A classification tree for predicting recurrent falling in community-dwelling older persons

Stel, V.S.; Pluijm, S.M.F.; Deeg, D.J.H.; Smit, J.H.; Bouter, L.M.; Lips, P.T.A.M.

published in
Journal of the American Geriatrics Society
2003

DOI (link to publisher)
10.1046/j.1532-5415.2003.51452.x

document version
Publisher's PDF, also known as Version of record

A Classification Tree for Predicting Recurrent Falling in Community-Dwelling Older Persons

Vianda S. Stel, MSc, Saskia M. F. Pluijm, PhD,* Dorly J. H. Deeg, PhD,* Johannes H. Smit, PhD,† Lex M. Bouter, PhD,* and Paul Lips, MD, PhD*‡*

OBJECTIVES: To develop a classification tree for predicting the risk of recurrent falling in community-dwelling older persons using tree-structured survival analysis (TSSA).

DESIGN: A prospective cohort study.

SETTING: A community in the Netherlands.

PARTICIPANTS: One thousand three hundred sixty-five community-dwelling older persons ($\geq$65) from the Longitudinal Aging Study Amsterdam (LASA).

MEASUREMENTS: In 1995, physical, cognitive, emotional, and social aspects of functioning were assessed. Subsequently, a prospective fall follow-up, specifically on recurrent falls (two falls within 6 months) was conducted for 3 years.

RESULTS: The classification tree included 11 end groups differing in risk of recurrent falling based on a minimum of two and a maximum of six predictors. The first split in the tree involved two or more falls versus fewer than two falls in the year preceding the interview. Respondents with two or more falls in the year preceding the interview (n = 193) and with at least two functional limitations (n = 98) had a 75% risk of becoming a recurrent faller, whereas respondents with fewer than two functional limitations were further divided into a group with regular dizziness (n = 11, risk of 68%) and a group with no regular dizziness (n = 84, risk of 30%). In respondents with fewer than two falls in the year preceding the interview (n = 1,172), the risk of becoming a recurrent faller varied between 9% and 70%. Predictors in this branch of the tree were low performance, low handgrip strength, alcohol use, pain, high level of education, and high level of physical activity.

CONCLUSION: This classification tree included 11 end groups differing in the risk of recurrent falling based on specific combinations of a maximum of six easily measurable predictors. The classification tree can identify subjects who are eligible for preventive measures in public health strategies. **J Am Geriatr Soc 51:1356–1364, 2003.**

Key words: accidental falls; aged; classification; risk factors; survival analysis

Older persons fall often. Approximately 30% of the community-dwelling persons aged 65 and older fall at least once per year, and about 15% fall two or more times per year.[1–4] Falls may have serious consequences, such as injury and disability, that are a major threat to the independence and well-being of older adults.[4–6] Moreover, fall-related injuries rank as the third leading cause of years lived with disability, according to the World Health Organization report "Global Burden of Disease."[7] As a consequence, the healthcare costs associated with falls and fall-related injuries are high.[8] Because of these consequences, prevention of falls is mandatory. Several studies have shown that intervention strategies have beneficial effects on the risk of falling in community-dwelling older persons,[9–17] but because of efficiency and cost-effectiveness, interventions should preferably be focussed on older persons with a high risk of falls.[14,18] Therefore, a strategy to determine which older people are at high risk of falling is needed.

So far, risk profiles to identify community-dwelling older persons at high risk of falling were developed using multiple logistic regression modeling.[2,3,19–24] Despite the great merit of these risk profiles, they have some disadvantages in practice. The assessment is time-consuming because the healthcare provider should measure all predictors of the risk profile. Furthermore, the models might contain complex algorithms such as interaction terms and calculation of a risk score. Moreover, all studies so far have demonstrated that the likelihood of falling increases with the number of predictors present, but these models do not provide information about specific combinations of predictors. Knowledge of these might provide a more purposeful preventive strategy. The present study uses an

From the *Institute for Research in Extramural Medicine (EMGO Institute) and Departments of †Sociology and Social Gerontology and ‡Endocrinology, VU University Medical Center, Amsterdam, the Netherlands.

The study is based on data collected in the context of the Longitudinal Aging Study Amsterdam (LASA), which is funded by the Ministry of Health, Welfare, and Sports of the Netherlands. The study on falls was supported by ZonMw, The Hague.

Address correspondence to Paul Lips, MD, PhD, Department of Endocrinology, VU University Medical Center, PO Box 7057, 1007 MB Amsterdam, the Netherlands. E-mail: p.lips@vumc.nl

JAGS 51:1356–1364, 2003

0002-8614/03/$15.00

alternative statistical methodology, called tree-structured survival analysis. This method has been used to predict the probability of survival in patients with coronary heart disease,[25] cancer,[25,26] and acquired immunodeficiency syndrome.[27] With this method, several groups can be identified by a limited number of predictors and characterized by an empirically estimated risk of becoming a recurrent faller. The results provide an easy classification of subjects and a clear insight in specific combinations of predictors for falls.

The aim of the present study was to develop a classification tree for predicting the risk of recurrent falling in community-dwelling older persons using tree-structured survival analysis.

METHODS

Study Sample

The study was conducted within the Longitudinal Aging Study Amsterdam (LASA).[28] A random sample of older men and women (aged 55–85) stratified by age and sex and according to expected 5-year mortality, was drawn from the population in the west, northeast, and the south of the Netherlands. The baseline examination (1992/1993) was performed in 3,107 subjects. The sampling and data collection procedures have been described in more detail elsewhere.[29]

The present study was performed in a subsample of the LASA cohort, consisting of participants who were aged 65 and older as of January 1, 1996, participated in the second data collection cycle of LASA (1995/1996), and were living in the community (n = 1,421). Trained research nurses visited the respondents at home. After the second data collection cycle in 1995/1996, a 3-year follow-up on falls was conducted. Informed consent was obtained from all respondents, and the ethical review board of the VU University Medical Center approved the study.

Assessment of Falls

For 3 years, respondents were asked to report their falls weekly on a fall calendar and to mail the calendar page to the research center at the end of every 3 months. Respondents were contacted by telephone if they were unable to complete the fall calendar, if the fall calendar was not returned even after a reminder, or if it was completed incorrectly. A fall was defined as "an unintentional change in position resulting in coming to rest at a lower level or on the ground."[30]

Definition of Recurrent Faller

The choice of the definition of recurrent faller was based on previous research. A study in the context of LASA varied the definition of recurrent falling by varying the time unit in which two falls had to take place and by varying the number of falls per time unit.[31] The stringent definition (at least two falls within 6 months) showed the strongest association between the predictor cognition and the outcome. Other studies by this research group support a greater predictive value of fall risk profiles using the outcome variable "at least two falls within 6 months."[21–23,32] Therefore, this definition was adapted for the tree-structured survival analysis. The survival time was defined as the time to the second fall of a pair of falls that occurred less than 6 months apart.

Predictors

During the second data collection cycle of LASA (1995/1996), several aspects of physical, cognitive, emotional, and social functioning were assessed. The predictors for falls were based on a previous study in homes for the elderly in the Netherlands[32] and on literature.[3,19,20] Potential predictors for falls were classified into eight categories: sociodemographic characteristics, chronic diseases and medication use, physical impairments and general health, body composition, activity and mobility, psychosocial functioning, lifestyle, and other potentially fall-related predictors. All potential predictors for falls are presented in Table 1. Predictors that were included in the final classification tree are described in more detail below. (Descriptions of other predictors are available on request from the authors.)

Level of education was assessed by asking the respondent for the highest educational level completed, ranging from primary to university education. The responses were converted into years of education (range 5–18 years). High education was defined as more than 10 years of education. Dizziness was assessed by asking whether the respondent was dizzy regularly (yes/no). The number of falls in the year before the interview was asked retrospectively. Pain was assessed by asking whether the respondent had pain during the last 4 weeks.

Functional limitations were assessed with a questionnaire concerning the degree of difficulty of the following six activities of daily living (ADLs): climbing stairs, walking 5 minutes outdoors without resting, rising from and sitting down in a chair, dressing and undressing oneself, using own or public transportation, and cutting one's own toenails.[33,34] The scores on these six items were summed to a total score that ranged from 0 (does not have any difficulties with the activities) to 6 (has difficulties with all activities).

Physical performance was assessed using three tests, including the walking test (time needed to walk 3 meters, turn 180° and walk back), the chair stands (time needed to stand up and sit down five times with arms folded), and the tandem stand (ability to stand with one foot placed behind the other in straight line for at least 10 seconds).[35] For the walking test and chair stands, 1 to 4 points were given corresponding to the quartile of the distribution of time needed. The more time that was needed, the lower the physical performance scores. Subjects who did not complete the test were given a score of 0. For the tandem stand, 0 points were given to those who could not perform the tandem stand, 1 point to those who stood less than 10 seconds, and 2 points to those who stood at least 10 seconds. The three items were summed to a final score (range 0–10).[35]

Grip strength was measured using a strain-gauged dynamometer (Takei TKK 5001, Takei Scientific Instruments Co. Ltd, Tokyo, Japan). Respondents were asked to perform two maximum force trials with each hand. The maximum values of the right and left hand were summed and used as the final score.[36]

Physical activity was assessed with the validated LASA Physical Activity Questionnaire (LAPAQ).[37] Six "yes–no"

Table 1. Baseline Characteristics of the Participants (Non- and Once-Fallers vs Recurrent Fallers) (N = 1,365)

Potential Predictor Variables for Recurrent Falling	Non- and Once-Fallers (n = 1,028)	Recurrent Fallers[†] (n = 337)	*P*-value
Sociodemographic characteristics			
Age, years, mean ± SD	74.8 ± 6.2	76.8 ± 6.8	< .001*
Female, %	51.0	51.6	.83
Education, years, mean ± SD (range 0–18)	8.8 ± 3.3	9.3 ± 3.5	.02*
Living in highly urbanized area, %	26.3	35.0	.002*
Chronic diseases and medication use			
Number of chronic diseases, mean ± SD (range 0–6)	1.2 ± 1.1	1.4 ± 1.1	.008*
Osteoarthritis, %	42.0	52.5	< .001*
Medication use, n, median (25th–75th percentile)	2 (0–3)	2 (1–4)	< .001*
Physical impairments and general health			
Involuntary loss of urine, %	21.5	32.0	< .001*
Dizziness, %	12.2	29.9	< .001*
Systolic blood pressure, mmHg, mean ± SD	153.8 ± 26.1	150.3 ± 26.0	.04*
Orthostatic hypotension, %	13.5	13.1	.85
Visual impairment, %	16.8	26.9	< .001*
Hearing impairment, %	34.2	44.0	< .001*
Foot problems, %	26.9	31.0	.15
Poor self-perceived health (very poor or poor vs fair, good, or excellent), %	35.4	43.9	.005*
Hospital admission past 6 months, %	8.9	11.6	.14
≥ 2 falls in the previous year, %	9.2	29.6	< .001*
Pain, %	27.3	39.5	< .001*
Body composition			
Body weight, kg, mean ± SD	75.3 ± 13.0	72.7 ± 12.6	< .001*
Body height, meters, mean ± SD	166.9 ± 9.2	165.7 ± 9.3	.04*
Activity and mobility			
Number of functional limitations, mean ± SD (range 0–6)	1.3 ± 1.6	2.0 ± 2.0	< .001*
Performance tests, mean ± SD (range 0–10)	7.2 ± 2.7	6.1 ± 2.8	< .001*
Walking aid, %	3.4	7.3	.002*
Grip strength, kgf, mean ± SD	57.8 ± 19.9	52.7 ± 21.1	< .001*
Number of physical activities, mean ± SD (range 0–6)	3.4 ± 1.4	3.3 ± 1.5	.24
Psychosocial functioning			
Cognitive impairment (MMSE score ≤ 24), %	12.9	17.9	.02*
Depression (CES-D ≥ 16), %	12.8	19.5	.003*
Fear of falling (FES), median (25th–75th percentile) (range 0–30)	0 (0–3)	1 (0–5)	< .001*
Loneliness median, (25th–75th percentile) (range 0–11)[‡]	1 (0–3)	2 (0–4)	.005*
Living alone, %	38.0	40.4	.45
Lifestyle			
Alcohol use (number of glasses per week), median (25th–75th percentile)	3 (0–7)	3 (0–12)	.11
Current smoker, %	18.3	17.6	.76
Other potentially fall-related predictors			
Dogs and cats in household, %	16.5	19.9	.16
Special adjustments in house, %	26.1	32.3	.03*

Note: To compare the background characteristics of the non- and once-fallers (n = 1,028) and recurrent fallers (n = 337), a *t* test was used for continuous variables with a normal distribution, a Mann Whitney test was used for continuous variables with skewed distribution, and a chi-square test was used for categorical variables.
* $P < .05$.
† A recurrent faller was defined as a subject who fell at least two times within 6 months.
‡ Self-reported loneliness was assessed on an 11-point scale (1 = not lonely to 11 = very lonely). Participants were considered to be lonely when their score was 5 or higher.
MMSE = Mini-Mental State Examination; CES-D = Center for Epidemiologic Studies—Depression scale; FES = Falls Efficacy Scale.

questions from this questionnaire about the following activities of the previous 2 weeks were used: walking outside, cycling, light and heavy household activities, and two sport activities. The scores on these six questions were summed (range 0–6). Higher scores indicate a higher level of physical activity.

Alcohol consumption was assessed by asking the mean number of glasses of alcohol per week.[38]

Data Analysis

Tree-structured survival analysis (TSSA) was used for developing a risk model for recurrent fallers.[39,40] TSSA is an extension of classification and regression trees[41] to survival analysis.[39,40] The analysis started with the entire cohort, also called the root node. The root node was divided into subgroups. These subgroups were again partitioned, and a tree-structure was created. The groups that emerged without further splitting were called the end nodes. The predictor that was superior in identifying recurrent fallers during the 3 years of follow-up defined the best partition. To create a tree-structure with binary splits, each predictor was dichotomized (see last paragraph of Data Analysis). To determine the best partition at each node, two Kaplan-Meier survival curves were created for each dichotomized predictor (see Figure 1). The log rank statistic compared the Kaplan-Meier survival curves of the two resulting groups. The higher the value of the log rank statistic, the better the discrimination between the groups during 3 years of follow-up with respect to recurrent falling. Thus, at each node, the predictor with the highest significant value of the log rank statistic was defined as the best partition. According to this method, a large tree was constructed to capture all potentially important splits. Nevertheless, such a tree is statistically uninformative, because the end groups are small ($n \leq 5$).[42] Alternatively, a tree that is too small cannot predict recurrent fallers well. Therefore, the "pruning" algorithm, as previously reported,[42] was used to find the optimal tree size. In short, the values of the log rank statistics of all chosen predictors were placed in decreasing order. The first pruned tree resulted from locating the node in the tree with the smallest value of the log rank statistic and removing all its descendants. The second pruned tree was then obtained by reapplying this process to the first pruned tree. This process went on until all that remained was the root node. Then, the optimal tree was selected by plotting the number of end nodes (x-axis) against the smallest value of the log rank statistic (y-axis) and selecting the tree corresponding to the characteristic kink in the curve. Before the kink, the value of the log rank statistic decreased, whereas the number of end nodes increased.

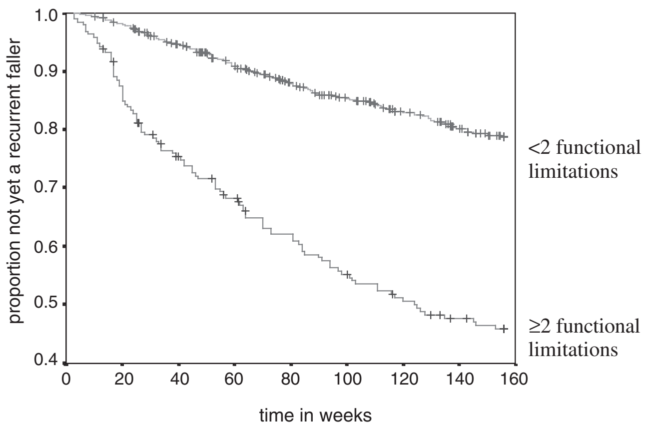

Figure 1. Kaplan-Meier curves for the prediction of recurrent falling for respondents with two or more functional limitations (lower curve) and respondents with fewer than two functional limitations (upper curve) at 3-year follow-up. + = censored.

After the kink, the values of the log rank statistic remained almost the same, and these predictors added no substantial information to the classification tree.

If two or more predictors had (almost) similar values of the log rank statistic, preference was given to the predictor that was easier to measure. The right-side node of each binary split contained the highest proportion of recurrent fallers during follow-up. Cases with missing values on the best splitting variable were sent to the left-side daughter node. Only potential predictors with less than 15% missing values were included. To avoid a power problem (especially in the lower part of the tree), only potential predictors with a prevalence of 15% or more were used for the development of the classification tree. Censored data concerned those in whom the 3-year fall follow-up was discontinued because they died, refused, or had severe physical or cognitive problems.

The cutoff points for cognitive impairment (Mini-Mental State Examination) and depression (Center for Epidemiologic Studies—Depression scale) were chosen at a preestablished point[43,44] and for orthostatic hypotension according to the clinical standard.[45] For continuous and several ordinal variables (chronic diseases, functional limitations, performance tests, physical activity, fear of falling, and loneliness), the cutoff points were specifically determined at each node of the tree. For these variables, the log rank value of the Kaplan–Meier survival curves of different cutoff points was determined at each node. For the continuous variables, the cutoff points of the 20th, 25th, 50th, 75th, and 80th percentiles were determined, whereas for the ordinal variables, cutoff points for every point of the rating scale were determined. The cutoff point with the highest log rank value was defined as the optimal cutoff point. Sex-specific cutoff points were determined for body weight, body height, and handgrip strength because of the substantial differences between men and women. Furthermore, two cutoff points were determined for the predictors age (<75 vs ≥ 75 and <80 vs ≥ 80 years) and the number of falls in the year before the interview (0 vs ≥ 1 and <2 vs ≥ 2 falls). For these two variables, the optimal cutoff point was again determined at each node.

RESULTS

Sample

Of the 1,421 eligible respondents, 56 (3.9%) did not participate in the study; 35 refused, 12 died before the fall follow-up started, eight had severe physical or cognitive problems, and one was lost to follow-up. To check for attrition, the 1,365 participants were compared with the 56 nonparticipants on all variables that were included as predictors with chi-square test or *t* test ($P < .05$). After correcting for age, the nonparticipants appeared to live significantly more often in rural areas; to report lower self-perceived health; to have cognitive impairment more often; and to have more functional limitations, lower physical performance, and a lower level of physical activity. One thousand three hundred sixty-five respondents were enrolled in this study: 667 men and 698 women with a mean age $\pm$ standard deviation (in 1995/1996) of 75.3 ± 6.4 (range 64.8–88.6).

Recurrent Faller

Of the 1,365 respondents, 1,092 (80%) completed all 12 periods of 3 months of the fall follow-up. Three hundred thirty-seven respondents (24.7%; 174 women and 163 men) reported at least two falls within 6 months during the 3-year follow-up and were defined as recurrent fallers. Table 1 shows the characteristics of respondents who reported no or one fall (non- and once-fallers) or at least two falls within 6 months (recurrent fallers) during the 3-year follow-up. With respect to most health-related and other potentially fall-related characteristics, recurrent fallers were significantly worse off than non- and once-fallers.

Within 3 years of follow-up, 460 respondents fell at least two times. Of these, 123 (26.7%) did not fall twice within a 6-month period and were not defined as recurrent fallers. One hundred two of these 123 respondents (82.9%) fell two times, 19 (15.4%) fell three times, and four (3.3%) fell four times within 3 years of follow-up. Of the 337 respondents who fell two times within 6 months and were defined as recurrent fallers, 276 (81.9%) reported three or more falls, and 210 (62.3%) reported four or more falls during the 3 years of follow-up. It can be concluded that the misclassification resulting from the used definition of recurrent falling is limited.

In the first year of follow-up, 143 respondents were defined as recurrent fallers, whereas in the second year, an additional 114 and in the third year, 80 respondents were defined as recurrent fallers. The hazard ratio for recurrent fallers per 100 person years was 10.2 at 1-year follow-up and 11.0 at 3-year follow-up.

The Classification Tree

The classification tree for the 3-year follow-up is presented in Figure 2. The classification tree consists of 11 end groups, each having a different risk of becoming a recurrent faller. The classification tree shows that a minimum of two and a maximum of six predictors can identify the end groups.

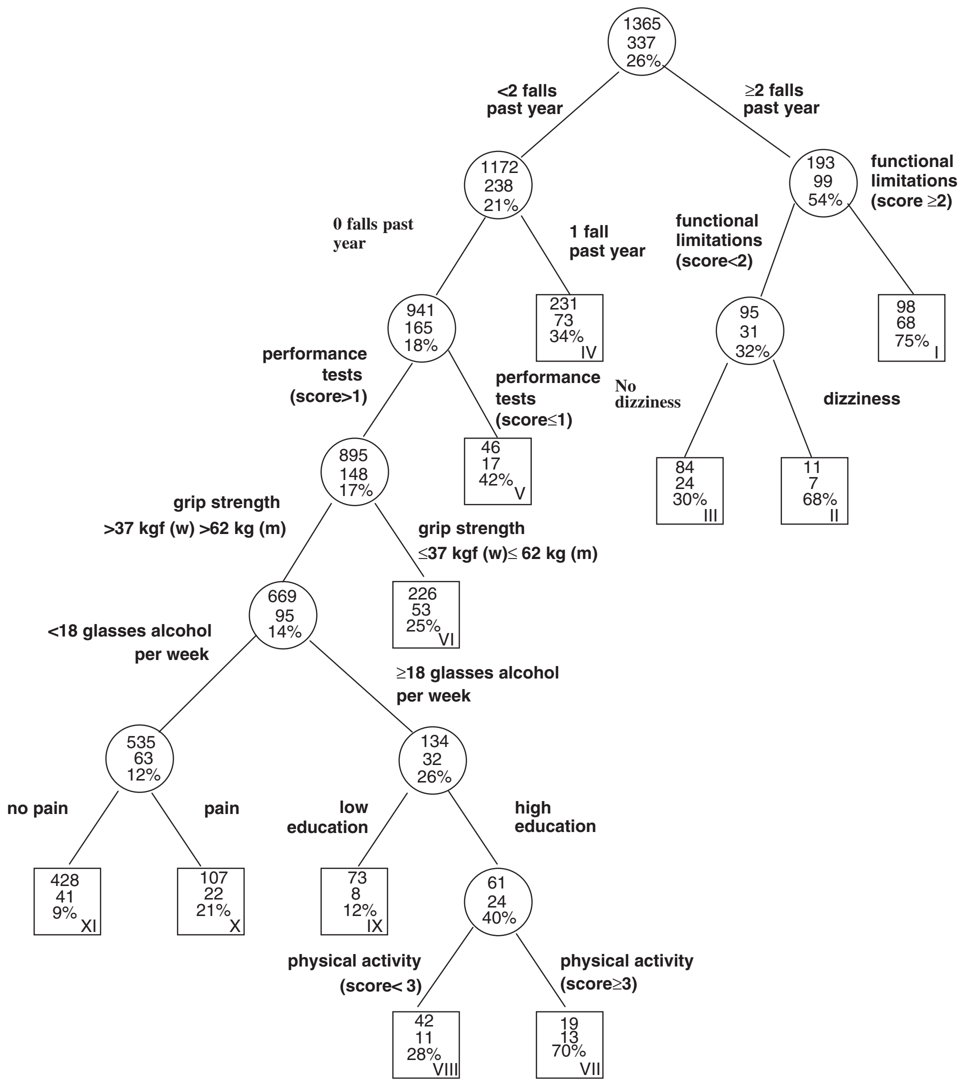

Figure 2. The classification tree for predicting the risk of recurrent falling in community-dwelling older persons at 3-year follow-up. Squares (Roman numerals) indicate the end nodes, and circles indicate the intermediate nodes. The squares and circles contain the group size (top number), the number of recurrent fallers (middle number), and the proportion of recurrent fallers at the end of 3 years of follow-up (bottom number). At each node, the split variable and cutoff values are shown on the resulting branches.

The first major split in the tree involved the predictor "two or more falls" versus "fewer than two falls" in the year before the interview (Figures 1 and 2). The 54% of the respondents who fell at least two times in the year before the interview became recurrent fallers in the 3 years of follow-up, whereas 21% of the respondents who fell fewer than two times in the year before the interview became recurrent fallers.

TSSA identified three end nodes for respondents who fell at least two times in the year before the interview (Figure 2). The group of subjects that had sustained two or more falls in the year before the interview and had two or more functional limitations formed end node I, with the greatest risk (75%) of becoming recurrent fallers in the 3 years of follow-up. Respondents with fewer than two functional limitations were further divided into those who reported dizziness and those who did not report dizziness and formed end group II, with a risk of 68%, and group III, with a risk of 30%.

The respondents who fell less than two times in the year before the interview were further divided into a group that fell one time and a group that did not fall in the year before the interview. Only one end group was identified for respondents who fell once in the year before the interview (end node IV, with a risk of 34%). For respondents who did not fall in the year before the interview, seven end nodes were identified. Respondents who did not fall in the year preceding the interview and scored no or one point on the performance tests formed end node V, with a risk of 42%. End node VII had the highest risk (70%) of this branch. This group was characterized by respondents who had no falls in the year preceding the interview, had a score of more than one on the performance tests, had a handgrip strength of more than 37 kg for women or more than 62 kg for men, drank 18 or more glasses of alcohol each week, were highly educated, and performed three or more physical activities in the past 2 weeks. End node XI formed the most favorable survival group of this cohort, with a risk of 9%. Respondents in this group had no falls in the year preceding baseline, had a score of more than one on the performance tests, had a handgrip strength of more than 37 kg for women or more than 62 kg for men, drank fewer than 18 glasses of alcohol per week, and had no pain. The risk of recurrent falls of the other end nodes (VI, VIII to X) varied between 12% and 28%. In this branch, it occurred once that, at one node, more than one predictor was candidate for the best partition (almost equal values of the log rank statistic). The predictors high level of education and physical activity (≥ 3 physical activities in the last 2 weeks) had similar log rank values.

Figure 3 shows the risk of becoming a recurrent faller and the confidence intervals of the end groups. Figure 3 clearly shows that end group I had the highest risk of becoming recurrent fallers. Furthermore, end groups II and VII also had high risks of becoming recurrent fallers, but the confidence intervals of these end groups are relatively large, because of the small numbers of respondents.

To examine whether the same variables predicted recurrent fallers at a follow-up of less than 3 years, a classification tree was developed at 1-year follow-up (Figure 4). The first split in the classification tree at 1-year follow-up involved two or more falls versus fewer than two falls in the year preceding the interview. The best split in the classification tree for respondents with two or more falls in the year preceding the interview (n = 193) was two or more functional limitations versus fewer than two functional limitations. Respondents with two or more falls in the year preceding the interview (n = 193) and with at least two functional limitations (n = 98) had a 42% risk of becoming recurrent fallers at 1-year follow-up. The best predictor in respondents with fewer than two falls in the year preceding the interview (n = 1,172) at 1-year follow-up was grip strength (men <60 kg and women <35 kg, with a risk of 12%, vs men ≥ 60 kg and women ≥ 35 kg, with a risk of 6%). The classification tree could not be further divided because of the limited number of recurrent fallers at 1-year follow-up. At the left side of the classification tree, respondents with no or one fall in the year before the interview had the same risk of becoming recurrent fallers in the first year of follow-up ($P<.05$), but after 1-year of follow-up, the risk of becoming a recurrent faller became higher in respondents who reported one fall than in respondents who reported no falls in the year before the interview.

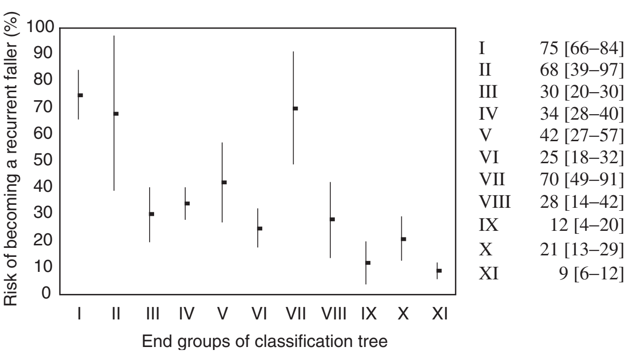

Figure 3. The risk of becoming a recurrent faller with 95% confidence intervals in the 11 end groups of the classification tree at 3-year follow-up.

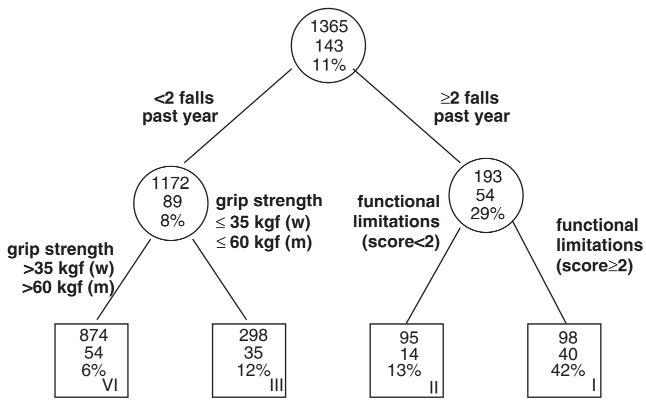

Figure 4. The classification tree for predicting the risk of recurrent falling in community-dwelling older persons at 1-year follow-up. Squares (Roman numerals) indicate the end nodes, and circles indicate the intermediate nodes. The squares and circles contain the group size (top number), the number of recurrent fallers (middle number), and the proportion of recurrent fallers at the end of 1 year of follow-up (bottom number). At each node, the split variable and cut-off values are shown on the resulting branches.

DISCUSSION

This is the first study using tree-structured survival analysis for the development of a classification tree for the prediction of falling. The results of this 3-year prospective cohort study showed a classification tree of 11 end groups, each having a different risk of recurrent falling. The end groups could be identified with a minimum of two and a maximum of six easily measurable predictors.

The definition of the outcome variable was based on previous findings. Predictors appear to be stronger for recurrent fallers (≥ 2 falls during the study period; often associated with an intrinsic cause) than for once-fallers (incidental falls often associated with an extrinsic cause).[3,31] When using a follow-up of 3 years, it is possible that a person fell once in the first year and once in the third year. Because these falls occurred 2 years apart, they might be incidental. Therefore, a more stringent definition of recurrent falling is needed. According to previous research (see also Methods section: definition of recurrent faller), predictive values appear to be greater using the outcome variable "at least two falls within 6 months" than with less stringent definitions.[21–23,31,32] Therefore, the survival time defined for the tree-structured survival analysis was based on the outcome variable at least two falls within 6 months. Additionally, the current study shows that only a few respondents who were not defined as recurrent fallers reported several falls during 3 years of follow-up. Alternatively, the majority of those who were classified as recurrent fallers reported more than two falls during the 3 years of follow-up.

In contrast to the fall risk profiles developed by multiple logistic regression, the classification tree clearly shows specific combinations of predictors identifying the different end groups. Respondents with two or more falls in the year before the interview had other predictors than respondents with one or no falls in the year before the interview. Moreover, in several studies, all respondents with at least two falls in the past year were classified as high risk and were eligible for intervention programs,[18,46] but from the classification tree it can be seen that not all end groups with at least two falls preceding the interview had a large risk of becoming recurrent fallers; respondents with at least two falls in the year preceding the interview who had fewer than two functional limitations and no dizziness had almost the same risk of becoming recurrent fallers (end group III, risk of 30%) as the total cohort (risk of 26%). For respondents with one fall in the year before the interview, further separation into recurrent and nonrecurrent fallers was not possible. This group probably consisted of relatively healthy respondents (even younger adults can fall sometimes) and relatively frail respondents (who might become recurrent fallers in the future). Additionally, from the classification tree, it can be seen that a small, relatively healthy, active group also had a high risk of falls (end group VII, risk of 70%). This is a highly educated group with a high level of physical activity and moderate to high alcohol use. The combination of alcohol and physical activity may increase fall risk, but risk profiles do not provide information about causal relationships, because no adjustments for relevant confounders were made.

The classification tree also provides practical advantages. First, the number of predictors that the healthcare provider should measure is limited. In the risk profiles developed using multiple logistic regression, all predictors included in the model need to be measured for identifying the risk of falls. However, with the classification tree, not all predictors in the tree need to be measured, because specific combinations of predictors identify different end groups. Few predictors can therefore identify several end groups. For instance, the risk of recurrent falling of respondents who fell at least two times in the year preceding baseline can be determined by additionally measuring only one or two easily measurable predictors. Second, the classification tree does not contain a complex algorithm. No score has to be calculated, because the risk profile gives rise to an end group with a matching risk for recurrent falls. Third, although risk profiles do not provide information about causal relationships, knowledge about the combination of predictors of the end groups might provide a more purposeful assignment of preventive strategies. For respondents from the high-risk end groups I and II, it might be useful to participate in an exercise intervention program to reduce the number of falls or to wear hip protectors to reduce the effect of falls.[47] End group VII (risk of 70%) consists of relatively healthy, active respondents with "risky" behavior. In this group, it might be more useful to provide information on risk factors for falls than to assign an exercise intervention program.

Existing risk profiles developed using logistic regression, which included similar predictors for falls, such as falls in the past year,[19,21] dizziness,[2] and inactivity and impaired mobility, support these findings. In a previous study in the context of LASA, a risk profile was developed with multiple logistic regression in the same participants and using the same data set as the current study. Similar predictors (falls in the past year, dizziness, functional limitations, poor mobility) were found to identify recurrent fallers (≥ 2 falls within 6 months) compared with the classification tree.[22,23] Additionally, in the previous and the current study, high levels of education and alcohol use were predictors for recurrent falling, whereas these predictors were not found in other fall risk profiles.

To examine the consistency of the predictors observed at 3-year follow-up, a classification tree at 1-year follow-up was developed. Similar predictors were found for the right side of the classification tree at 1- and 3-year follow-up. In the left side of the tree, minor differences were observed. The predictive values for identifying high-risk end groups of recurrent fallers were lower at 1-year follow-up than at 3-year follow-up, because of the limited number of recurrent fallers at 1-year follow-up. During follow-up, predictors could change values, but a majority of the respondents had no change in predictors after 3 years (data not shown). For instance, 80.7% and 82.7% of the respondents reported similar answers on dizziness and the number of functional limitations after 3 years.

Several limitations of the tree-structured survival analysis and the study need to be considered. First, the fall risk profile was not validated in another population. TSSA may involve a high risk of data fitting. Therefore, the fall-risk profile should be validated in a separate data set before it can be implemented in health care. However, it should be noted that the study was performed in a large sample of older men and women, with a long fall follow-up. Second, TSSA could identify more candidate splits (similar log rank values), and only one predictor is shown in the classification tree. Third, because this classification tree was developed in a group of relatively healthy community-dwelling older persons aged 65 and older, this fall risk profile cannot be generalized to institutionalized people. It should be noted that 3.9% of the eligible respondents (56 of 1,365) could not participate in the current study. Fourth, because the assessment of falls was based on self-report, nondifferential misclassification may have occurred. This may have led to an underestimation of the predictive power. Finally, the consequences of falls were not measured; thus, the risk of injurious falls could not be determined.

In conclusion, the classification tree consists of 11 end groups differing in the risk of recurrent falling in 3 years of follow-up. Moreover, the classification tree clearly shows specific combinations of predictors identifying the different end groups. Because groups with a high risk of recurrent falling can be easily identified with the classification tree, this fall risk profile seems to be a useful instrument in classifying the risk of becoming a recurrent faller in community-dwelling older people. Identification of risk groups can be used for preventive measures in public health strategies.

ACKNOWLEDGMENTS

The authors thank Jan Poppelaars, Mariëtte Westendorp, Els Lommerse, Sylvia Witteveen, Marieke van Asselen, and Mohammad Asad Abdullah for their help in collecting and processing the data and Natasja van Schoor for the useful advice.

REFERENCES

1. Tromp AM, Smit JH, Deeg DJ et al. Predictors for falls and fractures in the Longitudinal Aging Study Amsterdam. J Bone Miner Res 1998;13:1932–1939.
2. O'Loughlin JL, Robitaille Y, Boivin JF et al. Incidence of and risk factors for falls and injurious falls among the community-dwelling elderly. Am J Epidemiol 1993;137:342–354.
3. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N Engl J Med 1988;319:1701–1707.
4. Campbell AJ, Borrie MJ, Spears GF et al. Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study. Age Ageing 1990;19:136–141.
5. Tinetti ME, Williams CS. Falls, injuries due to falls, and the risk of admission to a nursing home. N Engl J Med 1997;337:1279–1284.
6. Vellas BJ, Wayne SJ, Romero LJ et al. Fear of falling and restriction of mobility in elderly fallers. Age Ageing 1997;26:189–193.
7. Murray CJL, Lopez AD. Global and regional descriptive epidemiology of disability: Incidence, prevalence, health expectancies and years lived with disability. In: Murray CJL, Lopez AD, eds. The Global Burden of Disease. Boston, MA: Harvard University Press, 1996, pp 201–246.
8. Alexander BH, Rivara FP, Wolf ME. The cost and frequency of hospitalization for fall-related injuries in older adults. Am J Public Health 1992;82:1020–1023.
9. Tinetti ME, Baker DI, McAvay G et al. A multifactorial intervention to reduce the risk of falling among elderly people living in the community. N Engl J Med 1994;331:821–827.
10. Buchner DM, de Cress ME, Lateur BJ et al. The effect of strength and endurance training on gait, balance, fall risk, and health services use in community-living older adults. J Gerontol A Biol Sci Med Sci 1997;52A:M218–M224.
11. Campbell AJ, Robertson MC, Gardner MM et al. Randomised controlled trial of a general practice programme of home based exercise to prevent falls in elderly women. BMJ 1997;315:1065–1069.
12. Campbell AJ, Robertson MC, Gardner MM et al. Falls prevention over 2 years. A randomized controlled trial in women 80 years and older. Age Ageing 1999;28:513–518.
13. Wolf SL, Barnhart HX, Kutner NG et al. Reducing frailty and falls in older persons: An investigation of tai chi and computerized balance training. J Am Geriatr Soc 1996;44:489–497.
14. Gardner MM, Robertson MC, Campbell AJ. Exercise in preventing falls and fall related injuries in older people: A review of randomized controlled trials. Br J Sports Med 2000;34:7–17.
15. Steinberg M, Cartwright C, Peel N et al. A sustainable program to prevent falls and near falls in community dwelling older people: Results of a randomized trial. J Epidemiol Community Health 2000;54:227–232.
16. Close J, Ellis M, Hooper R et al. Prevention of falls in the elderly trial (PROFET): A randomized controlled trial. Lancet 1999;353:93–97.
17. Gillespie LD, Gillespie WJ, Robertson MC et al. Interventions for Preventing Falls in the Elderly People. In: Cochrane Library, Issue 3, 2000.
18. Rizzo JA, Baker DI, McAvay G et al. The cost-effectiveness of a multifactorial targeted prevention program for falls among community elderly persons. Med Care 1996;34:954–969.
19. Nevitt MC, Cummings SR, Kidd S et al. Risk factors for recurrent nonsyncopal falls. A prospective study. JAMA 1989;261:2663–2668.
20. Campbell AJ, Borrie MJ, Spears GF. Risk factors for falls in a community-based prospective study of people 70 years and older. J Gerontol 1989;44: M112–M117.
21. Tromp AM, Pluijm SMF, Smit JH et al. Fall-risk screening test. A prospective study on predictors for falls in community-dwelling elderly. J Clin Epidemiol 2001;54:837–844.
22. Pluijm SMF, Smit JH, Tromp AM et al. Identifying community-dwelling elderly at high risk for recurrent falling. Results of a three year prospective study. In: Pluijm SMF. Predictors and Consequences of Falls and Fractures in the Elderly (PhD Thesis). Enschede: Ipskamp, 2001, pp 91–108.
23. Pluijm SMF, Smit JH, Tromp AM et al. Identifying community-dwelling elderly at high risk for recurrent falling. Results of a three year prospective study. Osteoporos Int 2002;13(Suppl. 1):S9.
24. Stalenhoef PA, Diederiks JPM, Knottnerus JA et al. Predictors of falls in community-dwelling elderly: A prospective cohort study. In: Stalenhoef PA. Falls in the Elderly: A Primary Care Based Study (PhD Thesis). Maastricht: Datawyse Universitaire Pers Maastricht, 1999, pp 101–123.
25. Carmelli D, Zhang H, Swan GE. Obesity and 33-year follow-up for coronary heart disease and cancer mortality. Epidemiology 1997;8:378–383.
26. Kwak LW, Halpern J, Olshen RA et al. Prognostic significance of actual dose intensity in diffuse large-cell lymphoma: Results of a tree-structured survival analysis. J Clin Oncol 1990;8:963–977.
27. Piette JD, Intrator O, Zierler S et al. An exploratory analysis of survival with AIDS using a nonparametric tree-structured approach. Epidemiology 1992;3:310–318.
28. Deeg DJH, Knipscheer CPM, van Tilburg W, eds. Autonomy and Well-Being in the Aging Population: Concepts and Design of the Longitudinal Aging Study Amsterdam. Bunnik: Netherlands Institute of Gerontology, 1993.
29. Smit JH, Vries de MZ et al. Data-collection and fieldwork procedures. In: Deeg DJH, Beekman ATF, Kriegsman DMW, eds. Autonomy and Well-Being in the Aging Population II. Report from the Longitudinal Aging Study Amsterdam, 1992–1996. Amsterdam: VU University Press, 1998, pp 9–20.
30. Kellogg International Work Group on the Prevention of Falls by the Elderly. The prevention of falls in later life. Dan Med Bull 1987;34:1–24.
31. van Schoor NM, Smit JH, Pluijm SMF et al. Different cognitive functions in relation to falls among older persons: Immediate memory as an independent risk factor for falls. J Clin Epidemiol 2002;55:855–862.
32. Graafmans WC, Ooms ME, Hofstee HM et al. Falls in the elderly. A prospective study of risk factors and risk profiles. Am J Epidemiol 1996; 143:1129–1136.
33. Kriegsman DM, Deeg DJH, van Eijk JT et al. Do disease specific characteristics add to the explanation of mobility limitations in patients with different chronic diseases? A study in The Netherlands. J Epidemiol Community Health 1997; 51:676–685.
34. Van Sonsbeek JLA. Methodological and substantial aspects of the OECD indicator of chronic functional limitations. Maandbericht Gezondheid (CBS) 1988;88:4–17.
35. Guralnik JM, Simonsick EM, Ferrucci L et al. A short physical performance battery assessing lower extremity function. Association with self-reported disability and prediction of mortality and nursing home admission. J Gerontol 1994;49:M85–M94.
36. Kallman DA, Plato CC, Tobin JD. The role of muscle loss in the age-related decline of grip strength: Cross-sectional and longitudinal perspectives. J Gerontol 1990;45:M82–M88.
37. Lips P, Pluijm SMF, Stel VS et al. Physical activity and the risk of falls in older men and women. J Bone Miner Res 2001;16:563.
38. Central Bureau of Statistics. Health Interview Questionnaire. The Hague: Central Bureau of Statistics, 1989.
39. Gordon L, Olshen RA. Tree-structured survival analysis. Cancer Treat Rep 1985;69:1065–1069.
40. Segal MR. Features of tree-structured survival analysis. Epidemiology 1997;8:344–346.

41. Breiman L, Friedman JH, Olshen RA et al. Classification and Regression Trees. Belmont, CA: Wadsworth, 1984.
42. Segal MR. Regression trees for censored data. Biometrics 1988;44:35–47.
43. Folstein MF, Folstein SE, McHugh PR. 'Mini-mental state'. A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 1975;12:189–198.
44. Radloff LS. The CES-D scale: A self-report depression scale for research in the general population. Appl Psychol Meas 1977;1:385–401.
45. Mader SL. Orthostatic hypotension. Med Clin North Am 1989;73: 1337–1349.
46. Hogan DB, MacDonald FA, Betts J et al. A randomized controlled trial of a community-based consultation service to prevent falls. Can Med Assoc J 2001;165:537–543.
47. Lauritzen JB, Petersen MM, Lund B. Effect of external hip protectors on hip fractures. Lancet 1993;341:11–13.