

**Significance of Overactive Bladder as a Predictor of Falls in Community-Dwelling
Older Adults — One Year Follow-up of the Sukagawa Study**

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Abstract

Purpose

Little is known about the fall risk of older adults with overactive bladder, especially in the absence of urgency incontinence. We aimed to evaluate the impacts of overactive bladder with and without urgency incontinence (OAB-wet and OAB-dry) on the fall risk in older adults, and to investigate the importance of overactive bladder as a predictor of falls by using tree-based models.

Materials and Methods

This prospective cohort study included 630 community-dwelling, independent older adults aged ≥ 75 years who attended a health checkup in 2017 with a 1-year follow-up. The associations of OAB-dry and OAB-wet with a fall history and future fall risk compared to no overactive bladder were assessed using logistic regression models. The contribution of overactive bladder as a predictor of falls was examined using a random forest and decision tree approach.

Results

Of the 577 analyzed participants (median age: 79 years), 273 (47%) were men. The prevalence of OAB-dry and OAB-wet at baseline was 15% and 14%, respectively. Multivariable logistic regression analysis revealed that both OAB-dry and OAB-wet were associated with a higher likelihood of prior falls (adjusted odds ratio versus no overactive bladder, 2.03 and 2.21, respectively; 95% CI, 1.23–3.37 and 1.29–3.78, respectively). Among the 363 participants without a fall history, the adjusted odds ratios (95% CIs) of OAB-dry and OAB-wet for the occurrence of falls during the 1-year follow-up were 2.74 (1.19–6.29) and 1.35 (0.47–3.87), respectively. The tree-based approach used for all participants showed that overactive bladder was an important predictor of falls in adults without a fall history; the model had 83.6% accuracy and 81.8% AUC.

Conclusions

Overactive bladder, even in the absence of urgency incontinence, is an important predictor of falls in older adults with a low absolute fall risk.

INTRODUCTION

Falls are an increasing global health burden in a super-aging society. They are common among older adults due to multiple risk factors and often lead to considerable negative health outcomes, such as fractures, frailty, disability, hospitalization, institutionalization, and death.¹⁻⁴ In 2015, the medical cost attributable to falls was approximately \$50 billion in adults aged ≥ 65 years in the United States alone.²

Recently, the association of LUTS, particularly storage symptoms such as UI and OAB, with falls has been studied intensively in older adults; results have suggested that both UI—specifically UUI—and OAB are associated with falls.⁵⁻⁸ OAB patients may or may not have UUI (i.e., OAB-wet and OAB-dry, respectively); however, little is known about the impact of OAB on falls in the absence of UUI. Regardless of the presence of UUI, gait speed and rhythmicity differ even in the same individual, depending on the presence or absence of a strong desire to void.⁹ Based on this finding, we hypothesized that even the people with OAB-dry have a higher risk of falls than those without OAB and, if so, more attention should be focused on OAB-dry in the context of fall prevention.

Previous studies have focused on developing models or algorithms for the prediction of falls in older adults in community and primary care settings.^{10,11} With the advent of machine learning approaches, recent studies have reported the application of a decision tree model with promising results; however, these analyses did not include OAB as a predictor of falls.^{3,12} For the above reasons, we also hypothesized that OAB is an important predictor in the decision tree model for predicting falls of community-dwelling older adults.

Thus, the aims of this study were to determine the impacts of OAB-dry and OAB-wet on the fall risk in older adults compared to those with no OAB, and to investigate the importance of OAB as a predictor of falls by using tree-based models.

MATERIALS AND METHODS

Study Setting and Participants

The Sukagawa Study was a prospective community-dwelling cohort study conducted in Sukagawa City, Fukushima Prefecture, Japan; detailed information has been described previously.^{13,14} We used the data of the Sukagawa Study, collected in 2017 and 2018. All participants aged ≥ 75 years in the health checkup and survey conducted by the local government in 2017 were followed up for one year. We excluded bedridden residents, those defined as having a loss of independence based on the Japanese long-term care insurance certification status, or those who had been hospitalized for longer than six months.¹⁵ Written informed consent was obtained from all participants. The Internal Ethics Review Board approved this study design and protocol, which were performed in accordance with the tenets of the Declaration of Helsinki (registered approval number: 2975).

Definition of OAB, OAB-dry and OAB-wet

The presence of OAB was evaluated using the OABSS validated by Homma et al.¹⁶ OABSS is a four-item questionnaire used to evaluate daytime frequency, nocturia, urgency, and UII over the previous week (Table S1). The total score was the simple sum of the four symptom scores (range: 0–15), and a higher score indicated an increased severity of OAB. Individuals with an urgency score of ≥ 2 and a sum score of ≥ 3 were considered to have OAB.^{16,17} Individuals without OAB were classified as non-OAB. Among those with OAB, individuals with an UII score ≥ 2 were considered to have OAB-wet; otherwise, they were

considered to have OAB-dry.^{18,19}

Outcome Measurement

The occurrence of falls (yes/no) was measured annually using the question, “How many times have you fallen down over the past year?” Response options were “zero,” “once,” “twice,” “three,” or “four or more times.” A fall history and the occurrence of subsequent falls were considered to be present if participants reported at least “once” to the question at baseline and 1-year follow-up, respectively.

Measurement of Confounders

Confounders were selected a priori based on previous studies, including age, sex, BMI, gait speed, presence of visual impairment and dementia, and a history of diabetes, hypertension, stroke, and depression.^{3,10–12,14} BMI in kg/m² was stratified into three categories as follows: underweight (<18.5), normal weight (range 18.5 to <25), and overweight (≥25).^{3,12,14} Gait speed was measured in m/s using a stopwatch over a distance of 10 m; each individual walked at his or her usual speed and used a walking aid as needed. However, gait speed was measured only at the largest health checkup site, where 318 participants underwent the measurement. Participants with dementia had scores of ≤2 points on the Mini-Cog test.²⁰ Visual impairment was assessed using two questions derived from the VFQ-J11 regarding “Role limitation: Accomplish less” due to vision and “Dependency: Need help from others” because of eyesight.²¹ The VFQ-J11 is a short Japanese version of the National Eye Institute’s Visual Function Questionnaire.^{21,22} Those who reported “all of the time,” “most of the time,” or “some of the time” to the “Role limitation” question and those who reported “definitely true” or “mostly true” to the “Dependency” question were considered to have vision impairment. Medical histories were identified using a self-

administered questionnaire.

Statistical Analysis

Participants were divided based on the presence/absence of OAB with/without UII as follows: non-OAB, OAB-dry, and OAB-wet. Baseline characteristics are presented using standard descriptive statistics: medians (IQR) for continuous variables, and number (%) for categorical variables. The Kruskal-Wallis test or one-way ANOVA was performed for continuous variables as appropriate based on data distribution, and the Fisher's exact test was used for categorical variables. The ORs and 95% CIs for the likelihood of falls were estimated using logistic regression models. We initially evaluated the associations of non-OAB (reference), OAB-dry, and OAB-wet with falls in the previous year, since fall history is the strongest risk factor for future fall incidents.^{11,12,23} Their associations with the occurrence of falls during the 1-year follow-up were then assessed, with a focus on non-fallers in the previous year, since they are considered to have a low absolute risk of falls. As a post-hoc analysis, we investigated the impact of OAB as a whole (namely, OAB-dry and OAB-wet combined) on future fall risk in non-fallers. In multivariable analyses, we created models adjusting for age and sex (models 1, 3, and 5), and models with adjustment for all the aforementioned confounding factors (models 2, 4, and 6). Additionally, we performed logistic regression analyses in all participants to evaluate the impacts of OAB-dry and OAB-wet on future fall risk compared with non-OAB, in which fall history was included as a covariate in addition to the aforementioned confounders, and the AUC was computed from the fully-adjusted model. Participants with complete data for exposure and outcome variables were included in the analyses. The Markov chain Monte Carlo data augmentation algorithm for multiple imputation was implemented for missing data on gait speed wherein 20 imputations were performed.

A CART model to predict the risk of falls was developed in the training set (80% sample randomly selected from 577 participants). This is a machine learning-based model, composed of hierarchical decision rules involving optimal cutoff values that recursively split independent factors into different groups (nodes).^{3,12} The optimal cutoff value is determined by the gain in information (decrease in Gini impurity). The five most important predictors among the aforementioned confounding variables in addition to fall history were identified based on the contribution of each predictor calculated using the random forest approach, in which 250 trees were created using a bootstrap sample, and introduced into the model development. The maximum tree depth was set to three and nodes were required to have a minimum size of 10 participants to avoid overfitting the CART model. Gait speed with missing data was excluded from the analysis. In the test set (the remaining 20% of samples), we measured the prediction performance of the model by computing confusion matrix results (i.e., accuracy, sensitivity, specificity, PPV, and NPV) and AUC.

A *P*-value of <0.05 was considered statistically significant. Statistical analyses were conducted using STATA version 14 (Stata Corp LP, College Station, TX, USA) and machine learning-based analyses were performed using Python 3.8.2 (package Scikit-learn).

RESULTS

Baseline Characteristics

A total of 630 older adults underwent the health checkup in 2017. After excluding 42 non-participants in 2018 and 11 with missing data for exposure or outcome variables, 577 were included in the analysis (Fig. 1). The baseline characteristics of participants are summarized in Table 1. Of the 577 analyzed participants (median [IQR] age: 79 [77, 83] years), 273 (47%) were men, 165 (29%) had OAB, and 214 (37%) had a positive fall history. Of the participants with OAB, 78 (47%) were categorized as having OAB-wet. There were

259 (45%) participants whose gait speed was not measured. No significant differences were found in measured variables, including OAB and fall history, except for age and presence of dementia between participants with and without data on gait speed (Table S2).

OAB and Fall History

Both OAB-dry and OAB-wet were associated with a higher likelihood of fall history compared with non-OAB in all models (Fig. 2).

OAB and Future Fall Risk

Of the 363 participants who had no fall history at baseline, 44 (12%) experienced at least one fall during the 1-year follow-up. In the crude analysis, OAB-dry but not OAB-wet was associated with a higher risk of future fall in comparison to non-OAB. After adjustment, associations between OAB-dry and future fall risk remained significant. On the post-hoc analysis in which OAB-dry and OAB-wet were combined together, OAB was associated with increased fall risk in all models compared with non-OAB (Fig. 3).

Additional analyses of all participants ($n = 577$) revealed the significant associations of OAB-dry and OAB-wet with a higher risk of future falls, although the significances disappeared after adjustment for fall history (Table S3); the AUC for the fully-adjusted model was 83.8%.

Random Forest and Decision Tree

In the random forest model for future falls, the most important predictors (calculated importance of each variable) were fall history (0.37), age (0.29), BMI category (0.06), sex (0.05) and OAB (0.05). The final decision tree for risk stratification of future falls in the training set (154 fall incidents among 461 participants) is shown in Fig. 4. The first decision

node identified by the model was the fall history, and OAB was used as a predictor in the participants without a fall history. The model yielded 83.6% accuracy, 88.4% sensitivity, 76.6% specificity, 84.7% PPV, 81.8% NPV, and 81.8% AUC in the testing set (47 fall incidents among 116 participants).

DISCUSSION

In community-dwelling, independent older adults aged ≥ 75 years, both OAB-dry and OAB-wet were significantly associated with a greater likelihood of previous falls compared with non-OAB. OAB-dry was also associated with a greater risk of falls during the 1-year follow-up among the non-fallers in the previous year. We further assessed the impact of OAB on their future fall risk; even among non-fallers, those with OAB had about twice the risk compared with those without OAB. A machine learning-based approach applied to all participants also revealed an important contribution of OAB as a predictor of future fall risk, specifically in non-fallers.

Few studies have longitudinally assessed future fall risk in people who have OAB with and without UI, particularly in those without a fall history who are considered to have a low absolute risk of falls. Noguchi et al. found that composite storage symptoms—but not OAB by definition—are associated with an increased risk of future falls even in the absence of UI among community-dwelling older men although they did not adjust for fall history in the analysis.²⁴ Our study, in which both men and women were included, showed that OAB-dry was significantly associated with a higher risk of future falls among the non-fallers. However, causal relationships remain undefined by the current observational study design. Interestingly, two recent studies have revealed that gait speed and rhythmicity differ even in the same individual with or without a strong desire to void among both continent and incontinent women.^{9,25} Such changes in gait speed and rhythmicity could conceivably cause a

fall regardless of the presence of UUI, particularly in older adults.

In our study, the nonparametric analysis using modern machine learning approaches identified OAB as an important predictor of falls. Parametric methods, such as logistic regression, are widely used for causal inference. Modern machine learning approaches are advantageous as they can account for non-linear, high-order interactions between predictors on less rigorous assumptions and gain more stable discrimination, although the predicted probabilities are less likely to be calibrated.^{26,27} To visualize the complex risk stratification with various predictors and to facilitate easier interpretation, we employed a tree-based model similar to previous studies.^{3,12} The findings of our CART model can encourage policymakers with limited resources to focus on people with OAB when implementing fall prevention among non-fallers.

To date, less attention has been focused on OAB in the evaluation and management of the risk of falls compared with other physical and psychological problems such as mobility dysfunction, visual impairment, depression, and cognitive impairment.²³ However, given our findings that OAB was significantly associated with falls independent of gait speed, visual impairment, depression, and dementia, OAB and falls should not be considered separate entities in older adults. A simple and quick questionnaire on OAB, such as the OABSS, is inexpensive and non-invasive, and our tree-based model is easily applicable as a screening tool to identify a population requiring earlier interventions for fall prevention in clinical and community settings.

This study has several limitations. First, given the wide 95% CIs of effect estimates in the logistic regression model, and that the decision tree model is prone to overfitting, further validations of our results are warranted in larger studies which include a wider range of older participants. Second, the study outcomes were measured based on self-reported fall incidents. Self-reported fall incidents could be underreported in older people, which might

have resulted in underestimation of the association between OAB and falls.²⁸ Third, other predisposing or precipitating factors for falls, which were not fully adjusted for, may have contributed to the increased risk as falls are often multifactorial. Specifically, we were unable to include the medication usage in our analyses. We did not include fear of falling as a confounder in the causal analysis between OAB and falls, although fear of falling is a well-known predictor of falls; here, we hypothesized that older people have a fear of falling as a result of OAB and/or other adjusted confounders, such as age, sex, fall history, impaired gait, depression, and cognitive impairment.²⁹ Moreover, excluding gait speed might have affected the results in tree-based models. Fourth, our results might only apply to community-dwelling, independent older adults. Finally, the presence of other urological disorders, such as urinary tract infections or use of urinary collection devices, could not be ruled out by the OABSS.³⁰

CONCLUSIONS

OAB was an important predictor of falls, even in the absence of UI, among the community-dwelling older adults with a low absolute fall risk. We developed a simple but promising tool for fall risk stratification using tree-based models that incorporate OAB as a predictor. Further validation studies with larger sample sizes are warranted.

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298

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303 **CONFLICTS OF INTEREST**

304 The authors declare that there is no conflict of interest.

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FIGURE LEGENDS

Figure 1. Flowchart of the study participants.

Figure 2. Estimated ORs and their CIs for the likelihood of previous falls according to OAB category among 577 participants.

Model 1: adjusted for age and sex.

Model 2: adjusted for age, sex, BMI category, gait speed, visual impairment, dementia, diabetes, hypertension, stroke and depression.

Figure 3. Estimated ORs and their CIs for the likelihood of future falls during the 1-year follow-up period in 363 participants who had no history of falls according to the OAB category.

Model 3, 5: adjusted for age and sex.

Model 4, 6: adjusted for age, sex, BMI category, gait speed, visual impairment, dementia, diabetes, hypertension, stroke and depression.

Figure 4. CART for predicting the risk of falls in community-dwelling older adults aged ≥ 75 years at 1-year follow-up.

Numbers inside nodes represent prevalence (as a percentage) of falls and the total number of participants who are indicated by the node.

Table 1. Baseline characteristics of the participants

Characteristics	Total (n = 577)	Participants with missing data, n	Non-OAB (n = 412)	OAB (n = 165)		<i>P</i> value
				OAB-dry (n = 87)	OAB-wet (n = 78)	
Age, year (IQR)	79 (77, 83)	0	79 (77, 82)	80 (77, 84)	80 (78, 84)	0.012
Male, n (%)	273 (47.3)	0	192 (46.6)	46 (52.9)	35 (44.9)	0.51
BMI, kg/m ² (IQR)	23.2 (20.9, 25.3)	0	23.2 (21.0, 25.0)	23.0 (20.6, 25.6)	23.6 (21.2, 25.6)	0.49
Underweight, n (%)	38 (6.6)	0	27 (6.6)	7 (8.1)	4 (5.1)	
Normal weight, n (%)	381 (66.0)	0	281 (68.2)	51 (58.6)	49 (62.8)	
Overweight, n (%)	158 (27.4)	0	104 (25.2)	29 (33.3)	25 (32.1)	
Gait speed, m/s (IQR)	1.2 (1.1, 1.4)	259	1.3 (1.1, 1.4)	1.2 (1.1, 1.3)	1.1 (0.9, 1.3)	0.0008
Total OABSS (IQR)	3 (2, 5)	0	2 (1, 3)	5 (5, 7)	9 (7, 11)	0.0001
Diabetes, n (%)	80 (13.9)	0	58 (14.1)	8 (9.2)	14 (18.0)	0.27
Hypertension, n (%)	328 (56.9)	0	232 (56.3)	49 (56.3)	47 (60.3)	0.8
Stroke, n (%)	16 (2.8)	0	12 (2.9)	1 (1.2)	3 (3.9)	0.6
Dementia, n (%)	60 (10.4)	0	47 (11.4)	7 (8.1)	6 (7.7)	0.56
Depression, n (%)	10 (1.7)	0	7 (1.7)	1 (1.2)	2 (2.6)	0.77
Visual impairment, n (%)	92 (15.4)	0	57 (13.8)	15 (17.2)	20 (25.6)	0.037
History of falls, n (%)	214 (37.1)	0	128 (31.1)	43 (49.4)	43 (55.1)	< 0.0001
Future fall-incidents, n (%)	201 (34.8)	0	119 (28.9)	40 (46.0)	42 (53.6)	< 0.0001

Continuous variables are presented as median (IQR). Categorical variables are presented as number (%).

Figure 1

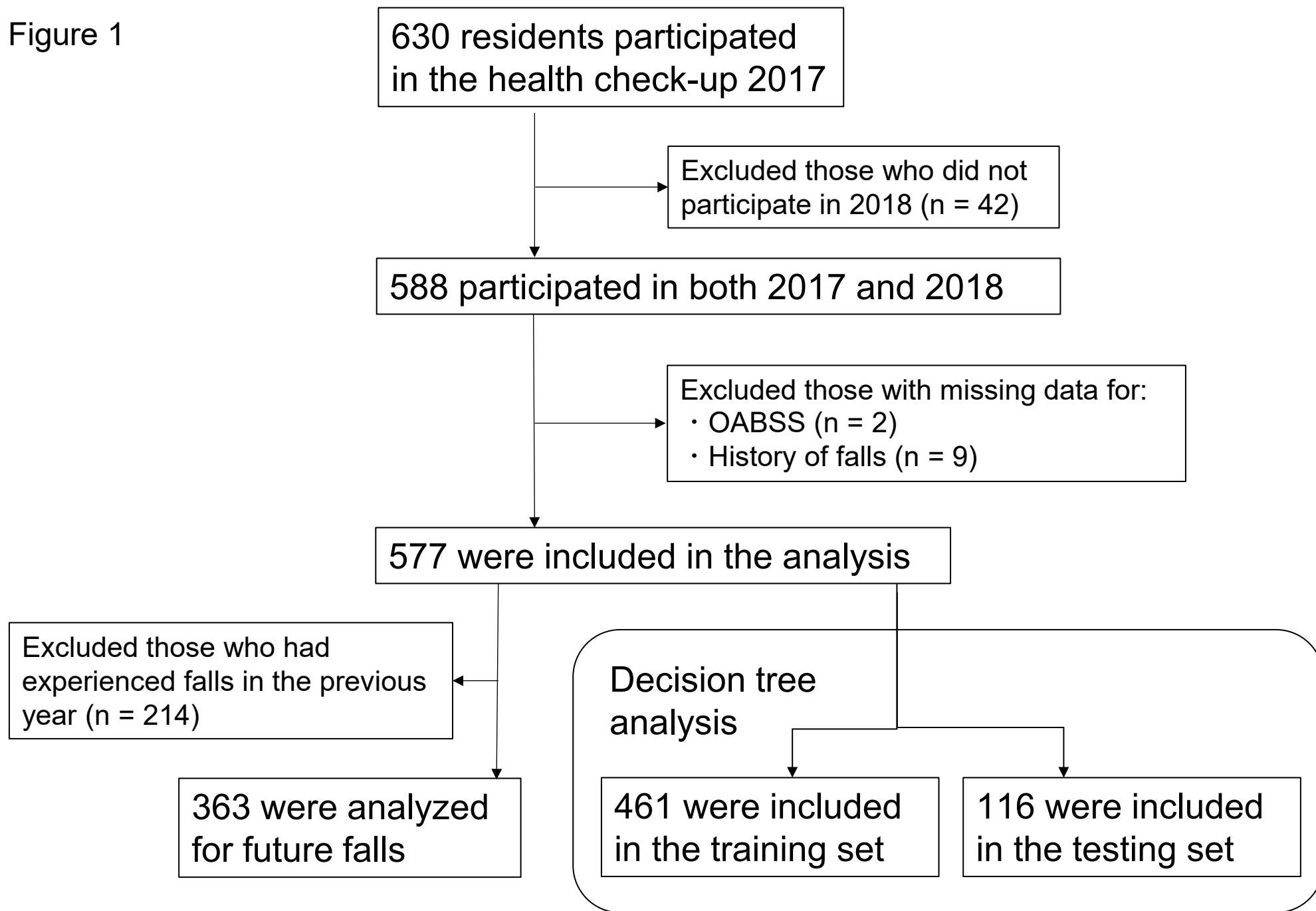


Figure 2

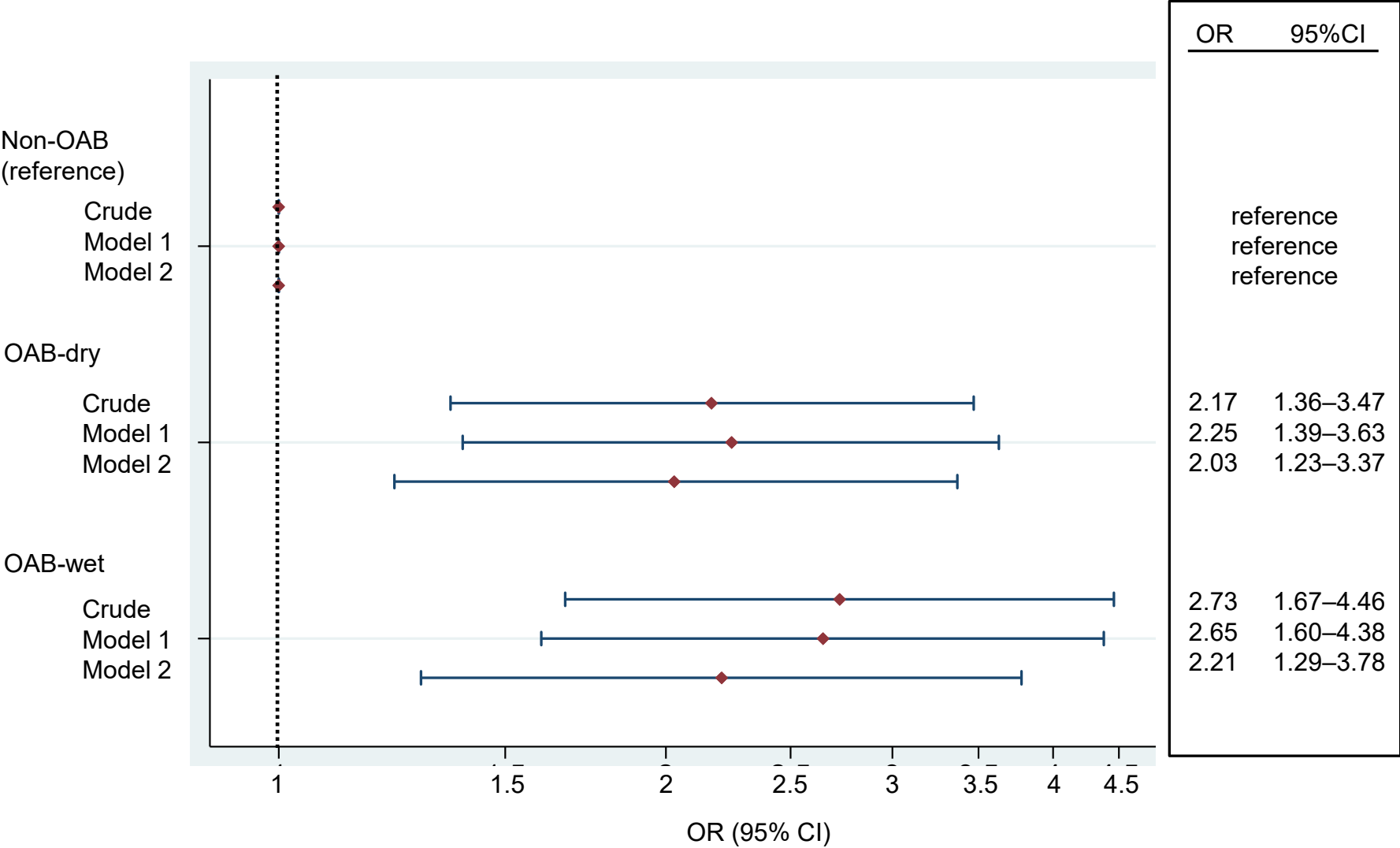


Figure 3

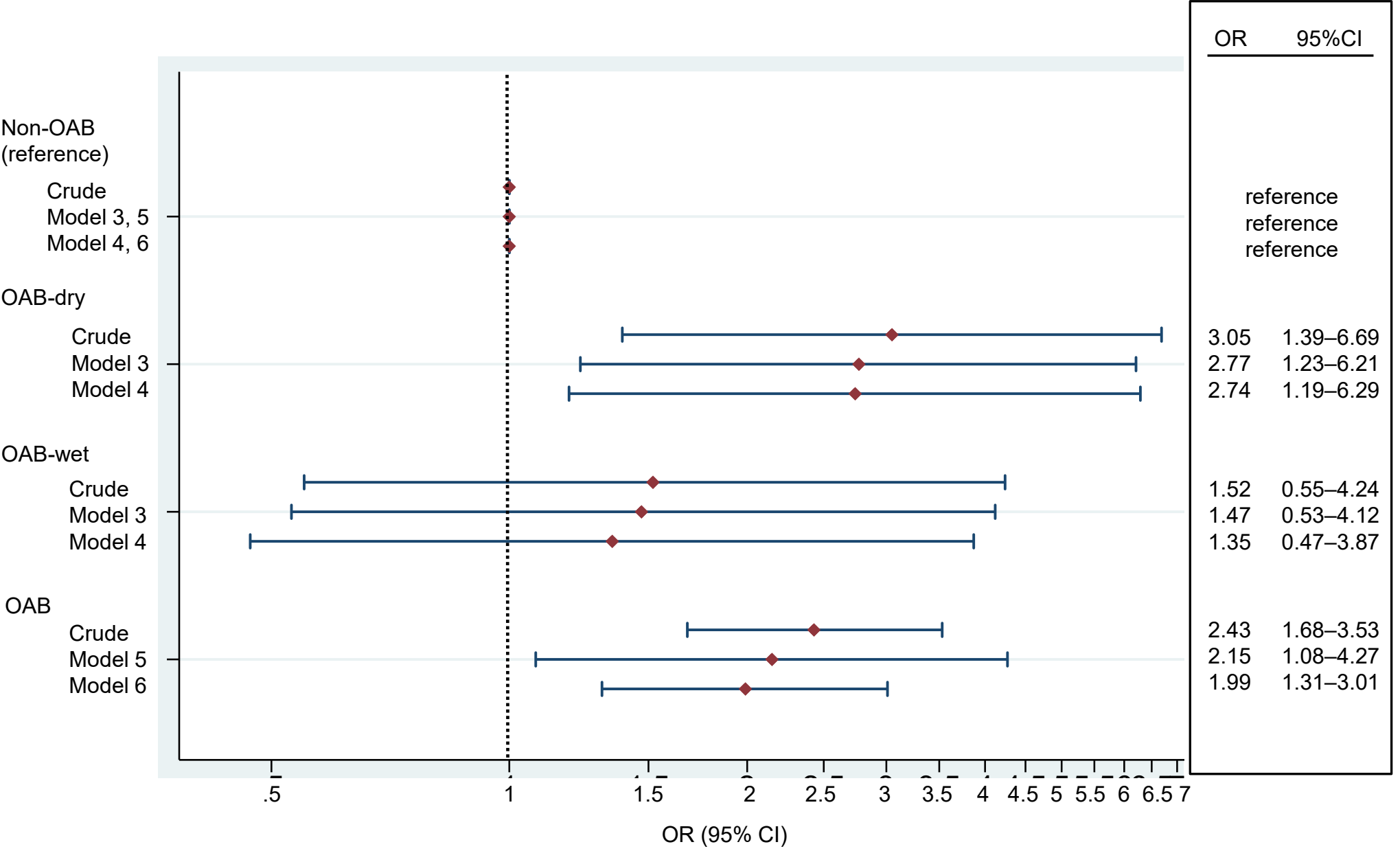


Figure 4

