A Classification and Regression Tree for Predicting Recurrent Falling among Community-dwelling Seniors Using Home-care Services

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ABSTRACT

Objectives: A prospective, observational study was undertaken to identify risk profiles of subjects regarding the recurrence of falling among community-dwelling seniors using home-care services.

Methods: A convenience sample of 868 community-dwelling older persons, aged 65 years or older, who use home-care services offered by public community-based centres in the province of Québec. Subjects were recruited between 2002 and 2005, assessed for fall-related risk factors, and monitored for prospective falls. Data were examined by a classification and regression tree (CART) and survival analyses.

Results: Ninety-nine participants reported two falls within six months of entry to the study. Thus, the incidence of recurrent fallers was 11.4%. The tree analysis classified the population into five groups differing in risk of recurrent falling, based on history of falls in the three months prior to the initial interview, Berg balance score, type of housing, and usual alcohol consumption in the six months preceding study entry. The relative risks varied from 0.7 to 5.1. The survival analysis showed that the length of time before becoming a recurrent faller varies among risk profiles.

Conclusion: The study permitted the construction of easily interpretable risk profiles of recurrent falling. These can guide clinicians and public health practitioners to identify high-risk individuals and to decide on the appropriate intervention and follow-up.

Key words: Accidental falls; elderly; home care services; multiple classification analysis; prognosis; public health; risk factors; risk assessment; survival analysis

La traduction du résumé se trouve à la fin de l'article.

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Approximately 30% of community-dwelling persons, aged 65 or older, fall at least once per year, and about 15% sustain multiple falls.¹⁻⁴ Multiple falls are associated with an increased risk of institutionalization and death.^{4,5} In addition to injury, recurrent falls can reduce self-confidence, mobility, and social contacts.⁶

Numerous factors might contribute to falls.⁷ Some can be corrected and, thus, the event can be avoided. The most efficient interventions are those which target screened fallers with the highest risk of falling again, rather than elderly people identified indiscriminately.^{4,7,8}

The increasing number of elderly people is leading to greater demand for home-care services. Preventing falls among community-dwelling seniors using home-care services has become a priority in Québec.^{7,9} Nonetheless, risk factors for falling are overlooked in this specific population.^{4,6}

Clinicians are interested in predicting adverse outcomes. The aim of this study has been to develop profiles for predicting the risk of recurrent falling, using a classification and regression tree-based survival analysis.

METHODS

Setting and subjects

The sample studied here was a convenience sample of volunteers recruited between March 2002 and July 2005 among community-living persons, aged 65 years or older, who were receiving public

home nursing care, personal care and support services because of a temporary disability or a loss of functional autonomy.¹⁰ People who could speak neither French nor English, those not able to walk more than six metres, and those with reduced communication and cognition according to the Functional Autonomy Measurement System¹⁰ were excluded. All subjects gave informed consent. The study was approved by the authorities of each participating centre.

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Additional methodological details are provided elsewhere.¹¹ Of the 959 persons who met the study inclusion criteria and agreed to participate, 868 participants were used in the analyses (Figure 1).

Assessment of falls and predictors

A fall was defined as an event resulting in the subject inadvertently coming to rest on the ground, floor, or other lower level. Excluded were sports-related falls.¹ The outcome was measured by self-report using monthly telephone questionnaire. A falls calendar was previously given to individuals to mark events each time they appear. Recurrent fallers were subjects who had fallen twice within the first six months of follow-up.^{3,12}

Potential predictors of recurrent falling and subjects' characteristics were ascertained at baseline at home. Number of falls in the prior three months was categorized as 0, 1, or ≥ 2 . Nutritional screening was performed on a graded 13-point scale to identify individuals at high risk of energy and nutritional intake deficiencies. Pre-established categories were defined as follows: 0-2, 3-5, and 6-13.^{13,14} Body weight was self-reported and height was measured. BMI values were defined as ≤ 20 , 21-29, and ≥ 30 . Gait and balance were assessed by the Berg scale¹⁵⁻¹⁷ on a 56-point scale (≤ 30 , 31-44, and ≥ 45), and by the Timed Up & Go test^{18,19} which measures the overall time, in seconds, to complete a series of functional tasks (≤ 20 , 21-29, and ≥ 30). The cutoff values used in the study are those proposed by the developers of each clinical risk assessment tool. Data about the use of benzodiazepines (yes/no) and number of daily consumed prescribed drugs were recorded from the containers. A history of alcohol consumption was obtained according to the Institut de la statistique du Québec questionnaire.^{20,21} Responses were categorized for both drinking in the preceding week (yes/no) and usual drinking during the last six months (non-drinker, <1-3 times a month, 1-6 times a week, every day). Subjects' homes were assessed for 37 environmental hazards using a standardized checklist with unknown validity and reliability.²²⁻²⁴ Overall and room-specific hazard scores were computed by counting the number of home hazards. Housing types included: single-family house; apartment building; row housing or other unique-entrance dwelling units; private community-based retirement facilities; other housing, including room in shared accommodation. Generally speaking, higher values of the measurements denoted higher risk, except for the Berg score where the opposite was true.

Statistical analyses

Statistical analyses were carried out using SPSS® version 15.0. We considered two-tailed p-values less than 0.05 as significant. A two-step analysis was performed to develop risk factor profiles for the prediction of recurrent falling.²⁵

We first performed a classification and regression tree (CART) analysis using AnswerTree SPSS® version 3.1.1. CART is a technique that recursively splits a parent group into two subgroups (called "nodes") within which covariates are homogenous and between which outcome is distinct.^{26,27} The partitioning algorithm started with the covariate and split threshold that best maximized the difference in the outcome between two subgroups. The process was repeated until the first occurrence of either: no covariate significantly dichotomized the nodes further nor did any subgroup reach a minimum specified size (parent node of 25 subjects and child node of 15).

Figure 1. Flow chart describing the study sample of community-dwelling seniors using home-care services

We next conducted a Kaplan-Meier analysis^{28,29} within each group to compare their risk of falling over time. The survival time was defined as the time to the second fall where the falls occurred less than six months apart. Data were censored upon reaching a specified time point earlier, withdrawal for any reason, or end of follow-up period. The log-rank (Mantel-Cox) test identified differences in the cumulative survival curves for all possible pairs of terminal nodes identified. The Bonferroni-Holm correction of alpha value was used for multiple comparisons.³⁰

RESULTS

Altogether 99 of 868 participants reported two falls within six months of entry to the study. Thus, the incidence for recurrent falling was 11.4%. Of the 769 non-recurrent fallers, 151 (19.6%) reported one fall, while the others did not declare any event. Study subjects were mainly women (77.2%), of whom 76.2% were 75 years or older. Table 1 shows the baseline characteristics of non- and recurrent fallers. The recurrent fallers included significantly more males, had a lower performance of gait and balance, and experienced falls more often than non-recurrent fallers in the three months prior to study entry.

Figure 2 shows the classification tree results for predicting recurrent fallers. The root node (n° 0) comprising the entire sample (n = 868) was first separated into nodes n° 1 and n° 2, involving the history of falls. The 29.8% of the participants from node n° 2, falling at least two times in the three months prior to study entry, became recurrent fallers during the following six months, whereas the 8.1% of participants from node n° 1, falling fewer than two times, became recurrent fallers. The analysis identified four end nodes for participants who fell at least two times in the three prior months. Among them, subjects who scored ≤ 30 on the Berg test and who reported consuming alcohol within the six months prior to baseline formed the end node n° 8 with the greatest relative risk (RR = 5.1) of becoming recurrent fallers (Figure 2 and Table 2). Conversely, those who sustained fewer than two falls prior to baseline remained undivided (node n° 1) and formed the most favourable group (RR = 0.7). Table 2 summarizes each terminal node.

Table 1. Baseline Characteristics of the Community-dwelling Elderly, According to Their Status

Risk Factor	Non-recurrent Fallers (n = 769)	Recurrent Fallers (n = 99)
Socio-demographic variables		
Age (yrs), $\bar{x} \pm SD$	79.5 $\pm$ 6.6	79.0 $\pm$ 6.9
≥ 75 yrs, %	75.9	77.8
Male, %	21.7	31.3*
Type of residence		
House/single-family home, %	57.1	54.5
Residential facility, %	12.2	18.2
Home hazards, $\bar{x} \pm SD$	3.2 $\pm$ 2.3	3.5 $\pm$ 2.6
Body composition		
BMI (kg/m^2), $\bar{x} \pm SD$	28.1 $\pm$ 6.9	27.4 $\pm$ 5.3
Underweight (BMI ≤ 20), %	10.1	8.1
Obesity (BMI ≥ 30), %	34.7	30.3
Nutrition		
Screening score, $\bar{x} \pm SD$	3.7 $\pm$ 1.9	3.8 $\pm$ 2.0
High nutritional risk (values ≥ 6), %	15.6	20.2
Gait, balance and mobility		
Berg balance score, $\bar{x} \pm SD$	43.9 $\pm$ 8.8	39.5 $\pm$ 8.5***
Impaired balance (Berg ≤ 30), %	8.6	15.2*
Timed Up & Go score (sec), $\bar{x} \pm SD$	23.5 $\pm$ 16.7	27.6 $\pm$ 17.2*
Impaired mobility (TUG ≥ 30), %	17.9	25.3
Medication use		
Distinct prescribed drugs daily, $\bar{x} \pm SD$	8.7 $\pm$ 4.2	9.4 $\pm$ 4.1
≥ 4 prescribed drugs per day, %	87.1	91.9
Benzodiazepine use, %	47.2	50.5
Alcohol use		
Consumption in past 7 days, %	20.2	21.2
Consumption in past 6 months, %	46.3	52.5
History of falls, in past 3 months, %	35.5	65.7***

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

Three profiles (node n° 8, 5 and 7) leave people at a significantly ($p \leq 0.01$) higher than average risk of becoming recurrent fallers during the follow-up (RR = 5.1, 2.5 and 2.1).

Survival curves for each of the terminal nodes are presented in Figure 3. Subjects in node n° 8, who fell earlier (average survival time = 124 days), were those who fell more often (RR = 5.1). Conversely, those in node n° 1, who fell later (average survival time = 176 days), were those who fell less often (RR = 0.7). The probability of not being a recurrent faller over the six-month follow-up is equivalent to 100 minus the incidence of recurrent falling. Statistical difference in the cumulative survival curves of each node are given in Table 3.

DISCUSSION

The CART and survival analyses divided the population into five specific combinations of predictors, and characterized them by an estimated risk of becoming a recurrent faller and of length of time before becoming a recurrent faller.

The methodology identified three profiles of higher short-term risk of recurrent falling among the community-dwelling elderly who

Figure 2. Classification tree for predicting the risk of recurrent falling at six-month follow-up among community-dwelling seniors using home-care services

Each divisible group is identified as a circle; each end group as a rectangle. The number of subjects (e.g., 868 in node 0), the incidence of recurrent fallers (e.g., 11.4% in node 0), as well as the split covariables and their threshold values, are indicated on the resulting branches. In the example of node 0, the values "0-1 fall" and "≥2 falls" divide the covariable "history of falls in past three months" into two parts.

use home-care services. A history of falls in the three months prior to the initial interview emerged as a predictor of recurrent falling; results seemed to indicate that a recurrent faller was likely to remain so. Also at a high risk of becoming recurrent fallers were participants with ≥ 2 prior falls and a score of ≤ 30 on the Berg balance scale (node n° 4) – particularly those who drank alcohol in the six months preceding their examination (node n° 8) – as well as participants with as many prior falls but with a score higher than 30 on the Berg scale, who lived in a private residential facility (node n° 5).

Leclerc et al.³¹ have previously compared different statistical methods to identify predictors of falls among community-dwelling

Table 2. Summary of the Tree for Predicting Recurrent Fallers at Six-month Follow-up among Community-dwelling Seniors Using Home-care Services, in Descendant Order According to the Relative Risk

Node n° and Profile	Number of Subjects	Incidence of Recurrent Fallers (%)	Relative Risk
#8: ≥ 2 falls in prior three months, ≤ 30 on Berg balance scale, alcohol intake in prior six months	33	57.6*	5.1
#5: ≥ 2 falls in prior three months, > 30 on Berg balance scale, living in private residential facility	21	28.6*	2.5
#7: ≥ 2 falls in prior three months, ≤ 30 on Berg balance scale, no prior alcohol intake	45	24.4*	2.1
#6: ≥ 2 falls in prior three months, > 30 on Berg balance scale, living in single family house or other types of personal housing	32	9.4	0.8
#1: < 2 falls in prior three months	737	8.1*	0.7
Total	868	11.4	1.0

* The incidence of recurrent fallers in node differs significantly from the total sample incidence at the 0.05 level, after Bonferroni-Holm adjustment for multiple comparisons.

Figure 3. Estimated Kaplan-Meier survival curves for predicting the risk of recurrent falling at six-month follow-up among community-dwelling seniors using home-care services, according to the risk profiles (nodes)

At the start of the study, each group contains 100% of participants. Over time, more and more participants become recurrent fallers, and so the percentage of subjects who have still not become recurrent fallers decreases.

seniors who use home-care services. They have shown that a history of falling, the Berg balance score, and residential facility housing each appear to be a predictor of falls, whatever the outcomes (number of falls, time to first fall, and time to each recurrent fall). Our results concur with authors who consider a history of falls in the previous year as high-risk criteria for falling and for eligibility in intervention programs.⁷ Nevertheless, not all subjects with a history of falls run a greater risk of becoming recurrent fallers. Notably, elderly people in node n° 1 were significantly less likely than on average, even if they had already fallen once.

The first and only study applying a tree-based methodology for the prediction of falls was conducted by Stel et al.³ Although they did not use the same subset of predictors as we did, the history of falls in the previous year clearly emerged as the prime predictor of recurrent falls. They also used a similar approach, the tree-structured survival analysis. We preferred not to use it for the following reasons. It was developed for running on S-plus 3 by two programmers external to the statistical firm.^{32,33} The program has not been updated and TSSA is no longer supported by either the current versions of S-plus or the firm. We also noted that the algorithm implemented in the program could continue to divide a parent node, even in the absence of statistical significance of a split.

The tree-based methodology provides a number of advantages over linear, logistic, and Cox regression models. First, it is a non-parametric and non-linear technique. It does not require any *a priori* distributional assumption and knowledge about the underlying relationships between the predictors and the dependent variable.^{3,27,33,34} Hence, the method is useful in situations where there are interactions among variables: the cases are partitioned and each group is analyzed separately. Second, CART allows the construction of directly applicable fall risk profiles. Contrary to regression analy-

Table 3. Pairwise Comparisons of Survival Curves for Predicting Recurrent Fallers at Six-month Follow-up among Community-dwelling Seniors Using Home-care Services, According to the Log-rank (Mantel-Cox) Test

Node n°	1	5	6	7	8
1	1.000				
5	0.000*	1.000			
6	0.780	0.071	1.000		
7	0.000*	0.712	0.094	1.000	
8	0.000*	0.045	0.000*	0.003*	1.000

* Significantly different at the 0.05 level (two-tailed test), after Bonferroni-Holm adjustment for multiple comparisons.

ses where all predictors must be measured in order to identify the risk of falls, few predictors should be required to recognize the risk profile of a new case.³

A number of cautions arise from our study. First, monitoring falls in cohort studies relies on some form of self-report, typically done by having participants recall whether or not they have fallen over a designated time period. Active registration by the participant and a monthly phone call delivered by a caregiver reduce the problem of recall over long periods, but require that participants remember and make the effort to mark the event after having experienced a fall. Further, regardless of the method of self-reporting, seniors may be reluctant to admit they have fallen. These limitations around self-report have led to the conclusion that reliance on self-report likely produces an under-reporting.³⁵ Second, the findings with CART do not necessarily imply cause and effect relationships, but simple statistical associations. Third, we should remember that any data-driven clustering results must be validated by using a separate sample. Fourth, the question of what constitutes an appropriately sized tree remains unresolved. We selected stop-splitting criteria in order to attain a balance between the purity of the end-branching nodes and a reasonable number of subjects for clinical significance. Finally, biases may have occurred because of differences between the retained participants and the individuals lost to follow-up. Males, high nutritional risk (values ≥ 6), lower Berg score, as well as impaired balance (Berg ≤ 30) and mobility (TUG ≥ 30) at baseline, were more likely to be lost to follow-up. This would lead to an underestimation of the effects.

Our results tend to support the theory that multiple falls may have more intrinsic causes than a single fall,^{3,36} especially if the variables of "history of falling" and "living in a private residential facility" act as a surrogate measure of various chronic conditions and poorer functional autonomy.

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RÉSUMÉ

Objectifs : Identifier des profils d'aînés à haut risque de devenir des chuteurs récurrents parmi la clientèle des services de soutien à domicile.

Méthode : Il s'agit d'une étude d'observation prospective conduite auprès d'un échantillon de commodité de 868 personnes de 65 ans ou plus vivant dans la communauté et inscrits aux services de soutien à domicile de la mission CLSC des centres de santé et de services sociaux de la région de Lanaudière, au Québec. Le recrutement des volontaires a été effectué entre mars 2002 et juillet 2005. L'étude est caractérisée par la mesure des facteurs de risque au domicile du participant à son entrée dans le projet ainsi que par une relance téléphonique mensuelle dont le but était de documenter la survenue des chutes subséquentes. Les données ont été examinées au moyen d'un arbre de régression et de classification et d'une analyse de survie.

Résultats : Durant les six mois de leur suivi, 99 des 868 participants ont rapporté au moins deux chutes et sont considérés comme chuteurs récurrents. Cette valeur se traduit par une incidence de récurrence de 11,4 %. Les analyses statistiques ont révélé l'existence de cinq profils de risque distinctifs dont le risque relatif varie de 0,7 à 5,1. Vivre dans une résidence pour aînés, avoir des antécédents récents de chutes multiples ou des troubles de l'équilibre et consommer de l'alcool, même occasionnellement, sont les principaux facteurs associés à une probabilité accrue de devenir un chuteur récurrent et de chuter précocement.

Conclusion : Des profils de risque de chutes récurrentes à court terme ont été établis à partir d'un nombre restreint de facteurs validés par l'expérience. Ces profils facilement interprétables peuvent aider les cliniciens et les praticiens de santé publique à identifier les aînés à haut risque et à guider leurs choix vers des interventions et des suivis appropriés.

Mots clés : analyse de survie; arbre de régression et de classification; chutes accidentelles; facteurs de risque; personnes âgées; pronostic; services de soutien à domicile