Correlation between clinical tests for gait and stability using biomechanical variables in the gait of institutionalized elderly subjects

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Abstract

Study aim: This study aims to identify biomechanical gait variables explaining clinical test results in institutionalized elderly people.

Material and methods: Twenty-nine elderly (82.0 ± 6.3 years) residents in a nursing home were assessed. They were able to walk 10 meters without walking aids. First, the spontaneous gait was assessed using inertial measurement units in a 10-meter long corridor. Fifteen biomechanical gait variables were analyzed. Then, three clinical tests usually used in elderly subjects were applied: the Timed Up and Go (TUG) test, the Tinetti Scale and the Sit to Stand (STS) test. A correlation matrix using Pearson's correlation coefficient between clinical and biomechanical variables was performed, obtaining a total of 45 potential correlations. A stepwise multiple linear regression analysis was then performed to determine the influence of each variable.

Results: TUG, Tinetti and STS were significantly correlated with similar biomechanical variables, including temporal, temporo-spatial and kinematic variables. Adults over 80 years old and women showed stronger correlations. Single support and ankle angle at takeoff were the two most important variables in stepwise regression analysis.

Conclusions: In institutionalized elderly subjects, clinical variables for gait and postural stability are correlated with the biomechanical gait variables, especially in women and adults aged over 80 years.

Keywords: Older adults – Gait – Biomechanical phenomena

Introduction

Human gait, like other types of movements, is the result of a complicated process in which the nervous and musculoskeletal systems are involved [18]. Thus, the clinical assessment of gait has allowed healthcare professionals to assess the condition and security of neuromuscular systems [2]. In the elderly, postural stability or balance is one of the main elements evaluated in gait, given its strong relationship with the risk for falls in this population [32, 36]. There are many ways to assess postural stability, both at the clinical level (not instrumented) and at the instrumented level [22, 36].

Clinical evaluations are tests that can be performed with minimal instrumental requirements [36]; therefore they are the most widely used in healthcare centers. To

assess postural stability and/or the risk for falls in the elderly, the most popular tests include the Timed Up and Go (TUG) test [27, 28, 30], the Tinetti scale (composed of the gait and balance scores) [5, 21, 36], and the Sit to Stand (STS) test [20, 24, 34, 35]. Instrumented tests are more complex in their evaluation and more expensive equipment is needed for them to be carried out [36]. Instrumented assessments can be carried out in different contexts, gait being one of the most studied in the elderly given its importance in mobility and functional independence [5, 27, 32]. The biomechanical evaluation of gait implies the recording and analysis of temporal variables (unipodal, bipodal support time, etc.), temporo-spatial (gait speed, cadence, etc.), and articular kinematic variables (angular motion and its derivatives), among others [8, 13, 22, 36]. Many of these variables have been related to postural stability of the elderly [8, 11, 13, 36].

In recent years, thanks to technological advances, digital tools for assessment have been incorporated, such as inertial measurement units which are portable and easy to use; also, they facilitate the conducting of instrumented gait assessments in a clinical setting [33]. Yet despite this, the measurement of biomechanical gait variables in the elderly is uncommon at a clinical level. One reason may be the lack of clarity when interpreting or understanding the usefulness of the biomechanical gait variables. Faced with this, it is in our common interest to relate the behavior of these instrumented variables with those frequently used in the clinical setting, since if the magnitude of these relationships is known, it could be useful in different ways. On one hand, those biomechanical gait variables that are most related to clinical tests could be the most interesting for professionals who wish to implement instrumented gait analyses in elderly people, thus facilitating their use. On the other hand, those clinical tests that are most closely related to biomechanical gait variables could be most useful for the healthcare professionals working with elderly people, since with the use of these tests, an approach to the biomechanical gait behavior of each patient can be obtained. Based on the foregoing observations, the aim of this study was to identify biomechanical gait variables related to clinical tests results in institutionalized elderly people. Additionally, we sought to calculate these same correlations according to sex and age.

Materials and methods

Participants

Twenty-nine elderly patients (15 women, 14 men) residents at the Hogar San José, located in Santiago, Chile, aged between 65 and 95 years old were assessed. Participants had to be able to walk without technical assistance for a minimum of 10 meters. In addition, they required a score of at least 13 points in the abbreviated version of the Mini Mental State Examination (MMSE) scale [31] in order to ensure that patients could follow instructions and agree to participate in the study voluntarily. Participants with medical conditions that prevented them from properly testing, such as acute musculoskeletal injuries, sequelae of stroke, Parkinson's disease, use of medications that affect postural control, such as neuroleptic or psychotropic, etc., were excluded from the study.

Protocol of assessment

This study was in accordance with all ethical standards consistent with the Declaration of Helsinki and it was approved by the Scientific Ethical Committee of the Universidad de los Andes (Project folio K4015). All elderly patients participated in the study voluntarily, and they gave their prior consent to participate in the study.

The researchers visited the nursing home where participants resided to carry out the assessments. From the interviews, the review of records, general physical examination and the demographic variables (sex, age, height, weight, body mass index) were collected. Then, the biomechanical gait assessment and the clinical assessments were performed.

Biomechanical gait assessment: This assessment was carried out using a system with six inertial measurement units (Opal sensors, Mobility Lab, APDM Inc.), which were placed on both feet, both wrists, lower back and on the sternum of each volunteer. Then, they were asked to walk naturally in a 10-meter long corridor, with a flat surface and without obstacles. The trial was considered as valid every time the volunteer walked naturally, without stopping, and keeping his/her eyes straight ahead. The necessary tests were performed until a total of three valid trials were obtained. For each trial, between three and five central cycles were analyzed, and 15 biomechanical variables were obtained. In order to obtain a series of these repetitions which was representative of each volunteer, each variable was represented by its respective average of the three repetitions. The biomechanical analysis variables were as follows: gait speed; cadence; stride length; single support time; ankle angle at heel strike and takeoff; step angle; foot elevation at midswing; lateral step variability; sagittal, coronal and transverse motion ranges in the trunk and lumbar spine.

Clinical assessments: Once the biomechanical gait assessment had been performed, three clinical tests were evaluated: TUG, Tinetti scale and the STS test.

- TUG: This test assesses the time an elderly subject takes to get up from a seat (approximate height of 46 cm), to walk three meters, to walk back to the chair and sit again. Elderly subjects were asked to perform this test in the shortest time possible. Three repetitions were performed and the best of them was selected for analysis. Since this was the only variable in which a better performance is translated into a lower value, for the correlation matrix it was operationalized as its multiplicative inverse (1/duration time). All protocol details were based on other studies [27, 28].
- Tinetti scale: It is a scale divided into two sections; the first section consists of 9 items that assess elements of static postural control, while the second section consists of 7 items that assess gait. For the first section, the maximum score is 16 points, while for the second section, the maximum score is 12 points. The sum of these scores, or total Tinetti score, is considered as an indicator of risk for falls in the elderly. The details of each item and the assessment criteria are those described in the literature [11, 36].
- Sit to Stand (STS) test: Test commonly used to functionally test strength [20, 24, 35] in the elderly, although it has also been related to risk for falls and postural

control [20, 34, 35]. It consists of asking elderly patients to stand up and sit on a chair a certain number of times within a standardized time [20]. For the purposes of this study, elderly subjects were asked to stand up as many times as possible in 30 seconds; this number was taken as an indicator of postural strength/stability [34]. All protocol details were based on that described by Thapa *et al.* [34].

Statistical analysis

Firstly, all quantitative variables were characterized using mean and standard deviations, prior to the verification of the assumption of normal distribution with the Shapiro-Wilk test. Subsequently, using a Pearson correlation matrix, correlations between clinical tests (first axis) and biomechanical gait variables (second axis) were calculated. This analysis was performed for the total sample and categorized according to sex and age group (patients above and below 80 years old). Additionally, age was correlated with both clinical and biomechanical gait variables. The number of statistically significant correlations for each clinical test ($p < 0.05$) was counted, in order to determine which of them was more closely related to the biomechanical gait variables. To test the correlation strength, correlation heat-maps were made, and their coefficients were categorized

based on the classification proposed by Chan [7]. Thus, the intensity of color represents the magnitude of correlation, while the color represents the direction (blue= direct correlation; red= inverse correlation). Then, a stepwise multiple linear regression was performed, considering one regression model for each clinical test as dependent variables. For this analysis, p -values < 0.05 were considered significant. Statistical analyses were performed and graphs created using the R Studio Desktop 1.2.5 software (Boston, USA) and STATA/IC 14 software (StataCorp LLC, USA).

Results

A total of 29 elderly patients were assessed (82.0 ± 6.3 years old), of whom 14 were men (79.9 ± 5.9 years old) and 15 women (83.6 ± 6.3 years old); 13 were between 65 and 80 years old and 16 were over 80 years old. The quantitative variables are shown in Table 1.

Correlation matrix

When the clinical and biomechanical variables are correlated in the general sample (Figure 1), the TUG test showed eight significant correlations with the

Table 1. Description of the study variables ($n = 29$). Values are expressed as mean $\pm$ standard deviation

		All	Men	Women	≤ 80 years	≥ 81 years
Clinical tests	Timed up and go [s]	12.8 ± 4.7	12.5 ± 2.9	12.9 ± 6.1	12.0 ± 2.9	13.3 ± 5.9
	Tinetti [score]	23.9 ± 3.7	23.8 ± 3.9	24.1 ± 3.7	24.0 ± 2.9	23.9 ± 4.4
	Sit to stand [repetitions]	12.5 ± 3.6	13.0 ± 3.8	12.0 ± 3.5	12.3 ± 2.7	12.6 ± 4.3
Biomechanical gait variables	Gait speed [m/s]	0.8 ± 0.2	0.8 ± 0.2	0.8 ± 0.3	0.8 ± 0.2	0.7 ± 0.2
	Cadence [steps/minute]	107.0 ± 9.8	105.2 ± 9.5	108.8 ± 10.0	108.3 ± 10.1	106.0 ± 9.7
	Stride length [m]	0.8 ± 0.2	0.9 ± 0.2	0.8 ± 0.2	0.9 ± 0.2	0.8 ± 0.2
	Single support [% cycle]	37.3 ± 3.3	37.4 ± 3.0	37.3 ± 3.7	38.0 ± 2.9	36.8 ± 3.6
	Ankle angle at heel strike [deg]	14.9 ± 7.0	17.4 ± 7.8	12.6 ± 5.5	15.5 ± 7.0	14.4 ± 7.3
	Ankle angle at takeoff [deg]	26.1 ± 6.7	25.4 ± 6.7	26.8 ± 6.8	26.2 ± 5.7	26.1 ± 7.6
	Step angle [deg]	10.8 ± 6.6	11.4 ± 5.8	10.2 ± 7.4	10.6 ± 7.9	10.9 ± 5.5
	Elevation at midswing [cm]	1.4 ± 0.6	1.5 ± 0.7	1.4 ± 0.5	1.7 ± 0.7	1.3 ± 0.4
	Lateral step variability [cm]	3.4 ± 0.9	3.3 ± 1.0	3.5 ± 0.9	3.7 ± 0.9	3.2 ± 0.9
	Sagittal lumbar RoM [deg]	5.5 ± 2.0	6.2 ± 2.5	4.8 ± 1.7	5.6 ± 2.5	5.4 ± 2.0
	Sagittal trunk RoM [deg]	4.4 ± 1.3	4.5 ± 1.6	4.3 ± 1.1	4.8 ± 1.7	4.0 ± 0.8
	Coronal lumbar RoM [deg]	4.8 ± 1.6	5.0 ± 1.5	4.7 ± 1.7	5.0 ± 1.7	4.7 ± 1.5
	Coronal trunk RoM [deg]	4.6 ± 1.9	5.9 ± 1.7	3.3 ± 0.9	5.1 ± 2.3	4.2 ± 1.3
	Transverse lumbar RoM [deg]	7.4 ± 2.4	7.1 ± 2.2	7.7 ± 2.6	7.7 ± 2.6	7.2 ± 2.2
	Transverse trunk RoM [deg]	9.1 ± 2.5	9.0 ± 2.4	9.3 ± 2.6	9.4 ± 2.8	9.0 ± 2.3

RoM – range of movement.

Figure 1. Correlation matrix between biomechanical variables and clinical variables. Data of all participants was used to prepare the matrix ($n = 29$)
RoM – range of motion.

biomechanical variables. The Tinetti scale and the STS test showed six significant correlations.

In Figure 2, the analysis by subsample is shown. In women, there were eight, six and six significant correlations for TUG, Tinetti and the STS test respectively. In men, the STS test showed the largest amount of significant correlations (six correlations), followed by the Tinetti scale (four) and the TUG test (three).

When the subsample of 80 years old or below was analyzed, almost no significant correlations were found. The STS test showed five significant correlations, followed by the TUG test with 2 significant correlations. No biomechanical gait variable was correlated with the Tinetti scale. In patients aged 81 years old or above, the TUG test showed seven significant correlations, followed by the Tinetti and STS test (six each).

Multiple regression analysis

The results of the stepwise multiple regression analysis for the TUG test, Tinetti scale and STS test are shown in Table 2. The three stepwise analyses only included one independent variable ($p < 0.05$): single support (for TUG and STS) and ankle angle at take off (Tinetti scale). The r^2 value of these models were 0.540, 0.490 and 0.563 for the TUG, Tinetti scale and STS test respectively.

Finally, there were no statistically significant correlations between age and the other parameters tested ($p > 0.05$).

Figure 2. Correlation matrix by sub-sample: men, women, older adults aged 80 years or below and older adults aged 81 years or over
RoM – range of motion; i – Timed up and go test; ii – Tinetti score; iii – Sit-to-Stand test; y – years.

Table 2. Multiple regression analysis of Timed up and go test, Tinetti scale and Sit-to-stand test on biomechanical gait variables. All regression models only included one variable in stepwise analysis

	Coefficient (95% confidence interval)	p-value	r ²
Timed Up and Go			
Single support [% cycle]	-1.047 (-1.428, -0.665)	<0.001	0.540
Tinetti scale			
Ankle angle at takeoff [deg]	0.391 (0.233, 0.548)	<0.001	0.490
Sit to stand			
Single support [% cycle]	0.813 (0.530, 1.095)	<0.001	0.563

Discussion

The aim of this study was to identify biomechanical gait variables related to clinical test results in institutionalized elderly people, in order to determine what clinical tests are more closely associated to the biomechanical characteristics of gait in elderly people. In this study, moderate and strong correlations were observed between clinical tests and temporal variables (single support), temporo-spatial (especially, gait speed and stride length) variables, angle of the ankle at contact with the ground and takeoff of the toes, and lateral step variability. On the other hand, single support and ankle angle at takeoff explain around 50% of the variance of the clinical tests. Based on this, it can be stated that these three clinical tests – the TUG test, the STS test and the Tinetti scale – are very closely related to the biomechanical gait behavior in its different dimensions. Some of this information is consistent with the literature, although in populations other than those of this study. Mikos *et al.* correlated the TUG test and the STS test with the gait speed in people aged between 21 and 84 years old. As in this study, they observed that better performance in these tests is related to greater gait speed [23]. Similar results have also been obtained in other studies, such as associations between the Tinetti scale and gait speed [15], or associations between the TUG test and gait speed [1, 16, 29], stride length [3, 16] or support/oscillation phase duration [3]. However, the latest studies were carried out in patients with Parkinson's disease [15, 16], elderly patients residing in the community [1], or other younger age groups [29]. The above suggests that, apparently, in different populations, including institutionalized elderly subjects, there are important relationships between clinical tests and the temporo-spatial gait variables. Therefore, it seems to be of great importance to evaluate the temporo-spatial gait variables, especially gait speed and single support duration, since enough information about the postural stability of institutionalized elderly subjects

could be obtained. In addition, such variables have already been related to other factors such as risk for falls or functionality [10, 17, 25]. However, these studies are limited to correlation of the different clinical tests with temporo-spatial gait variables; thus analyses with other biomechanical variables such as kinematic variables are scarce in the literature. Among the few studies on this matter, Bonnyaud *et al.* tried to predict biomechanical gait variables in patients with sequelae of stroke using the TUG test, in which correlations with the temporo-spatial variables but not with the kinematic variables were observed [4]. In contrast, in this study, greater ankle angulation at contact and takeoff of the toes was related to better performance in all clinical tests. A possible explanation for this is raised in the study of Canseco *et al.* [6], in which adults and elderly with lower functional capacity showed lower ankle movement during gait. Likewise, kinematic ankle abnormalities would be associated with changes in all structures of the foot, impacting in the takeoff propulsion of toes, and also in parameters such as gait speed [6]. Other variables, such as lateral step variability or cadence, also seem to be related to clinical tests for postural control, but to a lesser extent, while the step angle, foot elevation in midswing, and spinal/trunk mobility do not seem to be related to these clinical tests.

When magnitudes of correlations in the different clinical tests were analyzed, in general, similar correlations were observed. Thus, all these clinical tests would be importantly related to the biomechanical gait behavior in institutionalized elderly subjects. However, this behavior seems to be somewhat heterogeneous in the different subsamples. In women, the strength of correlations was much greater than in men, especially in the STS and TUG tests. Something similar appears when analyzing the subsamples classified by age group, in which magnitudes of correlations were moderate to very strong in the group of elderly subjects above 80 years old, unlike the younger ones, where the correlations were mild to moderate. Both phenomena could be explained due to

the risk for falls naturally shown by the different subsamples. Both women [9, 14, 25] and older adults [8, 30] are at greater risk for falls compared to men and younger adults, respectively. This would suggest that, apparently, in elderly subjects who show an increased risk for falls, the clinical tests assessing postural control seem to be more closely related to the biomechanical behavior of their gait. Therefore, the assessment of gait in elderly subjects at greater risk for falls seems to be of great importance, especially in women and older persons, since how this movement is performed could give a useful insight into their postural control. In the clinical setting this is very useful, since the biomechanical gait variables that were the most strongly related to clinical postural control tests were the temporo-spatial variables, which can be easily assessed with a few instruments [19]. The fact that male and female elderly subjects seem to have different gait patterns may be another possible explanation for the differences in the correlations in the subsamples [14, 26] and risk factors for falls [9, 12, 14], which also occur between the young-old and old-old age groups [26]. However, more evidence supporting this hypothesis is required to prove the latter.

This study was not exempt from limitations. Firstly, the number of volunteers assessed was chosen for convenience, so the size of this sample may not be sufficient to extrapolate the results to all institutionalized elderly subjects. Secondly, and like in many of the studies conducted in these populations, a great variety of drugs and chronic pathologies in the volunteers is found. Even though those medications that showed the greatest impact on postural control were excluded, it was not possible to control many other factors. Finally, some dimension-dependent biomechanical variables, such as stride length or gait speed, were not normalized, and this could have affected the results. Faced with this, more studies in this area are required using more representative samples in order to come to more concrete conclusions.

Conclusions

Relationships between the clinical test for postural control and biomechanical gait variables were found in elderly residents in a nursing home, and these seem to be stronger in women and older persons. Also, as no major differences in the relationships among the different clinical tests were found, this indicates that each of them individually could be representative or indicative of how the biomechanical gait behavior in the elderly is, and vice versa. This could be very useful both for the promotion and interpretation of gait assessments in this population.

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