

ORIGINAL ARTICLE

Relationship between Dynamic Trunk Balance and the Balance Evaluation Systems Test in Elderly Women

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Objective: Falls are major contributors to elderly subjects becoming bedridden. Consequently, it is important to evaluate and minimize the risk of falls in the elderly. Trunk stability is important for balance function and is related to fall prevention in elderly women. We developed a balance-measuring device that uses a dynamic sitting position to safely measure balance function. The Balance Evaluation Systems Test (BESTest) is useful method to assess balance function, a recently developed balance evaluation test that can detect minor balance problems not captured by previous tests. The purpose of the present study was to examine the relationship between dynamic trunk balance and findings of the BESTest in elderly women. **Methods:** Thirty-one healthy women aged 60 years or more participated in this study. The evaluation items were the BESTest total score, scores for each of the six elements of the BESTest, dynamic sitting balance, static postural balance, and muscle strength. **Results:** The mean total BESTest score was 85.4 points. The mean total trajectory length of the center of gravity (COG) during the dynamic sitting balance test was 1447.5 mm. A negative correlation ($r=-0.481$, $P=0.006$) was observed between the total COG trajectory length and the BESTest score. A negative correlation was also found between the total COG trajectory length and biomechanical constraints ($r=-0.492$, $P=0.005$) and anticipatory postural adjustments ($r=-0.532$, $P=0.002$). There were no correlations between the dynamic sitting balance total COG trajectory length and the stationary standing COG trajectory length or muscle strength. **Conclusions:** In elderly women, the total COG trajectory length during dynamic sitting was negatively correlated with the BESTest total score.

Key Words: dynamic trunk balance; elderly women; the Balance Evaluation Systems Test (BESTest)

INTRODUCTION

The aging of the Japanese population has progressed rapidly, with 27.7% aged 65 years or more.¹⁾ Population aging is expected to accelerate even further, and it is estimated that in 50 years, at least 1 in 3 Japanese people will be more than 65 years old.¹⁾ Dementia, cerebrovascular disease, senility, fractures, and falls are major contributors to elderly subjects becoming bedridden, a condition that leads to loss of inde-

pendence. Further, about 70% of the fractures that result in elderly people becoming bedridden are femoral fractures, and about 90% of femoral fractures are caused by falls.²⁾ Therefore, it is important to evaluate and minimize the risk of falls in the elderly.^{2,3)}

Risk factors for falls include visual impairment, cognitive impairment, decreased balance function, muscle weakness, walking, dizziness, and medications.⁴⁾ Furthermore, particularly for elderly people, it is important to prevent the

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Table 1. Summary of the 27 items comprising BESTest under each of the six system categories

I. Biomechanical constraints	II. Stability limits/vertically	III. Anticipatory postural adjustments	IV. Postural responses	V. Sensory orientation	VI. Stability in gait
1. Base of support	6. Sitting verticality (left and right) and lateral lean (left and right)	9. Sit to stand	14. In-place response, forward	19. Sensory integration for balance (modified CTSIB)	21. Gait, level surface
2. CoM alignment	7. Functional reach forward	10. Rise to toes	15. In-place response, backward	Stance on firm surface, EO	22. Change in gait speed
3. Ankle strength	8. Functional reach lateral (left and right)	11. Stand on one leg (left and right)	16. Compensatory stepping correction, forward	Stance on firm surface, EC Stance on foam, EO	23. Walk with head turns, horizontal
4. Hip/trunk lateral strength		12. Alternate stair touching	17. Compensatory stepping correction, backward	Stance on foam, EC	24. Walk with pivot turns
5. Sit on floor and stand up		13. Standing arm raise	18. Compensatory stepping correction, lateral (left and right)	20. Incline, EC	25. Step over obstacles
					26. Timed "Get Up & Go" Test
					27. Timed "Get Up & Go" Test with dual task

CoM=center of mass, ROM=range of motion, CTSIB=Clinical Test of Sensory Integration for Balance, EO=eyes open, EC=eyes closed.

deterioration of balance function and muscle strength that occur with age.^{4,5)}

Trunk stability is important in balance function and is related to fall prevention.⁵⁾ Elderly people retain the ability to acquire trunk stability through trunk training.⁶⁾ Therefore, increasing the trunk balance function may be useful for preventing falls in the elderly.

Various balance function evaluations are available, e.g., the Functional Reach Test (FRT), which is based on a single task;⁷⁾ tests that evaluate the sway of the center of gravity (COG) with the subject in a stationary position;⁸⁾ and assessments composed of multiple tasks, such as the Berg Balance Test (BBS).⁹⁾ Although these evaluations can measure balance function, they do not indicate the type of problem that may be present, making it difficult to determine appropriate interventions.

The Balance Evaluation Systems Test (BESTest) is a balance evaluation test developed in 2009 that has been translated for use worldwide.^{10,11)} This test measures problems associated with balance function based on six factors: (1) biomechanical constraints, (2) stability limits/verticality, (3) anticipatory postural adjustments, (4) postural responses,

(5) sensory orientation, and (6) gait stability. The six factors consist of 27 item tests. The maximum BESTest score is 108 points, and scores of 93 points or less are considered to indicate a failure of balance.¹⁰⁾ The 27 items include the FRT and the Timed Up & Go test (TUG),¹²⁾ which are common balance evaluation tests (**Table 1**). Compared with the BBS, an existing balance evaluation test, the BESTest has no ceiling effect, suggesting that it can detect minor balance problems that might not be indicated by other tests.

When trunk balance disorders occur, especially in the elderly, the dorsum of the spine is strengthened, the spine leans forward, and the COG fluctuates when standing, increasing the possibility of falls.^{13,14)} Methods for assessing trunk balance include the standing COG swing test using force plates, the FRT, and the TUG. However, these tests methods assess problems with the lower limbs and do not reflect balance of the trunk alone. In addition, for elderly people, these tests are associated with a risk for falling due to dizziness or other issues; therefore, the evaluation itself may be dangerous and difficult to complete.

We developed a balance-measuring device using a dynamic sitting position to safely measure balance function.¹⁵⁾

Because this device applies a disturbance load while subjects are seated, dynamic trunk balance alone can be measured. Moreover, elderly people are safe during this test because they remain in a seated position.

To the best of our knowledge, several studies have examined the relationship between falls and the BESTest score. For example, Marques et al. investigated the relationship between BESTest and falls in older people living in the community.¹⁶⁾ The BESTest has excellent interrater reliability with a mixed population of individuals with neurological disorders and balance limitations, and it has excellent test-retest reliability for individuals with Parkinson's disease.^{17,18)} In addition, there are reports that the relation between fall risk and BESTest score of healthy elderly people depends on age, and the fall risk detection is reliable.^{19,20)} However, there is no report on the relationship between BESTest scores and trunk balance evaluated by dynamic sitting. The purpose of the present study was to examine the relationship between dynamic trunk balance and BESTest scores in elderly women.

METHODS

Patients and Study Design

Thirty-one women volunteers aged 60 years or more with no obvious brain or nerve disorders or joint diseases and who could walk unaided were enrolled. The evaluation items were the BESTest total score, the scores of each of the six elements of the BESTest, dynamic sitting balance, static postural balance, and muscle strength (back muscle, iliopsoas muscle, and quadriceps). The protocol was approved by the Ethics Committee of our institute. Written informed consent for the study and its publication was obtained from all subjects.

Evaluation Items and Equipment

The BESTest total score and the scores for each of the six elements of the BESTest were measured. The BESTest consists of 27 tests, and the measurements took 40–50 min; as a result, the BESTest was performed only once.

Dynamic sitting balance was measured with a dynamic sitting balance measuring device that we developed and described previously.¹⁵⁾ This device tilts to a maximum of 3° to either side by means of a direct current motor (BHM62MT-G2; Oriental Motor, Tokyo, Japan). The subject's COG can be measured using three triaxial force sensors arranged under the seat. Participants sit on the device with their arms folded across the anterior chest, eyes open, and their feet off the floor. Dynamic trunk sway during external stimuli was measured as the length of the COG trajectory for 30 s; in

this way, the ability to respond to external stimuli was assessed. The external stimulus was applied to the subjects by the device automatically tilting the seat left and right. The total length of the COG trajectory and the rectangular area containing the COG were considered indicators of dynamic postural balance. The test was performed twice, and the mean of the two scores was used.

Static postural balance was measured with a stabilometer (UM-BAR; Unimec, Tokyo, Japan). The COG deviation was recorded using a microcomputer with the participant standing unaided in the upright position with the eyes open for 30 s and then with the eyes closed for 30 s. The total movement of the COG during measurement was calculated as the total length.

To assess muscle strength, the strengths of the iliopsoas and quadriceps muscles were measured twice on each side with a hand-held dynamometer (Power Track II; JTEC Med, Salt Lake City, UT, USA), and the mean values of the left and right sides were used. Back muscle strength was measured twice as the isometric muscle strength using a strain gauge (DPU-1000 N digital force gauge; Imada, Toyohashi, Japan) with subjects in the prone position, and the maximum value was used.

Statistical Analysis

Spearman's rank correlation coefficient was used to investigate the relationship between the sitting dynamic locus COG total trajectory length and the BESTest total score, the scores of each of the six elements of the BESTest, the COG sway in the standing position, and muscle strength. In addition, multiple regression analysis was performed with the dynamic sitting balance of total length of COG trajectory length as the objective variable and age, total BESTest score, and the six BESTest element scores as explanatory variables. Data were analyzed using SPSS version 19.0 for Windows (SPSS, Chicago, IL, USA). A P-value of <0.05 was considered statistically significant.

RESULTS

Table 2 shows the background data of the subjects. The mean age was 73 years (range, 64–87 years).

Table 3 shows the results of each of the 27 items of the BESTest. The mean total BESTest score was 85.4 points (**Tables 4**), with a score of 93 points or less indicating some balance disorder.¹⁰⁾ **Table 5** shows the total COG trajectory length of the 30-s dynamic sitting test; the stationary standing COG sway test; and muscle strengths of the back, the

Table 2. Baseline characteristics of the participants

No. of subjects (n)	31
Age (years)	73±6
Height (cm)	150±6
Weight (kg)	52±8
Body mass index (kg/m ²)	23.3±3.9

Values are given as the mean ± standard deviation.

iliopsoas, and the quadriceps.

A negative correlation ($r=-0.481$, $P=0.006$) was observed in the total locus length of the COG for the dynamic sitting test and the BESTest total score (**Fig. 1**). Among the six items of the BESTest, a significant negative correlation was found between the total locus length of the COG and biomechanical constraints ($r=-0.492$, $P=0.005$) and anticipatory postural adjustments ($r=-0.532$, $P=0.002$). There were no correlations between the dynamic sitting test total COG trajectory length, the stationary standing COG length, and muscle strength (**Table 6**).

DISCUSSION

We hypothesized that dynamic trunk balance in older women is related to the BESTest results. In support of this hypothesis, a significant negative correlation was found between the total dynamic sitting test COG trajectory length and the BESTest total score. Although balance function is said to decrease with age,^{17,21} BESTest total scores in elderly women were similarly low.¹⁷ Furthermore, in the current

study, there was a negative correlation between the dynamic sitting test COG total trajectory length and the BESTest total score, suggesting that the decline in dynamic trunk balance ability may be associated with a low BESTest score.

In addition, biomechanical constraint, one of the six elements in which a negative correlation was recognized, is composed of five items: base of support, center of mass alignment, ankle strength and range of motion, hip/trunk lateral strength, and standing up from the sitting position. The base of support and the center of mass alignment assess malalignment between the sagittal and coronal planes of the spinal column. It is known that spinal alignment imbalances in older adults cause a decrease in balance function and are associated with falls.^{22–25} Moreover, the possibility that a decrease in BESTest static alignment affects trunk balance during dynamic sitting has been suggested.¹⁸

Anticipatory postural adjustments were also negatively correlated with the dynamic sitting test total COG length. The five items that make up the BESTest anticipatory postural adjustments category are sitting to stand, rising to toes, standing on one leg, alternate stair touching, and standing arm raise (**Table 1**). In this study, except for standing on one leg, maximum scores were almost always recorded (**Table 3**), suggesting a relationship with standing on one leg. Trunk function is related to stability when standing on one leg, and it is believed that the activity of the trunk muscle on the standing leg side increases to stabilize the pelvis against the increase in the load when standing on one leg.²⁶ Although there was no relationship between static postural balance with eyes open (COG swing of both legs standing) and the

Table 3. Results for the 27 items of BESTest

1		2		3		4		5		6	
Biomechanical constraints		Stability limits/ verticality		Anticipatory postural adjustments		Postural responses		Sensory orientation		Gait stability	
1	2.9±0.4	6	Sitting verticality Left: 2.5±0.7 Right: 2.5±0.4	9	3.0±0.0	14	2.3±0.8	19	Stance on firm surface eyes open 3.0±0.0 eyes closed 2.9±0.3	21	2.4±0.6
2	2.7±0.7			10	2.6±0.7	15	1.3±0.7			22	2.7±0.6
3	2.1±0.7			11	Lateral lean Left: 2.8±0.4 Right: 2.8±0.4	Left: 2.0±0.8 Right: 1.8±0.9	16			2.2±0.9	Stance on foam eyes open 3.0±0.0 eyes closed 2.5±0.6
4	1.0±1.0	7	2.1±0.5					12	2.5±0.5		
5	2.7±0.8	8	Left: 1.9±0.3 Right: 1.9±0.3	13	2.9±0.5	18	Left: 1.9±0.8 Right: 2.0±0.9			25	2.6±0.7
										26	2.5±0.7
										27	1.9±0.8

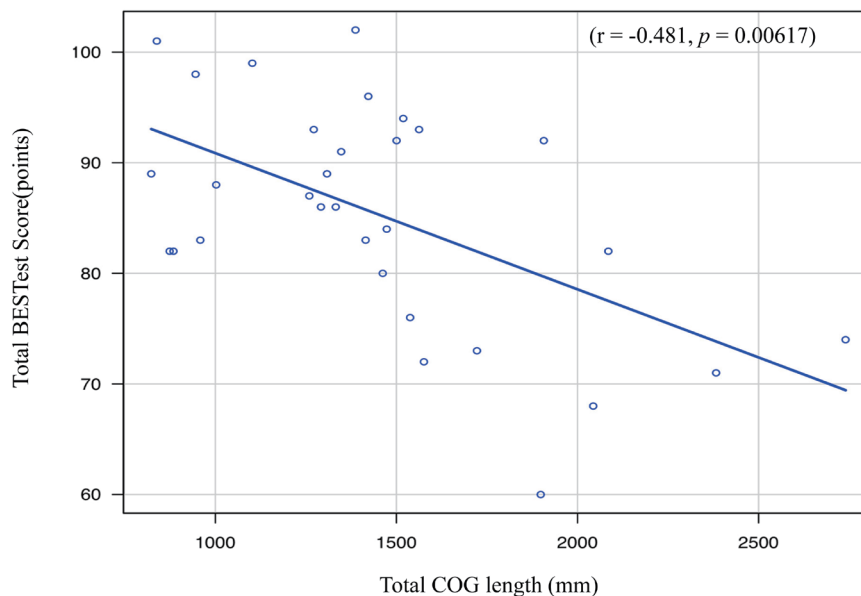
All 27 items were scored 0, 1, 2, or 3 points.

Values are given as the mean ± standard deviation.

Table 4. Average BESTest total score and the scores for the six categories

BESTest total score (108)	85.4±10.2
Biomechanical constraints (15)	11.4±2.3
Stability limits/verticality (21)	16.4±2.1
Anticipatory postural adjustments (18)	14.8±2
Postural responses (18)	11.4±3.2
Sensory orientation (15)	14.3±0.8
Gait stability (21)	17.0±3.1

Values are given as the mean ± standard deviation.
The numbers in parentheses are the maximum points for each category.

**Fig. 1.** Correlation diagram of BESTest and dynamic sitting balance total COG trajectory length.**Table 5.** Average total length of COG trajectories (dynamic sitting balance and static postural balance) and muscle strengths

Dynamic sitting balance	
Total length of COG trajectory (mm)	1447.5±454.5
Static postural balance with eyes open	
Total length of COG trajectory (cm)	84.1±43.6
Back extensor strength (N)	153.7±69.0
Iliopsoas muscle strength (N)	121.7±27.5
Quadriceps muscle strength (N)	147.5±30.0

Values are given as the mean ± standard deviation.

BESTest score in this study, it can be said that the relationship between the evaluation of the single leg standing by BESTest and the total COG trajectory length during dynamic sitting balance was affirmative of previous reports.

This study has some limitations. First, the study group was small and limited to older women. Second, trunk muscle activity was not evaluated using an electromyogram. However, our newly developed dynamic sitting balance device

Table 6. Correlation with dynamic sitting balance total trajectory length of COG

Item	Correlation coefficient (r)	P value
BESTest total score	-0.481	0.00617 *
Biomechanical constraints	-0.492	0.00492 *
Stability limits/verticality	-0.326	0.0731
Anticipatory postural adjustments	-0.532	0.00208 *
Postural responses	-0.326	0.0737
Sensory orientation	-0.0501	0.789
Gait stability	-0.349	0.0543
Static postural balance with eyes open	0.248	0.177
Back extensor strength	-0.304	0.0961
Iliopsoas muscle strength	-0.18	0.332
Quadriceps muscle strength	-0.222	0.23

*Significance set at $P < 0.05$.

measures the dynamic balance function of the trunk simply by quantifying the total COG trajectory length in a 30-s period. Therefore, we believe that this device could be useful for comparison with others. Finally, the center of mass alignment of the support basal plane, the sagittal plane of the spinal column, and the coronal plane were not evaluated using X-rays. In the future, we would like to measure spinal alignment in more detail and investigate the relationship between dynamic sitting and trunk function.

CONCLUSION

In elderly women, the trajectory length of the COG during dynamic sitting was negatively correlated with the BESTest total score. Future studies should investigate how the BESTest can be used to determine both the optimal treatment interventions to prevent falls and the efficacy of these interventions.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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