Relationship Between Balance and Abnormalities in Cerebral Magnetic Resonance Imaging in Older Adults

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Background: Falling is a major cause of disability and morbidity among older adults. Because poor balance is a major reason for frequent falls, assessment of balance and its risk factors are important. In this study, we postulated that cerebral changes identified on magnetic resonance (MR) imaging are related to balance, and that older adults with balance problems would have significantly greater prevalence of such brain abnormalities than older adults without balance problems.

Design and Measurements: Several measures of balance were examined in more than 700 community-dwelling older men and women, blacks and whites. Balance measures included dynamic posturography, functional reach, Romberg and 1-foot stand tests, tandem stand, and 1-foot stand. Cerebral MR imaging assessments included ventricular size, sulcal widening, white matter disease, and ischemic infarctions. Cardiovascular disease and hypertension were determined and controlled for in the analyses.

Results: A summary of the balance measures was significantly related to each of the 4 MR imaging measures, with those with poorer balance having more disease. The strongest associations with balance were seen for white matter disease and ventricular size. All but the ischemic infarction variable remained significantly associated with balance after adjustments for sex, race, age, cardiovascular disease, and hypertension.

Conclusion: Cerebral changes identified by MR imaging are associated with poorer balance among older adults.

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Falls are a major health problem of the elderly. Falling accounts for the majority of injury-related deaths, and injury is the sixth leading cause of death among older adults. This number would probably be even higher if cases in which a fall initiated a chain of events culminating in death were taken into account. Falling is also a major cause of morbidity and disability in the elderly. Those who survive falls often have restricted activity, soft tissue injuries, or fractures.

Multiple potential causes for falls are recognized, including neurologic, cardiovascular, and musculoskeletal disorders. Because disorders of balance and gait are frequently associated with falls in the elderly, the identification of risk factors for poor balance is important. Age-related changes in the nervous system may contribute to postural instability, gait disturbance, and falling in the elderly. These changes include both visual and vestibular information, in addition to reduced motor power, muscular atrophy, loss of proprioception and vibration sense, extrapyramidal dysfunction, and slowed reaction times.

Investigation of postural control capabilities is of increased importance for the elderly because of increasing frequency of falls with advancing age. The Romberg test has subsequently become a standard part of the neurologic and neuro-otologic examination. By comparing the patient’s balance with eyes open and closed, it can be used to assess the intactness of proprioceptive input when visual input is removed. Positive Romberg test results (ie, inability to perform the test) have been reported to be predictive of falls, as has the inability to stand on 1 foot. The concept of functional reach as a measure of balance was introduced in 1990 by Duncan et al, who established its validity and interrater reliability. Weiner et al demonstrated that functional reach assessments correlated well with other measures of physical performance; for instance, the correlation between 1-foot standing and functional reach was 0.64 (P < .001). While traditional assessments of balance typically measure the time a person can hold a postural position (Romberg test, tandem stand, 1-foot stand), a currently most advanced method of measuring postural control is dynamic posturography. This computerized measure, which is primarily used in clinical evaluations of balance disorders, measures balance by simulating various test
PATIENTS AND METHODS

STUDY PARTICIPANTS

Study participants were recruited from among participants in the Cardiovascular Health Study (CHS), an observational cohort study of cardiovascular diseases among community-dwelling older adults in 4 US communities. The design and recruitment methods for the CHS have been published. The CHS baseline examination was conducted in 1989 to 1990 and included a variety of physical and laboratory evaluations to identify the presence and severity of cardiovascular diseases and their risk factors. Participants were classified according to presence or absence of cardiovascular diseases following standard protocols and followed up prospectively for incident events. The prevalent disease category was updated regularly to include incident cardiovascular events occurring before the start of the study reported herein. Hypertension was defined as seated systolic blood pressure greater than or equal to 160 mm Hg, diastolic blood pressure greater than or equal to 95 mm Hg, or a history of high blood pressure and antihypertensive drug use. Borderline hypertension was defined as systolic pressure of 140 to 159 mm Hg or diastolic pressure of 90 to 94 mm Hg. Approximately 18 months after the CHS baseline examination, cerebral MR imaging was added to the protocol and implemented over a 2-year period.

The current study was conducted as an ancillary study to CHS in the Forsyth County, North Carolina, Field Center. The purpose of the study was to examine the association between different measures of balance and MR imaging–identified cerebral atrophy. All CHS participants who had completed cerebral MR imaging examinations were offered participation in the study. Of the 786 eligible subjects (i.e., those who had completed the MR imaging examination), 775 participated in the balance study. Overall, 62% of CHS participants completed MR imaging. Reasons for nonparticipation included lack of an appropriately timed follow-up visit, refusals, contraindications, and inability to be scanned, usually because of a complaint of claustrophobia, inability to lie still on the examination table during the MR imaging examination, or incomplete scans for other reasons. This should not affect the internal validity of the relationship between balance and MRI abnormalities, however.

An appropriate institutional review board approved both the CHS study and the ancillary study reported herein. Written informed consent was obtained from each participant before the study.

MAGNETIC RESONANCE IMAGING

The MR images were obtained on a high-field (1.5-T) MR imager according to a standard protocol previously described. T1- and T2-weighted images were obtained. Scans were archived on magnetic tape and sent to the CHS central MR image reading center for interpretation by neuroradiologists trained and certified in the CHS protocol. Images were interpreted directly from a digital workstation (PDS-4, Vortech, Dallas, Tex) consisting of four 1024 × 1024-pixel monitors capable of displaying all 96 images simultaneously. All studies were assessed and read without knowledge of the subject’s age, sex, race, balance, or cardiovascular disease status. Details of the reading protocol have been previously published, including intrarater and interrater reliability.

Cerebral ventricular size was assessed on a scale of 0 to 9 by comparison with a series of 8 studies with successively increasing ventricular size ranging from small and presumably normal (grade 1) to severe enlargement (grade 8). Studies considered to have ventricles smaller than those in grade 1 received grade 0, and those worse than grade 8 received grade 9. Similarly, sulcal widening was assessed by comparison with 8 studies with successively increasing sulcal size, with grades 0 and 9 assigned as for ventricular size. White matter disease was estimated as the total volume of periventricular and subcortical white matter–signal abnormality on spin density–weighted axial images compared with 8 studies that successively increased from barely detectable white matter changes (grade 1) to extensive, confluent changes (grade 8). Studies with no white matter changes received grade 0, and those with changes worse than grade 8 received grade 9. Ischemic infarctions were defined as those being 3 mm or greater, and were coded as being present or absent.

MEASURES OF BALANCE

Dynamic Posturography

Dynamic (moving) posturography is a computerized test that measures balance under various test conditions that can “neutralize” either visual or support surface orientation references and, therefore, require accurate vestibular input for posture control. The test apparatus consists of a platform that rotates about the ankle points. A canopy encompassing the subject’s visual field can be rotated in the anterior-posterior plane so that the axis of movement is colinear with ankle joint rotation. Strain gauges within the platform surface measure torsional forces exerted by the subject’s feet. Six test conditions were applied: (1) platform stable, horizon stable, eyes open; (2) platform stable, horizon stable, eyes closed; (3) platform stable, horizon moving, eyes open; (4) platform moving, horizon stable, eyes open; (5) platform moving, horizon stable, eyes closed; and (6) platform moving, horizon moving, eyes open. Of these, the first 2 are a quantitated standard Romberg test with the eyes open and closed on a stable platform. Steps 3 through 6 present the subject with altered sensory conditions by sway.
referencing of either the visual surround or the platform. Three trials are performed for each condition, and an equilibrium score is measured for each. The sensory organization test permits the quantitative description of the relative sensory contributions of visual, vestibular, and somatosensory support surface references to postural stability. The procedure takes approximately 10 minutes to perform.

A composite equilibrium score is calculated by adding the average equilibrium scores for conditions 1 and 2 to the equilibrium scores for each of the 3 trials of conditions 3 through 6 and dividing by 14. The composite score is useful in distinguishing normal from abnormal. The maximum possible score is 100, with higher score indicating better balance. Composite scores below the fifth percentile for age-matched controls are considered abnormal.

The posturography tests were conducted by 1 of 2 technologists in the Vestibular Laboratory, Baptist Hospital, Winston-Salem, NC, by means of a computer-based dynamic posturography diagnostic system (Equitest Dynamic Posturography System, NeuroCom International, Portland, Ore).

Romberg Maneuver

A Romberg maneuver was performed in a standard fashion to assess proprioception. Each participant was standing with shoes on, feet together, and eyes open, with the arms hanging at the sides. After a brief time to establish initial balance, participants were asked to close their eyes for 10 seconds. If the participants opened their eyes, moved their feet, or appeared to fall, they were considered to have failed the test.

Tandem Stand Test

The tandem stand was performed by asking the participant to stand with the heel of either foot in front of and touching the toes of the opposite foot. The examiner was permitted to support the participant until he or she had assumed the test position, after which the participant was asked to maintain this position with eyes open for 10 seconds or until loss of balance occurred. Participants who were not able to maintain the position for 10 seconds were considered to have failed the test.

1-Foot Stand Test

One-foot standing balance was measured by the procedure described by Tinetti. The participant was instructed to stand with the feet separated and to raise 1 foot for a maximum of 5 seconds, or until he or she lost balance or the raised foot touched the ground. Those who did not complete the 5 seconds were scored as having failed the test.

Functional Reach

Functional reach is defined as the maximal distance a subject is able to reach forward beyond arms' length while maintaining a fixed base in a standing position. The technique of Duncan et al was used. The test requires the use of a leveled, wall-mounted yardstick. Each participant was positioned with the right shoulder in front of the yardstick and an imaginary axis drawn through the shoulders perpendicular to the yardstick. The participant first extended the right arm horizontally and placed the fist with the thumb upraised next to the yardstick. The position of the third metacarpal was measured against the yardstick. Then the participant was asked to lean as far forward as possible without taking a step or losing balance. The position of the third metacarpal of the outstretched right arm was again measured against the ruler. If the participant touched the wall, took a step, or fell, the measurement was repeated. Functional reach was calculated as the distance in inches between the first and second measurements. The test was repeated 3 times and the average of these 3 attempts was recorded. A high score indicated better functional reach.

STATISTICAL METHODS

Data were screened for outliers and recoded so that the maximum value for white matter grade and ventricles was 7, and the maximum value for sulci was 6. A summary balance score was created, based on the first principal component of the 5 balance measures. The resulting measure accounted for 33% of the variation in the original measures and had the expected correlation with each individual balance measure. We then took the logarithm of the factor score to reduce skewness and rescaled it so that 0 was the lowest (worst) score observed and 100 was the highest (best) score in those tested.

All balance and control variables were tested for associations with race and sex with the use of t tests, χ² tests, or tests of linear correlation where appropriate. We also performed a nonparametric analysis (Spearman rank coefficient) for each comparison. Results were substantially the same, except for average functional reach, which was skewed to the right. We therefore used log average functional reach in the significance tests presented in the tables.

Since the primary goal was to show associations rather than estimate balance levels, we used correlation coefficients to represent the associations. Relationships between the MR imaging variables and the balance variables were assessed by means of zero-order correlation and also by partial correlations in which the set of control variables was partialed out. We also used multiple regression to determine whether the effect of each MR imaging variable on each balance variable showed an interaction with sex or race.
men and whites, aged 65 years and older.

A total of 452 women and 323 men had complete data on all balance and MR imaging variables. Mean age was 74.1 years among women and 74.9 years among men. Sex differences were observed for the MR imaging variables (higher scores indicate more disease): men had significantly greater values than women for ventricular size and sulcal widening. These sex differences were larger among whites than blacks. For the same variables, whites had significantly larger values than blacks, 3.54 vs 3.27 for ventricular size (P=.02) and 3.36 vs 2.76 for sulcal widening (P<.001). No significant sex or racial differences were found for white matter disease grade or prevalence of ischemic infarctions.

Significant sex differences were observed for all the balance variables except the Romberg test, with men scoring better than women on the continuously measured variables, and with a smaller proportion of men failing the tandem and 1-foot stand tests. Whites scored significantly higher (better balance) than blacks on the posturography test, and a smaller proportion failed the tandem and 1-foot stand tests. Consequently, the summary balance score was significantly higher (better balance) for whites vs blacks and for men vs women.

At the time of the study, 12% of men and 6% of women were diagnosed as having suffered a stroke or transient ischemic attack, 27% and 22% as having coronary heart disease (CHD), and 11% and 7% as having peripheral artery disease (men and women, respectively).

Table 2 shows unadjusted correlation coefficients between balance measures and demographic variables, MR imaging variables, prevalent cardiovascular disease, and hypertension. There was a consistent pattern between balance and MR imaging variables in the hypothesized direction of a positive association between worse MR imaging findings and poorer balance. The summary balance score was significantly related to each of the cerebral abnormalities (worse balance, worse disease). In addition, poorer balance was associated with advanced age, CHD, and hypertension.

Plots of the summary balance score vs cerebral MR imaging measures are shown in the Figure. At each level of the cerebral measures, women generally had worse balance than men, blacks worse than whites, and those with CHD worse than those without. Although the linearity and strengths of the trends vary, the general pattern is relatively consistent with that of poorer balance being associated with more cerebral disease, overall and within each category of sex, race, and CHD.
after adjustment for sex, race, age, age squared, cerebrovascular disease, peripheral vascular disease, CHD, and hypertension. Compared with results of the univariate analyses, the adjusted associations were generally weaker. However, the summary balance score remained significantly related to ventricular size, white matter disease, and sulcal widening ($P=.05$ for the last). Because ventricular size and sulcal widening showed significant interactions with race ($P=.02$ and .03, respectively), separate analyses were conducted for whites and blacks. Both associations were significant among blacks only ($P=.001$ for ventricular size and $P=.004$ for sulcal widening). A significant sex interaction was observed between white matter disease and the 1-foot stand test ($P=.01$); sex-specific analyses showed the association to be significant among men only ($P=.007$).

In a large study investigating the relationship between MR imaging–identified cerebral changes and various measures of balance, we have shown that community-dwelling older adults with even mild degrees of cerebral atrophy have more balance problems than people without cerebral changes. Because problems with balance generally induce a fear of falling, consequent hesitation to move may result in marked disability and reduced quality of life. Thus, the identification of causes of impaired balance may have important health implications among the elderly. The participants in our study were ambulatory,
community-dwelling, older adults who were generally healthy; these MR imaging findings may therefore be markers for early stages of impaired postural control.

Our study confirms previous reports that a substantial proportion of elderly people have difficulties with balance and with performing tests of functional mobility.35 In agreement with previous reports,27 tandem foot position or 1-foot standing is particularly difficult, with 29% and 20% of women and men, respectively, failing the former and 49% and 36% failing the latter. Better balance among men vs women, whites vs blacks, and younger vs older persons (among 70- to 79-year-olds) has also previously been reported.35

Measures of cerebral atrophy including those used here have previously been reported to increase with age.24,26 White matter abnormalities have been recognized with T2-weighted MR imaging in a substantial number of elderly patients, both demented38 and cognitively normal,21,27 and although the histological alterations underlying these changes vary, both the prevalence and severity of white matter changes have been found to increase with age.22-27 In the study by Hendrie et al,27 all 11 subjects aged 75 years and older demonstrated these lesions, as opposed to 31% of the 16 subjects between 63 and 75 years old. Hachinski et al39 proposed the term leuko-araiosis for these white matter abnormalities, whose origin and significance are not known.

Studies of the relationship between cerebral changes and balance are few, and those that have been conducted include only small numbers of people and 1 or 2 measures of balance. A few studies have found impaired gait to be associated with larger ventricles among older subjects.17-19 Sudarsky and Ronthal19 found CT measurements of ventricular enlargement to be significantly greater in 30 patients with gait disorders than in 28 age-matched controls with normal gait. It has been suggested that ventricular enlargement and gait disorders may be separate indicators of forebrain disease, and, in fact, classic features of gait abnormality have been associated with forebrain disease.40,41 The ventricular size could thus be a measure of ex vacuo hydrocephalus, which often accompanies hypertensive cerebrovascular disease.42

White matter lesions on CT scans have been associated with abnormalities of gait and equilibrium. Masdeu et al28 compared 20 older adults prone to falling with 20 control subjects, all recruited from a nursing home. The former group had significantly more white matter lesions than the control group. The degree of white matter lesions was positively correlated with the degree of impaired gait and equilibrium.

We could identify only 2 published studies on the relationship between MR imaging findings and measures of balance. Hendrie et al37 related MR imaging findings to gait, balance, and neuromuscular function but found no statistically significant association of increased MR imaging T2 signal foci with asymmetric motor examination or palomental or root reflexes in a study of 27 healthy elderly volunteers. They attributed this lack of correlation to the ability of MR imaging to show subclinical white matter changes. On the other hand, in agreement with the CT studies, they did find that gait abnormalities, in particular tandem walking difficulties, were associated with white matter lesions on MR imaging. While no patients with grade 0 or 1 white matter disease had abnormal gait, 14.3% of patients with grade 2 and 37.5% of patients with grade 3 changes had abnormal gait. When groups were combined into 0/1 and 2/3, the comparisons yielded a p value of .04, indicating an association between white matter disease severity and abnormal gait. The other identified study of cerebral MR imaging and balance was a case-control study by Baloh et al,28 in which 27 patients with abnormalities of gait and balance had significantly more severe subcortical white matter hyperintensities on MR imaging than did a matched control group.

Tandem stand and 1-foot stand tests were both significantly related to white matter disease in our study. These tests may be sensitive to early gait apraxia that may not be symptomatic but may correlate with T2 hyperintensities on MR imaging. White matter disease was also significantly related to the summary balance score. Although these lesions probably interfere with central processing of sensorimotor signals, leading to impaired postural control, the mechanisms by which periventricular white matter disease may interfere with normal gait and balance need further clarification. Long-loop reflexes, essential for adequate gait and balance, are mediated by ascending fibers from the ventrolateral nucleus of the thalamus to the paracentral lobule and by descending corticospinal fibers.43 These fibers course in the periventricular region, which is the distal territory of the perforating medullary vessels, and are thereby prone to acute or chronic ischemic damage as a result of arteriolar disease, hemorheological factors, anoxia, or hypotension.44,45 Postural impairment may be caused by periventricular involvement of descending and ascending pathways serving the lower part of the body. While extensive sub-

### Table 3. Partial Correlation Coefficients Between Magnetic Resonance Imaging Variables and Balance Measures (N=762)*

<table>
<thead>
<tr>
<th></th>
<th>Posturography Test</th>
<th>Functional Reach (Log)</th>
<th>Romberg Test</th>
<th>Tandem Stand</th>
<th>1-Foot Stand</th>
<th>Summary Balance Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventricular size</td>
<td>-0.10†</td>
<td>-0.10†</td>
<td>0.06</td>
<td>-0.09†</td>
<td>-0.09†</td>
<td>-0.15§</td>
</tr>
<tr>
<td>Sulcal widening</td>
<td>-0.09†</td>
<td>0.03</td>
<td>0.01</td>
<td>-0.02</td>
<td>-0.05</td>
<td>-0.07§</td>
</tr>
<tr>
<td>White matter disease</td>
<td>-0.04</td>
<td>-0.04</td>
<td>-0.02</td>
<td>-0.04</td>
<td>-0.08§</td>
<td>-0.08§</td>
</tr>
<tr>
<td>Ischemic infarctions</td>
<td>-0.07†</td>
<td>-0.05</td>
<td>0.01</td>
<td>-0.02</td>
<td>-0.00</td>
<td>-0.04</td>
</tr>
</tbody>
</table>

*Adjusted for sex, race, age, age squared, cerebrovascular disease, peripheral vascular disease, coronary heart disease, and hypertension.
†P<.01.
‡P<.05.
§P<.001.
cortical white matter disease associated with severe hypertension causes more severe gait abnormalities, it is possible that earlier stages of white matter lesions cause milder disturbances in gait and postural control. One of the strengths of our study is the large sample size and the participation of ambulatory, community-dwelling older adults. Subjects included a relatively large age spectrum within the older adult population, men and women, and blacks and whites. Previous studies have been much smaller, have not been biracial, and have typically focused on symptomatic subjects. The findings of our study are thus more generalizable to the older population at large. All MR images were centrally read in a standard fashion, with the readers blinded to participants’ characteristics, including demographics. We included several measures of balance, each representing at least slightly different aspects of motor and sensory control. The summary balance score, representing the domains of each of the 5 individual balance measures, was more consistently related to the various measures of cerebral MR imaging–identified abnormalities than each single measure was.

A limitation of our study is its cross-sectional nature, limiting the inferences regarding the directionality of the association between balance and cerebral atrophy. However, the consistent findings in each of the subgroups support our hypothesis of a true association between cerebral MR imaging–identified abnormalities and postural instability. Because balance is related to the risk of falling, the findings of this study contribute to the understanding of one of the major causes of morbidity and mortality in the elderly: fractures caused by falls.

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