Objectives: To study whether balance, function, and other health status indicators can predict serious fall related injury in elderly women living at home.

Methods: In this prospective study, the authors took a random sample of 307 women aged 75 years and over (mean 80.8 years, response rate 74.5%), living in the community. Serious fall injuries which occurred over a period of during one year were recorded, together with baseline registrations of health, function, and tests of walking and balance.

Results: In all, 155 women (50.5%) fell one or more times. One hundred and fifty-six (51%) of the 308 falls resulted in a fall related injury, 74 (24%) in a serious fall related injury, and 40 falls (13%) resulted in fractures. The presence of rheumatic disorders, inability to rise from the floor, arthrosis of the hip, having had more than one fall during the one year follow up period, and an increased tendency to sway in the frontal plane when doing a calculation task were independent and significant predictors for serious fall related injury (fractures included). The independent predictors of fall induced fractures were experiencing more than one fall in the follow up period, cognitive impairment, and receiving care from professional or other.

Conclusion: The study suggests that rheumatic disorders and the inability to get up from lying on the floor were the strongest independent risk factors for serious fall related injury. Experiencing more than one fall in the follow up period and cognitive impairment are the strongest independent predictors for fall induced fractures. Age was not a significant predictor of serious fall related injury. Assessment of these markers is feasible in a clinical setting and is a useful way of identifying those who are at risk of serious fall related injuries.

Abbreviations: ADL, activities of daily living; CI, confidence interval; MMSE, Mini-Mental State Examination; OR, odds ratio
the Regional Committee for Ethics in Medical Research, but
the committee did not allow us to contact non-attendants.

**Power calculation**
Suppose that the true rate of serious fall related injury in the
population studied is 15% among subjects with one legged
stance less than median, and 30% among those with one
legged stance above median. It may then be shown that a
sample size of 300 implies a probability of 88% to detect a
statistically significant difference in serious fall related injury
prevalence between these two groups.

**Tests**
Clinical tests of balance and walking were carried out in the
research laboratory. The research leader instructed the
subjects and demonstrated how the tests should be
performed. The subjects were allowed to practise each test
once, and only one try was allowed. This limitation was set
up in order not to tire the participants and also to make the
test situation clinically relevant. All the participants managed
sufficiently well after one trial. The tests were always
performed in the same order.

**Standing on one leg, eyes open**
The subject was asked to stand on the preferred foot, to flex
the opposite knee to allow the foot to rise from the floor, and
to stand as long as possible with the arms hanging down. The
foot being used was not allowed to move from the base
position, but compensatory movements of the arms and of
the lifted leg were allowed. The time (in seconds) before the
subject touched the floor with the other foot was recorded.
The validity and reliability of this test have been demon-
strated.16 18 19

**Tandem stance, eyes open**
The heel of one foot was placed in front of and touching the
toes of the other, the arms hanging down. The subject was
not allowed to move the feet from the base position, but
compensatory movements of the arms were allowed.
Whether the subject could maintain this position for at least
30 seconds was recorded. This test is also found to be reliable
and valid.19 20

**Ability to climb stairs**
This was a test of ability to mount boxes of increasing heights
(10, 20, 30, 40, 50, 60, and 70 cm) without using a handrail.18
The test has been evaluated for validity, though not for
reliability.19 20 The height of the highest box mounted was
recorded. The results were dichotomised at the median;
30 cm or less versus 40 cm or higher.

**Getting up from lying on the floor**
This was scored according to whether the subject managed
without assistance or not and is a validated measurement.20

**Functional reach**
Functional reach is the maximum distance (cm) one can
reach forward in the standing position while maintaining a
fixed base of support. This measure is reliable, valid, and
sensitive to change.19 21

**Timed up and go**
The subject was instructed to rise from a chair, walk 3 m as
fast as possible, turn around, return, and sit down again,
wearing regular footwear and using customary walking aids
if necessary. No assistance was given.21 The outcome was the
time from when the subject's back left the back of the chair
until the buttock touched the seat again. The test is a reliable,
sensitive, and specific indicator of increased risk of falling.22 24

**Maximum and comfortable walking speed**
The subject was asked to walk at a comfortable speed for
29 m along a corridor, and then to walk the same distance as
fast as possible.23 The test has been evaluated for validity and
reliability.20 22

**Force plate tests**
A calibrated Kistler (Switzerland) force plate (40 × 60 cm)
was used to measure displacement of centre of pressure with
gain set at 1000. The vertical forces were recorded on a
computer and expressed as position and movements in the
sagittal and frontal planes. The force plate signals were
sampled for one second, for a total of 15 times, with a
sampling frequency of 1000 Hz. Software from PEAK
(Englewood, CO, USA) was used to calculate the position
and the movement of the centre of pressure, called “sway”.
Before testing, the test position was demonstrated for the
subjects who stood barefoot on the force plate with their feet
in a fixed position (heels together, each foot toeing out at a
30° angle from the sagittal plane).

For further analyses, the force plate test data were exported
to a computer program (M Gutormsen, Norwegian
University of Sports and Physical Education, University of
Oslo) and filtered with a second order Butterworth filter at
20 Hz, and the length (mm) of the sway path in the anterior-
posterior and the mediolateral directions were then calcu-
lated. Analyses of variance showed that the variance over
time was small compared with the between-subject variance,
and we therefore decided to use the accumulated data from
the full 15 second registration period for further analyses.

The subjects had to stand as still and as symmetrically as
possible, with their hands clasped behind their backs.
Spontaneous sway was measured under four different
conditions with at least one minute's rest in between: (1)
with eyes open and looking at a target 4 m straight ahead;
(2) blindfolded in the same position; (3) as in (1) while
checking whether simple calculations presented by the
research leader were correct or not; (4) with a version of
Stroop's test, where 25 coloured words representing the
names of colours are shown on a white screen, but where the
name of the colour does not correspond to the colour in
which the word is written, and where the subject is asked
to name the colour.25 Best subset regression showed that the
test situation where subjects performed calculations gave the
best prediction of falling, and the data from this test situation
were therefore used in the further analyses.

**Indicators of health status and function**
Activities of daily living (ADL) were scored according to
whether or not the subject needed assistance with indoor
mobility, outdoor mobility, grooming, dressing, eating,
shopping, preparing meals, heavy housework, light house-
work, and medication. The participants were asked to bring
all current medications for verification. The drugs were coded
according to the ATC coding system,27 and the number of
drugs taken on a regular basis was used as a global indicator
of use of medication. Factor analyses of the ADL data gave
two factors with Eigenvalues over 1.0, named “personal
ADL” (PADL) and “instrumental ADL” (IADL), respectively.
The factor PADL contained the items grooming, dressing,
toileting, and eating, and the factor IADL contained the items
shopping, preparing one’s own meal, doing heavy house-
work, and doing light housework. Disability in PADL and
IADL was defined as a dependency on at least one item
within the respective factor.2 Cognitive disability was defined
as less than a full score on the MMSE short version.28 Body
mass index (weight (kg)/height (m)2)29 was also calculated.

The participants were asked if they had ever had any of the
following diseases: stroke, Parkinson’s disease, heart disease,
Statistical analyses were carried out using the BMDP Statistics of paralysis (as a stroke), an epileptic seizure. Falls were a person coming to rest inadvertently on the ground or other Registration of falls and serious fall related injury not. In this study a fall was defined as "an event which results in a calculation task. Arthritis/arthrosis of the lower limbs, insomnia, depression, anxiety, or other diseases. They were also asked if they had had a lower limb amputated. The participants provided information about if they needed care from health professionals or somebody else, and whether they lived alone or not.

Registration of falls and serious fall related injury
In this study a fall was defined as "an event which results in a violent blow, loss of consciousness, sudden onset of paralysis (as a stroke), an epileptic seizure". Falls were registered by means of a "fall calendar" issued to each participant for a full year. Every third month, the calendar was returned to the project leader. The subjects were asked to fill it in daily and to mark the date and place of falling (indoors or outdoors) if a fall had occurred. Subjects who did not return the calendar were contacted. The participants were also encouraged to phone the study office when a fall had occurred. Fractures, dislocations, head injuries resulting in loss of consciousness, and other injuries resulting in medical care were defined as serious fall related injuries. Multiple fractures resulting from the same event were treated as a single case. All the calendars were returned; though six of the women had to be contacted. All the fall induced fractures were confirmed by the hospitals the women had been referred to.

Statistics
Statistical analyses were carried out using the BMDP statistical package. Logistic regression analyses are applied in order to test associations between falls resulting in serious fall related injury and the baseline characteristics. The dependent variable, serious fall related injury or fracture, was coded 0 = experiencing one serious fall related injury or more and 1 = experiencing no fall related injury or fracture. explanatory variables showing statistically significant associations with the outcome in bivariate analyses were finally included in a multivariate logistic regression model in order to identify independent risk factors for serious falls. A value of p<0.05 on the \( \chi^2 \) goodness of fit test was used as an indicator of a poor fit of the model to the data.

RESULTS
Eighty seven women experienced only one fall, and 68 women had two or more falls (range 2–11). More than half of the falls occurred outdoors (57.5%, 95% confidence interval (CI) 51.9 to 63.0). The number of indoor falls ranged between one and six, and for outdoors between one and eight. Most of the indoor falls occurred at home except for two falls in a theatre and one at a holiday home. In all, 308 falls were reported, of which 156 (50.6%, 95% CI 45.1 to 56.2) resulted in a fall related injury. In 74 cases (24.0%) the injury was categorised as serious. Forty falls (13.0%) resulted in fractures; 15 of the upper and 13 of the lower extremities, and 12 of ribs. An additional 34 falls (11.0%) resulted in injuries that required medical treatment. There was no significant relation between place of falling (indoor or outdoor) and whether the fall caused a serious injury or a fracture.

Explanatory variables for serious fall related injury and fractures, reaching statistical significance in bivariate analyses, are shown in table 1. The occurrence of falls resulting in injury was not related to age (grouped 75–79, 80+, odds ratio (OR) 1.9, 95% CI 0.9 to 3.9) or whether the person lived alone (OR 1.4, 95% CI 0.6 to 3.1). The corresponding odds ratios for fractures were 1.5 (95% CI 0.67 to 3.3) for age and 0.85 (95% CI 0.4 to 2.0) for living alone.

The risk for serious fall related injury and fracture was significantly associated with number of falls during the follow up period, OR = 2.2 (95% CI 1.2 to 4.3) for injury and OR = 13.6 (95% CI 1.2 to 30.7) for fracture. But the experience of one or more falls during the six months before the study was a significant risk factor neither for serious fall related injury nor for fracture. Regarding the balance platform measurements, the travel distance of the centre of pressure was dichotomised between the first and the second quartile. A value in the second quartile or higher was statistically associated with a threelfold increase in the probability of a
serious fall related injury during the follow up period. Four of the clinical tests were significant predictors of a serious fall related injury, namely: inability to rise from the floor, to climb steps and to stand on one leg, and the maximum walking speed. The strongest predictor was inability to rise from the floor. Women suffering from rheumatic disorders demonstrated an almost fourfold greater risk of serious fall related injury, and those suffering from arthrosis of the hip had a threefold greater risk (table 1).

The use of antihypertensive drugs was significantly related to serious fall related injury, but not the use of any other classes of drugs. A significant relation was observed between a submaximal score on the MMSE and a serious fall related injury. Needing care or suffering from a disability on primary or instrumental activities of daily living also predicted future falls resulting in injury (table 1).

The final models of the multivariate analyses regarding serious fall related injury are shown in table 2. The presence of rheumatic disorders or arthrosis of the hip, inability to rise from the floor, and a long centre of pressure travel path when standing still were significant and independent predictors of serious fall injuries. Having more than one fall during the follow up period, needing care, and cognitive impairment were all significant predictors of fracture (table 3).

**DISCUSSION**

This study confirms that falls may have serious consequences even for relative healthy and mobile elderly Norwegian women aged 75 years or older. The primary purpose of the work was to explore the relation between health, function, and balance on the one hand, and a serious fall related injury (including fractures) on the other. Our observation that 24% of falls resulted in serious fall related injury fits in with the Cochrane report by Gillespie et al., which found that 10%–20% of older people who fall present themselves for medical attention. We found a high frequency of falls resulting in a fracture, mostly hip fracture. This fits well with the finding that Oslo had the highest incidence of hip fracture ever reported.11 Earlier studies (some of these including only women; others both men and women) have shown that fractures occur in 4%–16% of falls,12 13 15–17 which fits well with our 13%.

Most fractures in the elderly, if not almost all, are caused by falls.10 12 Controlling for the other variables shown in table 1, the women who fell more than once had an almost 14-fold increased fracture risk (table 3) and a two and a half times greater risk of serious fall injury (table 2) compared with those with one fall or less. Roy et al suggest that variation in fall rates could explain a significant variation in the incidence of limb fractures across Europe.18 In his study, falls were recorded retrospectively and fractures prospectively. In our study, falls that had occurred before inclusion did not predict fall related serious injury or fracture.

One reason for the high frequency of fall and fall related injury in our study may be the careful recording of falls, where the participants were encouraged to phone the research leader whenever a fall had occurred. This may to some extent have counteracted the effect of forgetting the incidence of falls, a phenomenon believed to have a definite impact on this kind of research.41

“Inability to rise from the floor”, “rheumatic disorders”, “centre of pressure travel path in the frontal plane”, “arthrosis of the hip”, and “inability to climb steps higher than 30 cm” were the variables that increased the risk of serious fall injury (table 1) with a factor of 2.5 or more. This corresponds well with the findings of others.29 33 42 40 43–45 Schwartz et al found that a history of arthritis or rheumatism was associated with a higher risk of falling, but an association with serious fall injury has, to our knowledge, not been reported. Corticosteroid therapy is widely used in the treatment of rheumatic disorders and corticosteroid induced osteoporosis could explain the association between rheumatic disorders and falls resulting in injury.39 Considering the wide confidence intervals in tables 2 and 3, the estimates should be interpreted cautiously.

Performance based measurements of physical capacity, particularly measurements of balance and gait impairments, are strong predictors of the risk of falling among elderly people.2 9 11 Our results and those of Cummings et al29 show that such measurements are also important for prediction of the most damaging falls—that is, those that lead to hip fractures and other serious injuries. Inability to rise from the floor appears to be a promising predictive marker for falls resulting in injury. In our population, this clinical marker could identify those who had a greater risk of serious fall related injury and who were possibly more likely to benefit from intervention. Inability to rise from the floor may serve as a simple proxy measure for some of the balance, function, and health variables used in this study, and also as a marker of frailty.40 Cognitive impairment, the presence of at least two chronic conditions, and impaired balance and gait are associated with serious fall injury.29 This fits in with our results both regarding serious fall injury, including fracture, and when looking at predictors of fracture separately.29 In the present study, approximately 15% had to be excluded owing to poor general function and major cognitive impairment, and presumably these subjects had a higher risk of fall related injury.16 There was also some attrition to the study in the sense that 2% died or moved to an institution. This may have been related to injuries resulting from falls. Thus, our incidence estimates may be too low.

The significance of the centre of pressure travel path is supported by a case-control study identifying the degree of displacement of the body at waist level as a risk factor for

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**Table 2** Independent risk factors for serious fall injury: multivariate logistic regression analyses, final model

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>OR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rheumatic disorders*</td>
<td>3.8</td>
<td>1.2 to 11.7</td>
</tr>
<tr>
<td>Inability to get up from lying on the floor</td>
<td>3.0</td>
<td>1.3 to 7.2</td>
</tr>
<tr>
<td>Centre of pressure travel path in the frontal plane (outpoint between 1st and 2nd quartile) when doing a calculation task</td>
<td>2.4</td>
<td>1.1 to 5.3</td>
</tr>
<tr>
<td>Arthrosis of the hip*</td>
<td>2.4</td>
<td>1.1 to 6.5</td>
</tr>
<tr>
<td>More than one fall during the follow up period*</td>
<td>2.4</td>
<td>1.2 to 5.0</td>
</tr>
</tbody>
</table>

In none of these analyses did the x² goodness of fit test indicate a poor model fit.

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**Table 3** Independent risk factors for fracture: multivariate logistic regression analyses, final model

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>OR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>More than one fall during the follow up period*</td>
<td>13.8</td>
<td>1.2 to 107.7</td>
</tr>
<tr>
<td>Cognitive impairment</td>
<td>2.4</td>
<td>1.1 to 5.4</td>
</tr>
<tr>
<td>Needs care from health professional or somebody else*</td>
<td>2.2</td>
<td>1.0 to 4.9</td>
</tr>
</tbody>
</table>

In none of these analyses did the x² goodness of fit test indicate a poor model fit.
injuries falls. The association between abnormal balance registered by the travel path in the frontal plane and fall injuries may be explained by an increased tendency of people with balance problems to fall to the side, and falls to the side are more likely to result in fall related injury than falls in other directions. There is accumulating evidence that the effects of aging on balance is more accentuated in the mediolateral direction. Lord et al., Maki et al., and Bergland et al. found that the amplitude of movement of the centre of pressure in the mediolateral direction is an independent and significant predictor of falls. Physiotherapists often treat people with impaired balance in order to improve overall function and prevent further falls and fall related injury, and they use simple clinical tests to evaluate and predict function. Typical examples of performance based tests used in clinical practice are the one leg stance, stair climbing, functional reach, the timed up and go, and the ability to get up from lying on the floor. The force plate balance test is, however, not often used. According to our results, tests of the ability to get up from lying on the floor, stair climbing, the one leg stance, and walking speed could be useful in a clinical setting. A limitation of this study is the use of self reports for some of the clinical variables. Registrations based upon self reported functioning and actual performances are assumed to complement each other. In self reports, recall bias can be a problem when respondents have been asked to remember past events, especially if they are of a sensitive nature or have had severe consequences for the individual. However, self reported measures are generally considered reliable and valid, in the elderly as well as the general population. During the tests, the surroundings were fixed and the motor activities were carried out at the person’s preferred speed. The walking tests were performed in an empty corridor. If the corridor would have increased markedly. Unless a test can incorporate open and challenging environments, clinicians should be aware that the balance assessments currently in use have definite limitations for predicting falls. A clinical balance test where attention demanding or situation factors are also included might, at least theoretically, give a better prediction of fall related serious injury or fall induced fracture.

Key points

- 50.5% of the women fell one or more times.
- 24% of the falls resulted in fall related injuries.
- 13% of the falls resulted in fall induced fractures.
- Rheumatic disorders, inability to rise from the floor, arthritis of the hip, having had more than one fall during the one year follow up period (fractures included).
- Increased tendency to sway in the frontal plane when doing a calculation task were independent and significant predictor for serious fall related injury (fractures included).

REFERENCES