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Added value of a triaxial accelerometer assessing gait parameters to predict falls and mortality among nursing home residents: A two-year prospective study

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Abstract.
BACKGROUND: Gait impairment seems to be a risk factor for falls and mortality. Because gait change cannot be determined easily with classical clinical tests, some authors have suggested that it might be useful to use a gait-analysis system among elderly community-dwelling people.
OBJECTIVE: The main objective of the present study was to determine the predictive value of a quantitative evaluation of the gait characteristics in nursing home residents for the occurrence of falls and death performed using a tri-axial accelerometer (Locométrix®).
MATERIAL AND METHODS: One hundred elderly nursing home residents (80 women and 20 men, mean age 86.4 ± 6.04 years) were included in this study with the aim to follow them for 2 years. Deaths and falls were systematically recorded. A quantitative evaluation of a 10-second walk was performed with a tri-axial accelerometer (Locometrix®). Demographic data (i.e. age, sex, body mass index) and clinical data (i.e. fall risk evaluated by the Tinetti test) were also recorded.
RESULTS: During the two years of follow-up, 27 patients died. After adjustment on all potential confounding variables, only body mass index was significantly associated with the risk of mortality with an odds ratio of 0.86 (95% CI: 0.77–0.96, $p =$ 0.04). At the end of the study period, 440 falls had occurred (mean: 4.44 ± 6.79 falls per patient) but no single factors were independently associated with fall incidence.
CONCLUSION: Our results show that a quantitative gait analysis performed using a tri-axial accelerometer is not predictive of long-term falls and mortality among nursing home residents.

Keywords: Mortality, falls, risk factors, nursing home

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1. Introduction

According to the European Commission (2013), the proportion of older people is increasing in all member states of the European Union. The total population will increase from 502 million in 2010 to 517 million in 2060. In 2009 in Europe, more than 3.8 million deaths (80.3% of total deaths) occurred after the age of 65 years [1]. Furthermore, frequency of falls increases with age: almost a third of people aged over 65 years and nearly half of those over 85 years are victims of at least one fall per year [2].

From a public health point of view, it is useful to identify groups with a high risk of mortality or falls, in order to develop specific programs to prevent these adverse events [3,4]. Prognostic factors for falls and mortality are known in community-dwelling older adults and hospitalized older patients [5–10]. According to these studies, the most predictive factors of mortality are age, male gender, high level of dependency and presence of comorbidities. In addition, these studies show the importance of gait impairment and poor body balance as risk factors for falls. Previous studies have demonstrated an association between changes in gait and occurrence of falls in older adult [11]. Because this gait change cannot be determined easily with classical clinical tests (i.e. the Tinetti test, the timed "get up and go" test), some authors have suggested that it might be useful to use a gait-analysis system [12,13]. A recent study suggested that in comparison with other classical validated clinical tests, the Locometrix®, a new gait analysis system, could usefully investigate gait parameters in elderly people [14]. Although, this new gait analysis system is well adapted for hospital out patients [15], to our knowledge it has never been tested in a nursing home for its predictive value of falls and death. It represents a gap in the literature that we were seeking to fill in with this study. Consequently, the main objective of the present study was to determine the predictive value of a quantitative evaluation of the gait characteristics in nursing home residents for the occurrence of falls and death performed using a tri-axial accelerometer (Locométrix®).

2. Materials and methods

2.1. Design of the study

This is a two-year prospective study of nursing home residents which began in August 2011 and was completed in September 2013.

2.2. Participants

Residents of two nursing homes in the area of Liège, Belgium ("La Passerinette", Soumagne and "Notre Dame de Lourdes", Liège) were eligible for the study if they were able to stand in an upright position and to walk with or without technical assistance. Exclusion criteria were 1) blindness, 2) deafness, 3) refusal of the patient. The protocol of this study was approved by the "Comité d'Ethique Hospitalo-Facultaire Universitaire de Liège". Informed consent was obtained from each subject prior to their participation in the study.

2.3. Data collection

A large number of variables potentially related to the risk of mortality and falls were collected at the inclusion of subjects in the study. These variables included demographic information such as age, gender or weight (measured using a weighing scale) and height (measured using a stadiometer) from which body mass index (BMI) was calculated, and secondly, other information about the patients' health status such as presence of comorbidities, wearing glasses (multifocals), use of walking aids (e.g. walking stick, walking frame), level of dependence (Katz index [16]), medication prescribed including vitamins and supplement (type and number), history of falls and fractures during the past 6 months (number and sites), as well as gait characteristics (with the Locometrix® and the Tinetti tests) and body balance evaluation (with the Tinetti test). These data were collected during a face-to-face interview and were completed with the patient record.

2.3.1. Quantitative gait analysis using a tri-axial accelerometer: Locometrix®

This gait analysis consists of a quantitative evaluation of a 10-second walk performed with a tri-axial accelerometer (Locometrix®). It has proven reliable for the assessment of locomotion disorders in the elderly [17]. The method is based on the recording of accelerations according to cranial-caudal, antero-posterior, and medial-lateral axes of the body at a point near the center of gravity, the median lumbar region. The device is applied on the lumbar region, at L3-L4 disc space high, using a semi-elastic belt. It is then connected to a computer which calculates the dynamic gait parameters: frequency, symmetry, stability, regularity of gait cycles, cranio-caudal, medio-lateral, and antero-posterior power. These data can then be interpreted in order to detect any gait deterioration of the subject. The patient had to walk 3 times 20 meters, at a normal walking speed. He was allowed to use his walking aid. The first run was a preliminary test, the second, a simple task analysis and the third was an arithmetic dual task analysis. In the dual task, the patient had to count down out loud from 70, by one digit at a time, while walking. The number of digits said out loud and the number of errors in the count down was recorded by the experimenter. Patients were informed to focus on the motor task in priority [18]. These data were collected at baseline (T0) and after 2 years of follow-up (T24).

2.3.2. Tinetti test

The Tinetti test or Performance-Oriented Mobility Assessment (POMA) was used to assess body balance and gait abnormalities. It is one of the most widely used tests in this field [19]. This test consists of 16 items: 9 for body balance and 7 for gait. The maximum score is 16 for body balance, 12 for gait and thus 28 for the global score (balance + gait). In general, a score below 19 indicates a high risk for falls, a score between 19 and 24 indicates a moderate risk for falls, and 28 points indicates no risk of falls [20]. This test was performed at the beginning of the study (T0) and after 24 months of follow-up (T24).

2.3.3. Assessment of death

During the 24-month study, deaths were recorded by the nurses from the nursing homes. The date and circumstances of deaths were recorded. The nurses were briefed in advance by the researchers to ensure that the correct and most complete data was obtained.

2.3.4. Assessment of falls

Falls were defined as unintentionally coming to rest on the ground, floor, or other lower level. During the 24-month study, falls were recorded by the nurses from the nursing homes. The date, circumstances and consequences of falls were recorded and encoded in the computerized register of falls. Records included both observed and reported falls.

2.4. Statistical analysis

Quantitative variables that were normally distributed were expressed as mean and standard deviation (SD), and quantitative variables that were not normally distributed were reported as absolute or relative frequencies. A Kolmogorov-Smirnov test verified the normal distribution for all parameters. Evolution of the parameters studied between T0 and T24 was assessed using the Student t test, Mann-Whitney U test or Pearson chi-square test when appropriate. The same tests were used to compare characteristics of "deceased" and "alive" patients and characteristics of "fallers" and "non-fallers". A logistic regression was performed on the characteristics that significantly differed at baseline between deceased and not-deceased patients. The correlation between changes in the Tinetti test and Locometrix® test was tested by a Pearson coefficient. Falls were analysed by "Kaplan-Meier survival curve" and pairwise method. Intention-to-treat analyses were performed. We used the last available data for the analysis. All analyses were performed with the Statistica 10 software. Results were considered statistically significant when two-tailed p-values were less than 0.05.

3. Results

3.1. Descriptive analysis

A total of 100 volunteer institutionalized patients were enrolled in this study. Table 1 shows the baseline characteristics of the patients included in this study. Briefly, patients were aged 86.4 ± 6.05 years on average and were predominantly female (80%). Thirty-one % of the subjects had a history of fall.

3.2. Mortality

Over the 2 years of prospective follow-up, 27 patients died. Some baseline characteristics of the deceased patients were significantly different from those of the still alive patients, as shown in Table 2.

The patients who deceased had, compared to subjects still alive, a body mass index significantly lower (23.3 ± 4.9 kg/m^2 vs. 26.5 ± 5.3 kg/m^2, $p = 0.007$), a Katz index of independence significantly higher (18.3 ± 4.9 vs. 15.3 ± 4.9, $p = 0.009$), a score of Tinetti significantly lower (16.9 ± 4.6 vs. 19.6 ± 4.4, $p = 0.008$) and a counting speed in dual task significantly lower (41.9 ± 18.0 vs. 52.2 ± 28.2, $p =$ 0.10). In addition, 48.1% of the deceased patients had a history of repeated falls against 24.7% among the patients still alive ($p = 0.01$).

In multivariate analysis, after adjustment on potential confounding variables, only body mass index was statistically significantly associated with the risk of mortality with an odds ratio of 0.86 (95% CI: $-0.24 - -0.005$, $p = 0.04$). It means that for each increase of 1 Kg/m^2 of BMI, the risk of mortality significantly decreases by 14%.

3.3. Falls

A total of 440 falls has been recorded during the 24-month study and 75 patients fell at least once (mean: 4.44 ± 6.79 falls per patient).

Based on Kaplan-Meier analysis, 25% of the subjects fell in the first 2 months of the study, half of them fell in the first 5 months of the study, while 75% of subjects fell during the first year of follow-up.

Baseline characteristics of "fallers" compared to "non-fallers" subjects were comparable, except for the score on the Tinetti test (18.4 ± 4.45 points among "fallers" versus 20.6 ± 4.73 points among "non-fallers", $p = 0.04$) and stride frequency measured in dual task condition (0.77 ± 0.22 cycles/s among "fallers" versus 0.66 ± 0.14 cycles/s among "non-fallers", $p = 0.02$). However, after adjustment for confounding variables, no factors were predictive of falls.

Table 1
baseline characteristics of study participants (n = 100)

Characteristics		Mean	SD	Frequency (%)
Sex	Women			80
Age (years)		86.4	± 6.05	
BMI (kg/m^2)		25.6	± 5.39	
Comorbidities (number)		7.14	± 1.00	
Drugs consumed (number)		9.29	± 3.29	
Walking support	none			39
	Walking stick			25
	Walking frame			36
Katz Index of independence (points)		16.11	± 5.03	
History of falls the last 6 months (number)		1.60	± 1.02	
History of repeated falls				31
Tinetti test (Points)	Yes	18.88	± 4.59	
Locometrix test Simple task				
Walking speed (m/s^2)		0.64	± 0.42	
Stride length (m)		0.72	± 0.27	
Stride frequency (cycles/s)		0.82	± 0.18	
Stride regularity (arb.unit)		137.8	± 59.6	
Stride symmetry (arb. Unit)		181.6	± 63.8	
Cranio-caudal mechanic power (W/kg)		0.54	± 0.48	
Antero-posterior mechanic power (W/kg)		0.31	± 0.24	
Medio lateral mechanic power (W/kg)		0.32	± 0.20	
Counting speed (number/s)		42.40	± 16.4	
Dual Task				
Walking speed (m/s^2)		0.46	± 0.21	
Stride length (m)		0.64	± 0.25	
Stride frequency (cycles/s)		0.75	± 0.21	
Stride regularity (arb.unit)		101.2	± 55.1	
Stride symmetry (arb. Unit)		166.0	± 63.9	
Cranio-caudal mechanic power (W/kg)		0.37	± 0.32	
Antero-posterior mechanic power (W/kg)		0.24	± 0.18	
Medio lateral mechanic power (W/kg)		0.27	± 0.18	
Counting speed (number/s)		2.56	± 3.11	
SD = standard deviation				

3.4. Functional and motor abilities

Evolution of functional and motor skills between T0 and T24 was assessed in this research. The final tests (T24) were performed on 36 subjects (27 deaths, 20 physical disability, 12 refusals and 5 relocations). Patients who completed the final tests showed, at baseline, clinical characteristics significantly different from patients who did not carried out these tests, at least for the Katz index of independence (13.6 ± 3.7 points vs. 17.5 ± 5.1 points, $p = 0.0001$), the Tinetti score (21.3 ± 3.8 points vs. 17.5 ± 4.5 points, $p = 0.00004$) and stride length measured in simple task (0.79 ± 0.24 m vs. 0.68 ± 0.27 m, $p = 0.03$).

In these 36 subjects, our results show that gait speed ($p = 0.0003$), step length ($p = 0.004$) and coefficient of regularity of gait cycles ($p = 0.00002$) decreased significantly between the beginning and the end of the study. Quantitative gait analysis, measured by dual task, showed a significant reduction in gait speed ($p = 0.00002$) and regularity of gait cycles ($p = 0.03$). The evolution of the Tinetti score, over the two-year period, was not significant ($p = 0.38$) but was significantly correlated with changes in stride length ($r = 0.57$) and regularity of gait cycle ($r = 0.75$).

Table 2
Baseline characteristics of deceased and not deceased patients

Baseline characteristics		Deceased ($n = 27$)	Not deceased ($n = 73$)	p-value
Sex	Women	19 (70.3)	61 (83.6)	
Age (years)		88.2 ± 5.41	85.7 ± 6.17	0.07
Body Mass Index (kg/m^2)		23.3 ± 4.95	26.5 ± 5.32	< 0.01
Comorbidities (number)		7.52 ± 3.57	8.29 ± 11.6	0.74
Drug consumed (number)		9.33 ± 3.07	9.27 ± 3.38	0.94
Walking support	None	8 (29.7)	31 (42.4)	0.96
	Stick	7 (25.9)	18 (24.7)	0.93
	Frame	12 (44.4)	24 (32.9)	0.38
Katz index of independence (points)		18.3 ± 4.89	15.3 ± 4.87	< 0.01
History of falls the last 6 months (number)		2.33 ± 2.74	2.68 ± 11.7	0.88
History of repeated falls	yes	13 (48.1)	18 (24.7)	
Tinetti test (points)		16.9 ± 4.56	19.6 ± 4.41	< 0.01
Locometrix test				
Simple task				
Walking speed (m/s^2)		0.59 ± 0.19	0.68 ± 0.47	0.09
Stride length (m)		0.7 (0.54–0.83)	0.76 (0.59–0.96)	0.22
Stride frequency (cycles/s)		0.79 ± 0.19	0.83 ± 0.18	0.37
Stride regularity (arb.unit)		124 (96.0–153)	146 (91.0–183)	0.16
Stride symmetry (arb.unit)		186 (137–238)	180 (130–223)	0.33
Cranio Caudal mechanic power (W/kg)		0.45 ± 0.36	0.58 ± 0.51	0.16
Antero-posterior mechanic power (W/kg)		0.25 ± 0.19	0.34 ± 0.25	0.09
Medio-lateral mechanic power (W/kg)		0.30 ± 0.17	0.32 ± 0.21	0.54
Counting speed (number/s)		30.5 ± 15.8	40.2 ± 19.4	0.03
Dual task				
Walking speed (m/s^2)		0.43 ± 0.18	0.48 ± 0.21	0.28
Stride length (m)		0.59 (0.48–0.76)	0.68 (0.42–0.88)	0.33
Stride frequency (cycles/s)		0.71 ± 0.20	0.76 ± 0.21	0.26
Stride regularity (arb.unit)		95.0 (56.0–114)	93.0 (57.0–147)	0.39
Stride symmetry (arb.unit)		156 (140–199)	160 (129–200)	0.82
Cranio Caudal mechanic power (W/kg)		0.36 ± 0.36	0.37 ± 0.31	0.84
Antero-posterior mechanic power (W/kg)		0.20 ± 0.19	0.26 ± 0.17	0.17
Medio-lateral mechanic power (W/kg)		0.27 ± 0.16	0.29 ± 0.19	0.94
Counting speed (number/s)		41.9 ± 18.0	52.2 ± 28.2	0.10

4. Discussion

Gait disorders are common among elderly subjects. Indeed, gait abnormalities are present in 14% of individuals aged between 65 and 75 years and this figure increases with advancing age [21]. These abnormalities are in part responsible for falls among elderly people. Falls are one of the main causes of disability, injury and mortality among older adults and therefore constitute a major important public health issue [22]. According to a recent review, the most important underlying risk factors for falls in the elderly population are lower-extremity weakness, gait and balance instability, poor vision, cognitive and functional impairment, and sedating or psychoactive medications [23], even if fear of falling could also be a risk factor [24].

Therefore, it seems essential to get validated gait and balance assessment tools. Tinetti scale is a commonly used and widely accepted approach in clinical settings to assess mobility dysfunctions in elderly patients [25]. The Tinetti test has previously demonstrated its usefulness but additional quantitative parameters can be obtained by a tri-axial accelerometer. Indeed, some authors showed that the quantification of locomotion is an efficient way of evaluating the mobility and the risk of falling [26]. However, in our study, none of these gait and body balance assessment tools were independently predictive of the two-year risk of mortality or falls. A more recent systematic review shows that history of falls, walking aid use and moderate disability are the most predictive factors of falls among nursing home residents [27]. In contrast to these data, our study showed no predictive value of these factors, which could be explained by the small number of subjects included in our study and by the long follow-up of subjects compared to other studies. Indeed, patients evaluated after 2 years were probably the patients who were, initially, the healthiest.

This research showed no change over a 24-month period for the Tinetti test. However, we observed the degradation of some gait parameters: gait speed and regularity of gait cycles measured by simple and dual tasks, and step length measured by simple task were significantly reduced at the end of the study. Yet, the evolution of step length and regularity of gait cycles is correlated to the evolution of the Tinetti test. Consequently, the Tinetti test seems to be less sensitive to changes than some gait parameters assessed quantitatively with an accelerometer. This is in accordance with a recent study indicating that the quantitative measurement variables which characterize mobility in older adults are more sensitive and more specific predictors of falls that the Tinetti test [28]. However, although quantitative gait measurement variables assessed by a tri-axial accelerometer has been shown to be sufficiently sensitive to change, and although several studies have suggested a potential interest of this analysis to predict falls [13,29–31], in our study, this analysis did not appear predictive of falls or mortality.

This study followed up nursing home residents for the occurrence of mortality and falls, over a two-year period. Our study first reports the risk factors of mortality over a two-year period among nursing home residents. Variables of multiple domain of risk of mortality, including demographics and functional status were considered. After adjustment on potential confounding variables, only BMI was found to be statistically significantly associated with risk of mortality (i.e. a low BMI is associated with an increased risk of mortality). Our results are consistent with a Japanese study that showed that a low BMI (< 18.5 kg/m^2) is associated with an increased risk of all-cause mortality [32]. However, this last study was conducted on community-dwelling people aged over 80 years. Similarly, another study has shown that among elderly patients (mean age, 71 years) with hypertension, a low BMI was associated with increased risk of mortality [33]. These results are consistent with a recent review showing that low-weight and weight loss are independent predictors of mortality among the elderly population [34]. BMI is considered as a short-term mortality predictor among institutionalized elderly, but a consensus has not been reached on its role in predicting long-term mortality in nursing home residents [35]. In this regard, our paper adds important information regarding the long term impact of BMI on mortality. Several papers showed that age, male gender, high level of dependency and presence of comorbidities were the most predictive factors of mortality [5–10] but these findings relate to subjects either living in the community or hospitalized, but not to institutionalized subjects. In the present study, these parameters have been evaluated, but did not emerge as statistically significant.

Some strengths of this study are worth being mentioned. First, the inclusion criterion "Nursing Home" enabled, on one hand, the experiment to be conducted on a group of patients located geographically in the same type of institution and therefore living in environmental conditions relatively standardized. On the other hand, it was selective of a particularly at risk population. Indeed, some authors, but not all, have shown that the incidence of falls was higher among institutionalized persons than among community-dwelling people [36,37]. Secondly, analysis of the results obtained from the Locometrix® tool was implemented on the second run. Indeed, we observe an improvement of the variation coefficients between the first and the second run. This difference is probably due to the phenomenon of learning and it has been suggested that the second walked distance is more representative of the subject's gait [14]. Third, statistical analyses were performed by intention-to-treat that limits an attrition bias.

A limit of this study lies in the recruitment. Indeed we might have introduced a bias by enrolling only patients who were able to walk 2 times 30 meters. However, nearly 70% of the total population of the two nursing homes were studied. We also pointed out an attrition bias as there are some differences between the baseline characteristics of the group initially included and the group that performed the final evaluation. Potential information bias characterized by falls not reported by caregivers or omitted by the elderly person was minimized by a constant stimulation of caregivers and patients to ensure rigorous monitoring. Mortality in elderly people frequently results from multiple causes and a single aspect of health status is rarely the sole or dominant predictor [38,39] and we should admit that many confounding factors were not taken into account in this study. These factors include weakness and frailty, muscle mass and strength, level of physical activity, vitamin D status, nutrition and presence of cognitive impairment. At last, as many factors may be involved, a better assessment and precise origin of each fall and death might have provided interesting information.

5. Conclusion

In conclusion, quantitative gait analysis performed using a tri-axial accelerometer is not predictive of falls and mortality among nursing home residents, over a two-year period. In this study, only a decreased body mass index seems to be a predictor of mortality among patients living in nursing homes. However, many confounding variables (frailty, level of physical activity, or the presence of cognitive impairment) were not evaluated in this study and therefore our results should be interpreted with caution. During this long period of follow-up, no single factor was independently predictive of fall in this nursing home population.

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