36. Musat G. Computerized posturography in the diagnosis and treatment of the instability of the elderly. *Romanian J Neurol*. 2013;XII(2). 2013.
37. Leandri M, Cammisuli S, Cammarata S, et al. Balance features in Alzheimer's disease and amnestic mild cognitive impairment. *J Alzheimers*. 2009;16. https://doi.org/10.3233/JAD-2009-0928. Dis113Y2.
38. Chong RK, Horak FB, Frank J, Kaye J. Sensory organization for balance: Specific deficits in Alzheimer's but not in Parkinson's disease. *J Gerontol Ser A: Biol Sci Med Sci*. 1999;54:M122–M128. https://doi.org/10.1093/gerona/54.3.m122.
39. Dickin DC, Rose DJ. Sensory organization abilities during upright stance in late-onset Alzheimer's-type dementia. *Exp Aging Res*. 2004;30(4):373–390. https://doi.org/10.1080/03610730490484416.
40. Cronin-Golomb A, Corkin S, Rizzo JF, et al. Visual dysfunction in Alzheimer's disease: relation to normal aging. *Ann Neurol*. 1991;29(1):41–52. https://doi.org/10.1002/ana.410290110.
41. Muir-Hunter SW, Graham L, Montero Odasso M. Reliability of the berg balance scale as a clinical measure of balance in community-dwelling older adults with mild to moderate alzheimer disease: a pilot study. *Physiother Can. Summer*. 2015;67(3):255–262. https://doi.org/10.3138/ptc.2014-32.
42. Merory JR, Wittwer JE, Rowe CC, Webster KE. Quantitative gait analysis in patients with dementia with Lewy bodies and Alzheimer's disease. *Gait Posture*. 2007;26:414Y9. https://doi.org/10.1016/j.gaitpost.2006.10.006.
43. Akyol AD. Falls in the elderly: what can be done? *Int Nurs Rev*. 2007 Jun;54(2):191–196. https://doi.org/10.1111/j.1466-7657.2007.00505.x. PMID: 17492994.
44. Yeung SY, Reijnierse EM, Pham VK, et al. Sarcopenia and its association with falls and fractures in older adults: a systematic review and meta-analysis. *J Cachexia Sarcopenia Muscle*. 2019 Jun;10(3):485–500. https://doi.org/10.1002/jcsm.12411.