3. Tinetti ME, Baker DI, McAvay G *et al.* A multifactorial intervention to reduce the risk of falling among elderly people living in the community. NEJM 1994; 331: 821–7.
4. Department of Health. The National Service Framework for Older People. 2001.
5. Ray WA, Taylor JA, Meador KG *et al.* A randomised trial of a consultation service to reduce falls in nursing homes. JAMA 1997; 278: 557–62.
6. Becker C, Kron M, Lindemann U *et al.* Effectiveness of a multifaceted intervention on falls in nursing home residents. J Am Geriatr Soc 2003; 51: 306–13.
7. McMurdo MET, Millar AM, Daly F. A randomised controlled trial of fall prevention strategies in old peoples' homes. Gerontology 2000; 46: 83–7.
8. Jensen J, Lundin-Olsson L, Nyberg L, Gusafson Y. Fall and injury prevention in older people living in residential care facilities. Ann Intern Med 2002; 136: 733–41.
9. Mahoney FI, Barthel DW. Functional evaluation: the Barthel ADL index. Mass Med J 1965; 14: 61–5.
10. Hodkinson HM. Evaluation of a mental test score for assessment of mental impairment in the elderly. Age Ageing 1972; 1: 233–8.
11. Matthias S, Nayak US, Isaacs B. Balance in elderly patients; the get up and go test. Arch Phys Med Rehabil 1986; 67: 387–9.
12. Tinetti ME. Performance orientated assessment of mobility problems in elderly patients. J Am Geriatr Soc 1986; 34: 119–26.
13. Lipsitz LA, Jonsson DV, Kelly MM, Koestner JS. Causes and correlates of recurrent falls in ambulatory frail elderly. J Gerontol 1991; 46: 114–22.
14. Donner A, Klar N. Design and Analysis of Cluster Randomisation Trials in Health Research. Arnold, 2000.
15. van Dijk PT, Meulenberg OG, van der Sande HJ, Habbema DF. Falls in dementia patients. Gerontologist 1993; 33: 200–4.

Received 2 November 2003; accepted 22 June 2004

Age and Ageing 2004; **33:** 602–607
doi:10.1093/ageing/afh218

Postural stability in the elderly: a comparison between fallers and non-fallers

I. Melzer, N. Benjuya, J. Kaplanski

Department of Clinical Pharmacology, Faculty of Health Sciences, Ben-Gurion University of the Negev and Key Institute of Education, PO Box 653, Beer-Sheva, Israel

Address correspondence to: J. Kaplanski. Fax: (+972) 7 6477629. Email: jacobk@bgumail.bgu.ac.il

Abstract

Background: the identification of specific risk factors for falls in community-dwelling elderly persons is required to identify older people at risk of falling.

Objective: the aim of the study was to determine the ability of various biomechanical measures of postural stability to identify fallers in the elderly population.

Method: 19 subjects (78.4 ± 1.3 years old) who reported having fallen unexpectedly at least twice in the last 6 months, and 124 non-fallers (77.8 ± 0.53 years old) participated in the study. Balance measurements were made in the upright position in six different conditions using a force platform, and the Limits of Stability Test was carried out. Static two-point discrimination (TPD) testing to the underside of the first toe was made to evaluate the innervation density of the slowly adapting receptors. Finally, maximal isometric lower limb strength was measured in major muscle groups. Repeated measures analysis of variance tests were performed to assess the mean differences between the two groups (fallers and non-fallers). The level of significance was set to 0.05.

Results and discussion: results suggest that control of balance in narrow base stance may be an important tool in identifying elderly fallers. The findings show an increase in mediolateral sway in narrow base stance in older people who experienced recurrent falls. Also, TPD appears to be impaired in elderly fallers (14.93 ± 1.1 mm versus 12.98 ± 0.3 mm).

Conclusions: simple and safe laboratory quantitative tests were able to differentiate between elderly fallers and elderly individuals who did not fall, suggesting a possible clinical application as a preliminary screening tool for predicting future risk of falling.

Keywords: *postural stability, force platform, centre of pressure, sway, limits of stability, falls, elderly*

Introduction

Balance and gait impairments in older people increase the risk of falls, which are the leading cause of accidental death and injury-related visits to emergency departments [1]. Overall, fall-related injuries constitute a public health problem associated with high financial costs as well as human suffering. The extent of the problem will continue to expand as the number of older people is projected to increase dramatically over the next few decades [1].

Thirty per cent of persons over 65 years old and 50% of persons over 80 years old experience at least one fall each year [2]. More than 90% of hip fractures occur as a result of falls [1]. One-quarter of older people who sustain a hip fracture die within 6 months of the injury. Hip fracture survivors experience a 10–15% decrease in life expectancy [3]. Most falls, however, do not result in significant physical injury or death, but the psychological impact of a fall can result in a fear of further falling, with an increased self-restriction of activities resulting in a decrease in physical and social activities, a greater risk of falling, and often leads to further dependence and a decline in overall quality of life [3–6].

Postural control is the foundation of our ability to stand and to walk independently. Deterioration in postural stability in older people may contribute to falls incurred during activities of daily life. Impaired balance has been correlated with an increased risk of falls [7]. Consequently, there is a crucial need to investigate postural instability in order to identify older people who are at risk of a falls-related injury or death, and to develop effective interventions for reducing balance impairment.

According to a logistic regression model, a score between 45 and 53 in the Berg Balance Test corresponds to individuals with a predicted probability of falling of between 20% and 75% [8]. A rational clinical approach for identifying fallers based on well designed studies was presented by the AGS/BGS/American Academy of Orthopedic Surgeons (AAOS) [9]. The falls prevention guidelines recommend that all older persons should be asked at least once a year about falls. Those who report a single fall should be examined using the 'Get up and Go Test'. Those who demonstrate balance and gait abnormalities or who have recurrent falls should have a more comprehensive falls evaluation that includes: a detailed history of previous falls, current medication, co-existing medical conditions, mobility difficulties, and an adequate clinical examination to include assessments of vision, gait and balance, lower extremity joint function, mental status, neurological status and assessment of cardiovascular function [9].

The present study aims to explore whether simple biomechanical tests can identify those older people who have fallen at least twice during the past 6 months, and to determine which parameter might prove most beneficial in identifying fallers.

Methods

Participants and design

One hundred and forty-three healthy volunteers aged 65 and over participated in an observational cohort study with retrospective documentation of falls. The subjects were tested in the biomechanical laboratory, and the clinical history including information on falls during the previous 6 months was collected by interview (Table 1). Nineteen of those subjects (mean age 78.4 ± 1.3 years old) reported having fallen at least twice during this time (fallers) and 124 subjects were defined as non-fallers (mean age 77.8 ± 0.53 years old).

Table 1. Physical and medical characteristics of faller and non-faller groups (mean ± SEM)

	Non-fallers	Fallers	*P* value
Age (years)	77.8 ± 0.53	78.4 ± 1.3	0.66
Height (cm)	159.2 ± 0.8	161.7 ± 1.7	0.20
Weight (kg)	68.3 ± 1.2	70.7 ± 2.2	0.42
Footlength (cm)	23.3 ± 0.2	23.3 ± 0.4	0.97
Number of females/males	91/33	16/3	0.4*
Number of medications per day	3.5 ± 0.3	4.3 ± 0.8	0.32
Number of diseases	4.0 ± 0.2	4.2 ± 0.6	0.78
Incontinence	1.1 ± 0.04	1.2 ± 0.12	0.63*
Dorsiflexion strength (Nm)	23.3 ± 1.3	18.3 ± 2.9	0.14
Plantar flexion strength (Nm)	55.3 ± 4.2	49.1 ± 3.7	0.50
Knee extensors strength (Nm)	98.2 ± 12.4	79.4 ± 18.7	0.44
Knee flexors strength (Nm)	48.9 ± 6.7	39.9 ± 8.8	0.45

P value compares baseline using independent (unpaired) *t*-test. Mean ± SEM in the two groups, unless otherwise indicated (**P* value based on chi-square). Nm = Newton metres.

Recruitment

The subjects were recruited from the community through advertisements. The volunteers were exposed to a brief interview before further testing to ensure they met the inclusion criteria of: (1) aged at least 65 years; (2) able to stand independently for 90 seconds; and (3) able to walk 10 metres (with a stick if needed). Exclusion criteria were: (1) serious visual impairment; (2) impaired cognitive status (score of less than 24 on the Mini Mental State Examination); (3) neurological disorders (stroke (cerebral vascular accident), Parkinson's disease, multiple sclerosis); and (4) previous lower limb surgery.

Volunteers who satisfied the interview, and who provided informed consent in accordance with the approved procedures by the Helsinki Committee (ethical review board) in Ben-Gurion University and Soroka Medical Center, Beer-sheva, Israel, were then included in the study.

The sample size estimation was based on data presented by Melzer *et al.* [10]. The number of subjects required to detect significant changes in stability parameters for older subjects compared with the values for younger subjects was estimated as 20 for each age group. The estimation was two-sided. Based on data presented by Salva *et al.* [11], 3.8% of men and 10.9% of women reported multiple falls, and Stalenhoef *et al.* [12] reported recurrent falls occurring in 19% of elderly subjects. Therefore, it was estimated that 10–20% of volunteers would report at least two falls, and that a sample size of 150 would produce an actual group of 15–30 fallers. We were able to recruit 143 older people in a 2-year period.

Multiple fallers were chosen because: (1) one unexpected fall can be a random event that does not reflect a balance disorder; (2) two or more falls would be more appropriate/

reliable for retrospective study, and this also enhances the difference between the two groups; and (3) multiple fallers show a significant increased mortality [13].

Measurements

Subjects were instructed to stand as still as possible on a single forceplate (AMTI, Watertown, MA, USA), with their hands folded behind their back. Six stability tests were registered over a period of 20 seconds: (1) wide stance [10], (1a) eyes open, (1b) eyes closed (blindfolded), (1c) eyes open standing on foam; and (2) same as (1a–c) performed in narrow stance (heels and toes touching). Centre of pressure (COP) data during the stability tests were sampled at a frequency of 100 Hz.

The Limits of Stability Test was measured in wide [10] and narrow stance, with the subjects instructed to lean forward, backward, left and right as much as they could, without bending the hips or lifting the heels or toes off the ground. Subjects were able to practise several times before the actual test. Strength measurements were made by having the subjects achieve Maximum Voluntary Isometric Contraction (MVIC) for 5 seconds, in ankle plantar and dorsi flexors, and knee flexors and extensors on the dominant leg using isokinetic dynamometer (Biodex-system2; Shirlery, NY, USA). The peak torque of three trials was taken.

Static two-point discrimination (TPD) testing of the skin of the underside of the first toe was made using a discriminator. The subject's task was to determine whether one or two prongs were touching them. The smaller the distance between the prongs that the subject could detect, the more sensitive the sense of touch. The static TPD test evaluates the innervation density of the slowly adapting fibre. The subject's two-point value was that at which he gave two correct answers out of three. The static TPD test has been found to be a valid measure of functional sensitivity in the hand [14], and a much greater variation was expected in the feet owing to variation in thickness of the skin.

Statistical analysis

The stability data were normally distributed (Shapiro–Wilks statistic). For each balance measurement, repeated measures analysis of variance (ANOVA) for the two groups (fallers versus non-fallers) and the six postural conditions was performed to assess the mean differences between the two groups in the following dependent variables: (1) COP path length; (2) COP velocities; (3) elliptical area; (4) medio-lateral (ML) sway; and (5) antero-posterior (AP) sway.

For the Limits of Stability Test, repeated measures ANOVA for the two groups (fallers versus non-fallers) and two postural conditions (narrow versus wide stance) was carried out to evaluate differences in maximum COP path length in AP and ML directions in centimetres.

To evaluate whether there were differences between the groups in muscle strength of the four lower limb muscles, repeated measure ANOVA (two groups × four muscle groups) was made to compare MVIC in Newton metres (Nm).

TPD values of groups were compared using the Independent (unpaired) t-test. Chi-square test was used for categorical variables. The results are presented as mean ± SEM with a two-tailed probability of 5%.

Results

There were no significant differences in age, weight, height and foot length between fallers and non-fallers. Differences in the number of co-existent diseases, types of diseases (diabetes mellitus, hypertension) and number of medications reported by the fallers and non-fallers were not statistically significant; and the percentage of female fallers was not significantly higher than in the non-fallers group (Table 1).

Wide stance

No significant differences were found between groups in postural stability in wide stance (Table 2A), suggesting that testing in wide stance cannot detect differences in postural stability between groups.

Narrow stance

Table 2B shows significant differences between fallers and non-fallers in most COP-based measurements in narrow stance. Fallers had significantly higher COP path length, COP velocity and ML sway in the eyes open condition, compared with non-fallers (21.6%, 26.3% and 27.5%, respectively). When standing on foam, fallers had significantly higher elliptical area and ML sway compared with non-fallers (14.1% and 28.5%, respectively).

With eyes closed, fallers had a significantly higher COP path length, COP velocity, elliptical area and ML sway (25%, 27%, 34.8% and 30%, respectively).

Multiple regression analysis revealed that those who had a higher ML sway had a three times higher risk of falling.

Limits of stability

AP displacement (cm) in wide stance was 11.5 ± 0.4 in non-fallers versus 9.4 ± 1.9 in fallers ($P = 0.07$), and 10.4 ± 0.4 versus 8.7 ± 0.8 (respectively) in narrow stance ($P = 0.08$). Non-significant differences were found in ML displacement (cm) in wide stance between non-fallers (15.2 ± 0.6) and fallers (13.7 ± 1.5) ($P = 0.44$) and in narrow stance (8.2 ± 0.3 versus 7.9 ± 0.6, respectively ($P = 0.67$)).

Lower limb isometric muscle strength

No significant differences were found in knee flexors, extensors and ankle plantar and dorsiflexors MVIC between fallers and non-fallers (Table 1).

TPD

Fallers had significantly poorer two-point discrimination with a value of 14.93 ± 1.1 mm compared with 12.98 ± 0.3 mm in the non-fallers group (Figure 1).

Discussion

Falls prevention is an important part of health care of the elderly. An ability to identify older people who have fallen, and to identify the risk of future falls, is needed in order to target high-risk individuals for preventive intervention. An attempt was made to assess the ability of a simple biomechanical test to identify elderly fallers.

Nineteen out of 143 healthy elderly volunteers (13.3%) reported two or more unexpected falls during the past 6

Table 2. Centre of pressure-based measures during wide base stance (feet apart) and narrow base stance (feet placed together) in three postural conditions (mean ± SEM)

		Non-fallers	Fallers	*P* value
(A) Wide base stance				
Eyes open	COP path (cm)	20.8 ± 0.9	22.0 ± 1.7	0.53
	Elliptical area (cm^2)	1.65 ± 0.1	1.96 ± 0.4	0.41
	COP velocity	1.0± 0.1	1.1 ± 0.1	0.53
	M-L sway (cm)	0.99 ± 0.09	1.1 ± 0.1	0.32
	A-P sway (cm)	1.99 ± 0.08	2.0 ± 0.1	0.65
Eyes closed	COP path (cm)	26.7 ± 1.3	29.2 ± 3.0	0.48
	Elliptical area (cm^2)	1.96 ± 0.2	1.66 ± 0.2	0.30
	COP velocity	1.3 ± 0.1	1.45 ± 0.15	0.52
	M-L sway (cm)	1.05 ± 0.08	1.0 ± 0.07	0.67
	A-P sway (cm)	2.3 ± 0.09	2.4 ± 0.2	0.63
Eyes open, standing on foam	COP path (cm)	35.6 ± 1.9	39.3 ± 5	0.48
	Elliptical area (cm^2)	4.3 ± 0.4	5.3 ± 0.9	0.34
	COP velocity	1.8 ± 0.1	1.96 ± 0.3	0.48
	M-L sway (cm)	1.9 ± 0.07	2.1 ± 0.2	0.35
	A-P sway (cm)	2.8 ± 0.1	3.2 ± 0.2	0.21
(B) Narrow base stance				
Eyes open	COP path (cm)	38.9 ± 1.1	47.3 ± 2.8	0.01
	Elliptical area (cm^2)	5.6 ± 0.3	6.7 ± 0.7	0.16
	COP velocity	1.9 ± 0.1	2.4 ± 0.1	0.01
	M-L sway (cm)	2.9 ± 0.09	3.7 ± 0.2	0.005
	A-L sway (cm)	2.5 ± 0.08	2.4 ± 0.15	0.88
Eyes closed	COP path (cm)	52.7 ± 2.1	65.7 ± 5.9	0.03
	Elliptical area (cm^2)	8.9 ± 0.5	12.0 ± 1.5	0.03
	COP velocity	2.6 ± 0.1	3.3 ± 0.3	0.03
	M-L sway (cm)	3.6 ± 0.1	4.7 ± 0.4	0.009
	A-P sway (cm)	3.1 ± 0.1	3.5 ± 0.3	0.17
Eyes open, standing on foam	COP path (cm)	51.8 ± 1.9	58.9 ± 5.4	0.16
	Elliptical area (cm^2)	8.5 ± 0.7	13.3 ± 4.3	0.047
	COP velocity	2.6 ± 0.09	2.9 ± 0.27	0.16
	M-L sway (cm)	3.4 ± 0.14	4.5 ± 0.59	0.014
	A-P sway (cm)	3.2 ± 0.11	3.5 ± 0.33	0.22

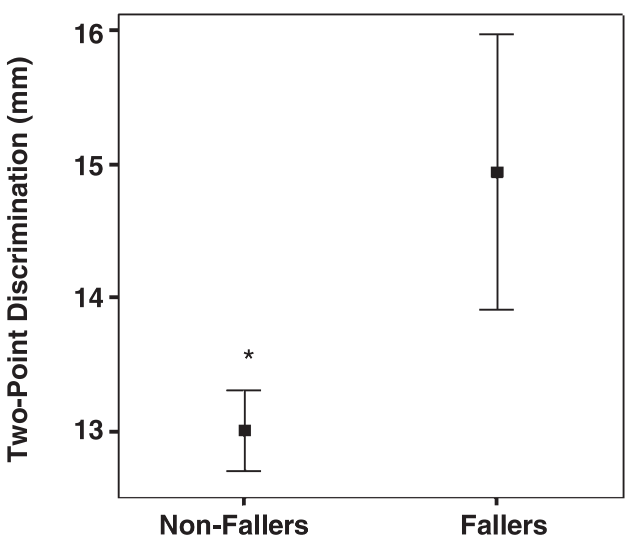

Figure 1. Two-point discrimination in millimetres (mm) in fallers and non-fallers (mean ± SEM). $^*P < 0.05$ significant difference non-fallers versus fallers.

months, 84.2% were female (compared with 73.4% female in the non-fallers group). Although intrinsic factors such as the number and type of co-existent disease and prescribed medications are reported to cause imbalance in the elderly [15], no significant differences were found in the present study. The lack of a statistically significant difference probably reflects the small sample size that was based on stability parameters.

COP-based findings showed that testing balance in wide stance was insufficient to discriminate elderly fallers. However, those who experienced recurrent falls showed an imbalance in narrow stance. Brauer *et al.* [16] found that COP motion in wide stance, and limits of stability, had a poor ability to predict fallers. However, by not monitoring sway in narrow stance, the authors have lost much information that might have changed their conclusions. Control of lateral stability (ML sway) appears to be a major variable in narrow stance, and loss of this was associated with falling. Regression models show that older people with increased ML sway in narrow stance were three times more prone to falling than those who had a lower ML sway. Fallers in the study by Maki *et al.* [17] showed increased ML COP excursions in both spontaneous sway and, in the induced sway test, lateral spontaneous sway was the single best predictor of future falling. Also, Lord *et al.* [18] found that subjects with a history of falls had increased ML sway in a near-tandem stability test with eyes open and closed. Fallers also had poorer visual acuity, proprioception and quadriceps strength [18]. In a 1-year prospective study, Lord *et al.* [19] found that discriminant function analysis identified visual contrast sensitivity, lower limb proprioception, quadriceps strength, reaction time and sway on foam with the eyes open as the variables that significantly discriminated between subjects who experienced multiple falls and subjects who experienced one fall or less.

Maki *et al.* [20] claimed that one of the more pervasive effects of ageing is loss of cutaneous sensation, which appears to correlate with impaired postural control and an increased risk of falling. Plantar cutaneous sensation appears to play an important role in certain aspects of postural control [21, 22]. Fallers in the present study had higher TPD values on the underside of the first toe. It may suggest that reduced plantar cutaneous sensation contributes, in part, to the impaired balance. We can speculate that impaired plantar cutaneous sensation in older people would delay compensatory step or grasp reaction times when a fall is initiated, owing to impaired ability to sense the COP movement under the feet. Menz and Lord [23] found that subjects with a history of multiple falls had a significantly greater foot problem than did those who had not fallen or who had fallen only once. In an earlier study, Benjuya *et al.* [24] suggested that, owing to reduction in foot sensation, older people adapt ankle co-contraction strategy to control balance.

Lord and Dayhew [25] found that subjects with good vision in both eyes had the lowest rate of falls, whereas those with good vision in one eye only or poor vision in both eyes had higher rates of falling. Turano *et al.* [26] found that subjects who reported falling in the last year showed less visual contribution to postural stability than those who reported no falls. Results of the present study indicate that somatosensory input appears to be more important than vision for elderly fallers especially in challenging conditions (narrow stance), whereas COP path length with the eyes blindfolded (no visual input) compared with the eyes open, increased by 35.5% in the non-fallers group, which is similar to fallers (38.9%). However, narrow stance on foam (reduction in somatosensory input) showed a 33.2% increase in COP path length compared with narrow stance without foam in the non-fallers group and only 24.5% in fallers. These findings suggest that fallers are less influenced by a reduction in somatosensory input from the feet, suggesting that both proprioception and cutaneous inputs are impaired in elderly individuals who fall and that they are less likely to use somatosensory information. These findings might associate between peripheral neuropathies, balance deficits and falls in older people. Also, Lord and Webster [27] claimed that the greater dependence on visual information shown by fallers in their study might be the result of reduced proprioceptive and vestibular function resulting from increased age and chronic health problems.

Less obvious is the association between falls and muscle strength. The present study shows no significant difference in lower limb muscle strength between fallers and non-fallers (Table 1). Similarly, Skelton *et al.* [28] found that 20 women with a history of falls were not significantly weaker compared with 15 women with no history of falls, apart from ankle dorsiflexion adjusted for body weight. The lack of a statistically significant difference between the groups may reflect the small sample size in both studies. However, Wolfson *et al.* [29] and Whipple *et al.* [30] found that both knee and ankle strength of fallers was significantly lower compared with non-falling subjects, with the ankles showing the greatest decrements.

In conclusion, there is evidence that simple, safe force-plate measurement of spontaneous postural sway can identify elderly individuals at risk of falls and can permit a possible application as a preliminary screening tool for the risk of falling. Further prospective research is under way to investigate whether simple biomechanical evaluation can predict future falls in older people.

Key points

- Balance testing in narrow stance is able to discriminate between older people who experience recurrent falls and non-falling elderly individuals.
- Findings show an increase in sway in narrow base stance, especially in a medio-lateral direction, in older people who experience recurrent falls.
- Two-point discrimination on the underside of the first toe appears to be impaired in older people who report two or more recent falls.

References

1. Black SE, Maki BE, Fernie GR. Aging, imbalance and falls. In: Sharp JA, Barber HO, eds. The Vestibulo-ocular Reflex and Vertigo. New York: Raven Press, 1993, 317–35.
2. Burt CW, Fingerhut LA. Injury visits to hospital emergency departments: United States, 1992–95. Vital Health Stat 1998; 13: 1–76.
3. Weigelt JA. Trauma. In: Advanced Trauma Life Support for Doctors: ATLS. 6th ed. Chicago: American College of Surgeons, 1997, 26.
4. King MB, Tinetti ME. A multifactorial approach to reducing injurious falls. Clin Geriatr Med 1996; 12: 745–59.
5. Berg KO. Balance and its measure in the elderly: a review. Physiother Can 1989; 41: 240–6.
6. Mahoney JE. Immobility and falls. Clin Geriatr Med 1998; 14: 699–726.
7. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N Engl J Med 1988; 319: 1701–7.
8. Shumway-Cook A, Gruber W, Baldwin M, Liao S. The effect of multidimensional exercises on balance, mobility and fall risk in community-dwelling older adults. Phys Ther 1997; 77: 46–57.
9. Guidelines for the Prevention of Falls in Older Persons. American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. J Am Geriatr Soc 2001; 49: 664–72.
10. Melzer I, Benjuya N, Kaplanski J. Age-related changes of postural control: effect of cognitive tasks. Gerontology 2001; 47: 189–94.

11. Salva A, Bolibar I, Pera G, Arias C. Incidence and consequences of falls among elderly people living in the community. Med Clin (Barc) 2004; 122: 172–6.
12. Stalenhoef PA, Diederiks JP, Knottnerus JA, de Witte LP, Crebolder HF. The construction of a patient record-based risk model for recurrent falls among elderly people living in the community. Fam Pract 2000; 17: 490–6.
13. Bath PA, Morgan K. Differential risk factor profiles for indoor and outdoor falls in older people living at home in Nottingham, UK. Eur J Epidemiol. 1999; 15: 65–73.
14. Dellon AL, Mackinnon SE, Crosby PM. Reliability of two-point discrimination measurements. J Hand Surg [Am] 1987; 12(5 Pt 1): 693–6.
15. Lawlor DA, Patel R, Ebrahim S. Association between falls in elderly women and chronic diseases and drug use: cross sectional study. BMJ 2003; 327: 712–7.
16. Brauer SG, Burns YR, Galley P. A prospective study of laboratory and clinical measures of postural stability to predict community-dwelling fallers. J Gerontol A Biol Sci Med Sci 2000; 55: 469–76.
17. Maki BE, Holliday PJ, Topper AK. A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. J Gerontol 1994; 49: 72–84.
18. Lord SR, Rogers MW, Howland A, Fitzpatrick R. Lateral stability, sensorimotor function and falls in older people. J Am Geriatr Soc 1999; 47: 1077–81.
19. Lord SR, Ward JA, Williams P, Anstey KJ. Physiological factors associated with falls in older community-dwelling women. J Am Geriatr Soc 1994; 42: 1110–17.
20. Maki BE, Perry SD, Norrie RG, McIlroy WE. Effect of facilitation of sensation from plantar foot-surface boundaries on postural stabilization in young and older adults. J Gerontol Biol Sci Med Sci 1999; 54: 281–7.
21. Magnusson, Enbom H, Johansson R, Pyykko I. Significance of pressor input from human feet in anterior-posterior postural control. Acta Otolaryngol 1990; 110: 182–8.
22. Watanabe I, Okubo J. The role of the plantar mechanoreceptor in equilibrium control. Ann N Y Acad Sci 1981; 374: 855–64.
23. Menz HB, Lord SR. The contribution of foot problems to mobility impairment and falls in community-dwelling older people. J Am Geriatr Soc 2001; 49: 1651–6.
24. Benjuya N, Melzer I, Kaplanski J. Aging-induced shifts from a reliance on sensory input to muscle cocontraction during balanced standing. J Gerontol A Biol Sci Med Sci 2004; 59: 166–71.
25. Lord SR, Dayhew J. Visual risk factors for falls in older people. J Am Geriatr Soc 2001; 49: 508–15.
26. Turano K, Rubin GS, Herdman SJ, Chee E, Fried LP. Visual stabilization of posture in the elderly: fallers vs. nonfallers. Optom Vis Sci 1994; 71: 761–9.
27. Lord SR, Webster IW. Visual field dependence in elderly fallers and non-fallers. Int J Aging Hum Dev 1990; 31: 267–77.
28. Skelton DA, Kennedy J, Rutherford OM. Explosive power and asymmetry in leg muscle function in frequent fallers and non-fallers aged over 65. Age Ageing 2002; 31: 119–25.
29. Wolfson L, Judge J, Whipple R, King M. Strength is a major factor in balance, gait, and the occurrence of falls. J Gerontol A Biol Sci Med Sci 1995; 50: 64–7.
30. Whipple RH, Wolfson LI, Amerman PM. The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. J Am Geriatr Soc 1987; 35: 13–20.

Received 17 March 2004; accepted in revised form 18 June 2004