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Research Article

Association of secondhand smoke with fracture risk in community-dwelling nonsmoking adults in Korea

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Abstract

Although the detrimental effects of active smoking on bone health have been widely recognized, the impact of secondhand smoke exposure on fracture risk in non-smokers remains less understood. A total of 4843 nonsmokers aged 40–69 yr, who participated in the Korean Genome and Epidemiology Study from 2001 to 2018, were analyzed. The participants were categorized into two groups based on their exposure status to secondhand smoke: currently exposed and unexposed. The exposure group was subsequently divided into two subgroups based on the median weekly exposure time (high vs low). The incidence of new fractures was determined using self-reported questionnaires. The identified fractures were categorized according to the fracture site: overall, vertebral, hip, non-vertebral, and non-vertebral non-hip fractures**.** The mean age of the participants was 52.4 yr (84.1% women). Exposure to secondhand smoke was associated with an increased risk of fracture (adjusted hazard ratio [aHR]: 1.27, $P = 0.028$) after adjusting for multiple covariates including age, sex, BMI, household income, bone density of mid-shaft tibia, C-reactive protein, alcohol consumption, and fracture history. Secondhand smoke remained as a significant risk factor for fracture, independent of the major osteoporotic fracture probabilities estimated using a fracture risk assessment tool (aHR: 1.24, $P = 0.038$). The high exposure group had higher risk of fracture than that of the unexposed group (aHR: 1.33, $P = 0.025$), whereas the fracture risk did not differ significantly between low exposure and unexposed groups (aHR: 1.18, $P = 0.253$), suggesting a potential dose–response relationship. Secondhand smoke showed robust association with increased risk of non-vertebral (aHR: 1.37, $P = 0.008$) or non-vertebral non-hip fractures (aHR: 1.36, $P = 0.013$), while its association with vertebral fracture was attenuated (aHR: 1.03, $P = 0.908$). Secondhand smoke was associated with an elevated risk of fracture in nonsmokers, independent of clinical risk factors.

Keywords: secondhand smoke, osteoporosis, fracture prevention, general population studies, fracture risk assessment

Lay Summary

This study aimed to investigate the fracture risk in individuals exposed to secondhand smoke. Enrolling 4843 nonsmokers aged 40–69, the study revealed an association between secondhand smoke exposure and an elevated risk of fracture (adjusted hazard ratio: 1.27, $P = 0.028$). Notably, the high exposure group had a greater fracture risk compared to the unexposed group, suggesting a dose–response relationship. These findings emphasizes the importance of raising awareness about the risks associated with secondhand smoke, particularly in the context of bone health.

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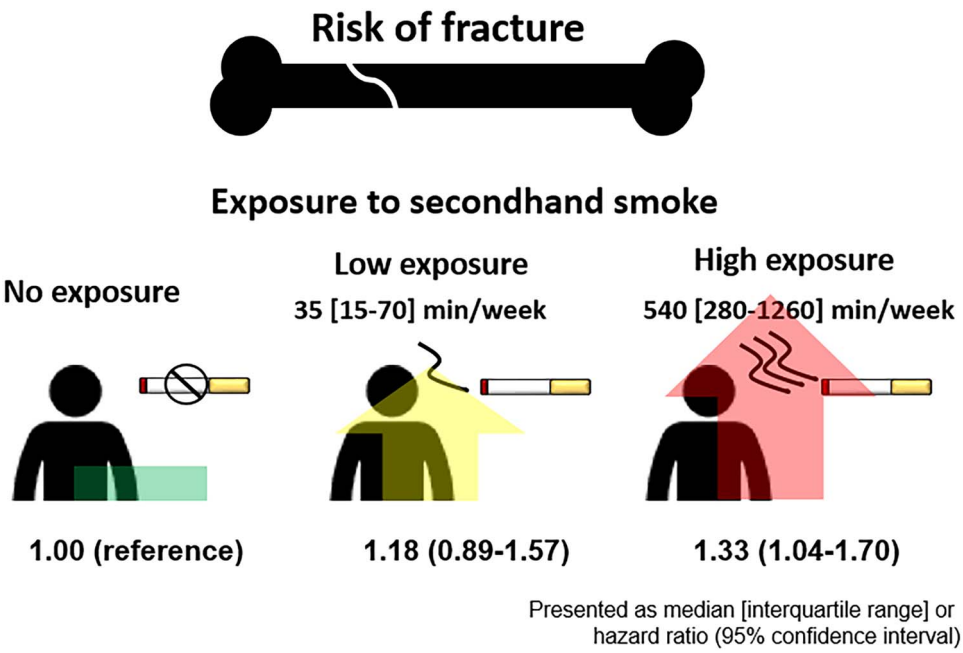
Graphical Abstract



Introduction

Osteoporotic fractures are a global disease burden associated with mortality and morbidity, as well as a loss of independence.[1] Fragility fractures increase the risk of death, with a 1-yr mortality rate of approximately 27%, following that of a hip fracture.[2] Although numerous pharmacological interventions aimed at decreasing the risk of fractures have been developed in recent decades, there still exists an unmet need to identify the modifiable risk factors associated with fractures and to reduce fracture risk further.

Smoking is a modifiable risk factor for fractures. The detrimental effects of smoking on bone health, such as osteoporosis and impaired fracture healing, are well established.[3-6] In contrast, the impact of secondhand smoke on health outcomes is frequently overlooked, despite its high prevalence. A previous global survey indicated that 62.9% of individuals are exposed to secondhand smoke at least once a week, and 32.5% are exposed to such smoke every day of the week; the secular trends of secondhand exposure remained unchanged over the past two decades.[7] Additionally, accumulating evidence underscores the unfavorable health outcomes of secondhand smoking. Secondhand smoke contains a multitude of toxic and carcinogenic substances, with thousands of components. The cardiovascular system exhibits heightened sensitivity to the toxins present in secondhand smoke, and even brief exposure to secondhand smoke has harmful effects similar to those of active smoking.[8] However, the impact of secondhand smoke on osteoporotic fractures remains unexplored.

In the current study, we aimed to investigate a potential correlation between exposure to secondhand smoke and the risk of incident fracture in nonsmokers using a community-dwelling cohort. Additionally, we aimed to investigate whether secondhand smoke and fracture risk exhibit a dose-dependent or fracture site–dependent relationship.

Material and methods

Study participants

The study participants from the Ansan–Ansung cohorts of the Korean Genome and Epidemiology Study, a community-based cohort study conducted in South Korea, were recruited for this study. The study aimed to investigate the genetic and environmental etiology of prevalent metabolic diseases and included six prospective cohorts. The Ansan and Ansung cohort study was initiated in 2001, and it included 10 030 Koreans aged 40–69 yr. The participants were recruited from a rural area (Ansung) or a medium-sized city (Ansan) near Seoul, Korea. Detailed information about the cohorts has been previously documented.[9] The eligibility assessment was conducted in 10 030 participants, who underwent regular clinical examinations, provided anthropometric measurements and blood samples, and completed questionnaires every 2 yr between 2001 and 2018. After excluding 4222 individuals who were current or ex-smokers or had missing data on smoking history, only 5808 nonsmokers remained. We further excluded individuals with missing data on secondhand smoke exposure or exposure time, as well as those who were lost to follow-up ($n = 965$). A total of 4843 individuals were finally enrolled in the study (Figure 1). This study was approved by the Institutional Review Board of Severance Hospital, Yonsei University Health System, Seoul, Korea (4-2021-1613). This study was reported according to the Strengthening the Reporting of Observational Studies in Epidemiology statement.

Secondhand smoke exposure

The study participants completed a self-questionnaire assessing their smoking status. According to smoking status, the participants were classified as nonsmokers, ex-smokers, and current smokers. To specifically investigate the impact of secondhand smoke on fracture risk, current and ex-smokers

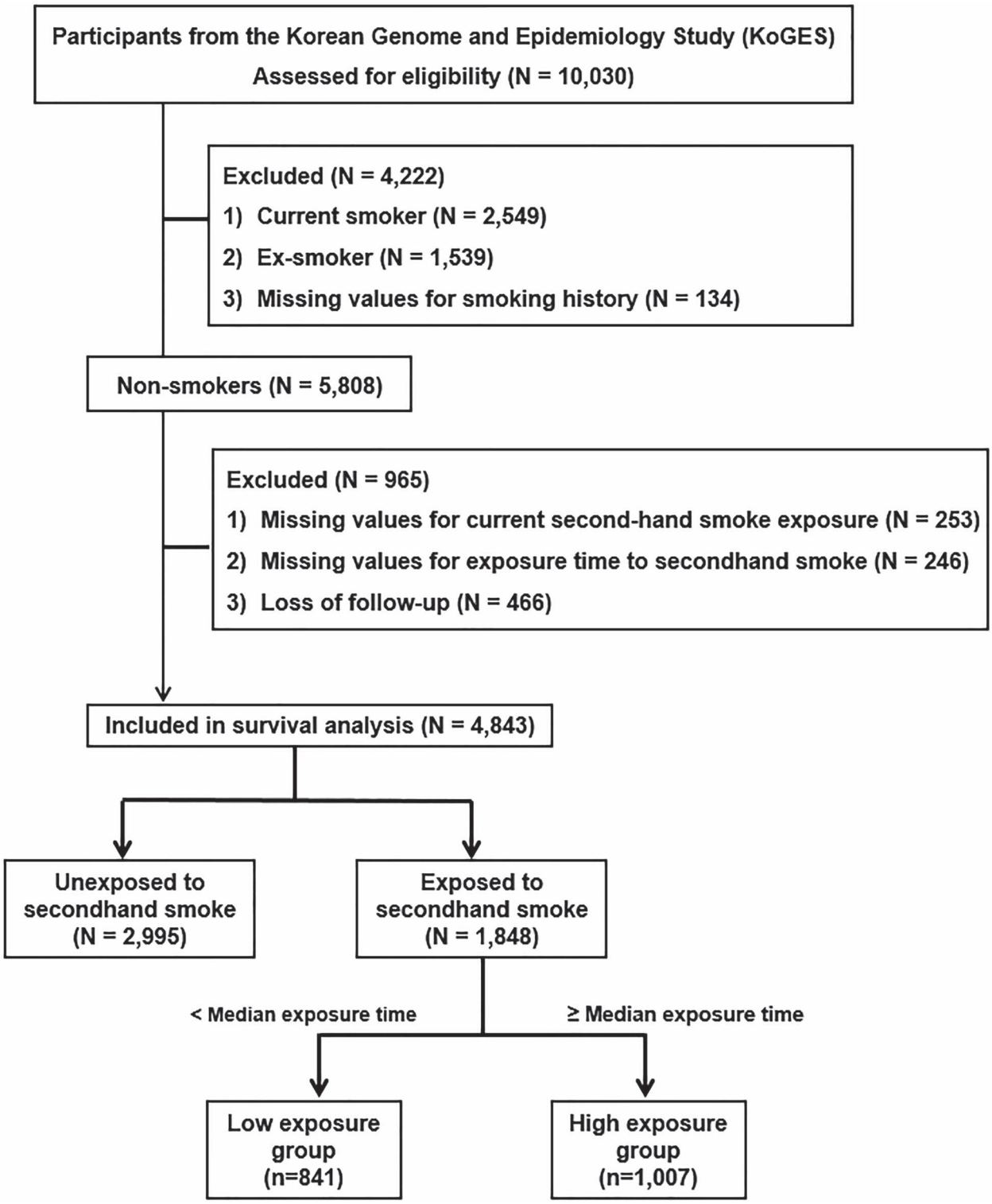


Figure 1. Flowchart of the study process: including participants from the Korean Genome and Epidemiology Study (2001–2018).

were excluded from the study. Nonsmokers were further categorized into the exposed and unexposed groups based on their extent of secondhand smoke exposure. The extent of secondhand smoke exposure was assessed by asking participants about the number of days per week and number of minutes per day that they had been exposed to cigarette smoke from other smokers. The weekly exposure to secondhand smoke was determined by calculating the total minutes per week of exposure reported by participants in both workplace and home settings. The exposed group was further categorized into two subgroups based on the participants' exposure time to secondhand smoke per week. Participants with an exposure time equal to or above the median exposure time per week (210 min/wk) were classified as the high exposure group, whereas those with an exposure time below the median exposure time per week were classified as the low exposure group.

For sensitivity analysis, a different cutoff using the highest quartile threshold (840 min/wk) was applied to define the high and low exposure groups.

Bone measurement and fracture events assessment

Bone ultrasonic speed of sound (SoS, m/s) was measured at baseline through quantitative ultrasonography (QUS; Omnisense 7000 s, Sunlight Medical Ltd, Petah Tikva, Israel). The measurement was performed at the midpoint between the patella and medial malleolus of the less frequently used leg. The mean value of three consecutive measurements was considered the final SoS value of the midshaft tibia. The fracture risk assessment tool (FRAX) score for major osteoporotic fractures was obtained without BMD as the BMD of the cohort had not been evaluated using DXA.

Sociodemographic and clinical factors

Body height and weight were measured at baseline, while participants were wearing light clothes. BMI was calculated by dividing weight in kilograms by height in meters squared (kg/m^2). The participants' serum C-reactive protein (CRP) level was measured using a turbidimetric assay method (ADVIA 1650 and ADVIA 1800; Siemens Healthineers).[10] Baseline clinical data, such as income level, education level, physical activity level, alcohol consumption, intake of oral glucocorticoids, rheumatoid arthritis, history of fracture, and parental history of hip fractures, were obtained using self-reported questionnaires. The participants' income level was divided into the following tertile groups based on the average per-person monthly income: low, <$697/month; middle, $697–1394/month; and high, ≥$1394/month. Total alcohol consumption was measured based on the number of glasses of "soju" consumed. One glass of soju contains approximately one unit of alcohol. In this study, three or more glasses of soju were considered as a high alcohol intake. Oral glucocorticoid use was considered positive if a participant was receiving glucocorticoids at the time of baseline examination. Participants who were previously diagnosed with rheumatoid arthritis or underwent treatment for the condition were considered to have rheumatoid arthritis. Previous history of fracture history was collected only in the Ansan cohort and was defined as any type of osteoporotic fracture that had occurred prior to the baseline investigation. The participants were also asked if either of their parents had experienced a hip fracture after the age of 50 yr.

Study outcome

The study endpoint was the first occurrence of a fracture. During follow-up, the participants were surveyed biennially and asked to report any new fracture events by completing a self-reported questionnaire. This survey not only collected information on the age at which the fracture occurred but also recorded other details, such as the site and cause of the fracture. For the analysis, asymptomatic vertebral fractures were included, whereas high-trauma fractures (resulting from accidents or falls from heights greater than standing height) and fractures of the skull, neck, ribs, sternum, fingers, and toes were excluded. This exclusion was made, as fractures at these sites may occur irrespective of bone fragility.[11] The main analysis focused on the first occurrence of any fracture and its corresponding site.

Statistical analysis

The baseline characteristics were expressed as the mean ± SDs for continuous variables with a normal distribution or as the median [interquartile range] for continuous variables with a non-normal distribution. Categorical variables were expressed as absolute numbers with percentages. Normality testing was performed using Q–Q plot and Shapiro–Wilk test. For intergroup comparison, normally distributed variables were analyzed using analysis of variance with Bonferroni post hoc group comparison, and non-normally distributed variables were assessed using the Kruskal–Wallis test with Dunn's pairwise multiple test. Categorical variables were analyzed using the chi-square tests. Kaplan–Meier analysis with a log-rank test was used to compare the cumulative incidence of fracture outcomes among the exposure groups. Survival time was defined as the interval between the baseline visit and the onset of the study outcome or last follow-up. Multivariable Cox proportional hazards models were constructed to determine the association between secondhand smoke exposure and fracture risk. The multiple regression models incorporated various clinical factors, such as age, sex, BMI, income level, SoS at the midshaft tibia, CRP, and FRAX score. The robustness of the association between secondhand smoke exposure and incident fractures was confirmed through a sensitivity analysis utilizing different cutoff values for defining high exposure. The associations were considered significant if the *P*-value was less than .05. All statistical analyses were performed using the STATA 16.1 statistical software.

Results

A total of 4843 participants were enrolled in the study, of whom 1848 (38.2%) were classified as the exposed group. The baseline characteristics of the participants according to the history of secondhand smoke exposure are summarized in Table 1. Based on the median [interquartile range] exposure time in the exposed group (210 [45–840] min per week), the exposed group was categorized into the following subgroups: high and low exposure. The median [interquartile range; range from minimum to maximum] exposure times to secondhand smoke were 540 [280–1260; 210–10 080] min per week in the high exposure group and 35 [15–70; 1.5–202.5] min per week in the low exposure group (Table 1). The high exposure group comprised individuals who were younger (50.8 yr vs 53.5 yr; $P < .001$) and predominantly women (86.20% vs 83.01%; $P = .006$) than those in the unexposed group. The mid-shaft tibia SoS did not differ among the groups. However, when the linear regression model was adjusted for age and the proportion of women, the high exposure group had a lower adjusted mid-shaft tibia SoS than that of the unexposed group (3858 vs 3874 m/s, group difference: −16, $P = 0.010$).

In a median follow-up of 8 [8–16] yr, 391 fracture events were reported (229 events [891/100 000 person-years] in the exposed group and 162 events in the unexposed group [763/100 000 person-years]). In a simple model adjusted for age, sex, and BMI, exposure to secondhand smoke was associated with a 28% elevated risk of incident fracture compared with non-exposure to secondhand smoke (adjusted hazard ratio [aHR]: 1.28; 95% CI, 1.05–1.58; $P = 0.017$) (Table 2). The association remained robust (aHR: 1.27, 95% CI, 1.03–1.56, $P = 0.028$) after further adjustment for income

Table 1. Clinical characteristics of the study participants.

Variable	Unexposed group ($n = 2995$)	Low exposure group ($n = 841$)	High exposure group ($n = 1007$)	*P*-value
Exposure time to secondhand smoke, min/wk	0	35 (15–70)	540 (280–1260)[a,b]	<.001
Age, yr	53.5 ± 9.0	50.5 ± 8.37[b]	50.8 ± 8.53[b]	.013
Women, *n* (%)	2486 (83.01)	721 (85.73)	868 (86.20)	.021
Height, cm	156 ± 7.3	156 ± 6.93	156 ± 7.20	.169
Weight, kg	60.2 ± 9.1	60.5 ± 8.85	60.9 ± 9.68[a]	.015
BMI, kg/m^2	24.78 ± 3.17	24.7 ± 3.08	25.0 ± 3.29[a]	.128
Income level, *n* (%)				<.001
Low, <697 $/month	1170 (39.67)	244 (29.26)	385 (38.97)	
Middle, ≥697 and <1394 $/month	869 (29.47)	267 (32.01)	267 (27.02)	
High, ≥1394 $/month	910 (30.86)	323 (38.73)	336 (34.01)	
High alcohol intake, *n* (%)	72 (2.40)	32 (3.80)	40 (3.97)	.012
Family history of hip fracture, *n* (%)	29 (0.97)	9 (1.07)	12 (1.19)	.826
History of fracture, *n* (%)	166 (5.54)	66 (7.85)	50 (4.97)	.018
History of glucocorticoid use, *n* (%)	2 (0.07)	2 (0.24)	3 (0.30)	.182
Rheumatoid arthritis, *n* (%)	55 (1.84)	12 (1.43)	13 (1.29)	.428
Speed of sound at the midshaft tibia, m/s	3867 ± 167	3885 ± 166[b]	3869 ± 160	.244
C-reactive protein, mg/dL	0.14 [0.06–0.23]	0.13 [0.05–0.23]	0.13 [0.06–0.23]	.306

Continuous variables are expressed as the mean ± SD or median (interquartile range), and categorical variables are expressed as numbers (%). [a] *P*-value <.05 using post hoc analyses when compared with low exposure group. [b] *P*-value <.05 using post hoc analyses when compared with unexposed group.

Table 2. Hazard ratios of incident fracture risk in the secondhand smoke exposure group.

	Basic model		Full model	
	Hazard ratio (95% CI)	*P*-value	Hazard ratio (95% CI)	*P*-value
Exposure to secondhand smoke (vs unexposed)	1.28 (1.05–1.58)	.017	1.27 (1.03–1.56)	.028
Age, per 1 yr increase	1.05 (1.04–1.07)	<.001	1.04 (1.02–1.06)	<.001
Women	1.98 (1.35–2.89)	<.001	1.73 (1.13–2.63)	.011
BMI, per 1 kg/m^2 increase	1.01 (0.98–1.04)	.609	1.00 (0.97–1.03)	.967
Income level				
Low (vs high)			1.61 (1.14–2.27)	.006
Middle (vs high)			1.58 (1.11–2.24)	.010
SoS, per 1 SD increase			0.90 (0.80–1.01)	.073
CRP, per 1 log increase			0.99 (0.91–1.08)	.826
High alcohol intake			1.02 (0.44–2.36)	.965
History of fracture			1.31 (0.76–2.27)	.327

Abbreviations: CRP, C-reactive protein; SoS, speed of sound

level, SoS at the midshaft tibia, CRP, high alcohol intake, and history of fracture. Moreover, participants in the high exposure group exhibited a significantly increased risk of incident fracture than those in the unexposed group (aHR: 1.33, 95% CI, 1.04–1.70, $P = 0.025$), whereas the risk was not significant in the low exposure group (aHR: 1.18, 95% CI, 0.89–1.57, $P = 0.253$) (Table 3). The robustness of the association between the high exposure group and increased risk of fracture persisted (aHR: 1.47, 95% CI, 1.07–2.02, $P = 0.017$) when the highest quartile threshold (840 min/wk) was applied to determine the high exposure group instead of the median in the sensitivity analysis. Furthermore, the Kaplan–Meier curves demonstrated that the exposed group had a significantly higher fracture probability than that of the unexposed group (log-rank $P = 0.013$) (Figure 2A). Particularly, a significant difference was observed in the cumulative fracture probability among the groups based on their levels of exposure (log-rank $P = 0.022$) (Figure 2B).

We further assessed whether the association between secondhand smoke exposure and fracture risk remained significant after adjusting for the FRAX score. Secondhand smoke exposure remained an independent risk factor for fractures even after adjusting for FRAX scores (aHR: 1.24; 95% CI, 1.01–1.52; $P = 0.038$) (Table 4). Furthermore, the high exposure group exhibited a significantly higher risk of fractures than that of the unexposed group after adjusting for FRAX scores (aHR: 1.34, 95% CI, 1.05–1.69, $P = 0.017$) (Table 4). To ensure the robustness of this finding, we incorporated variables such as age, sex, BMI, income, SoS, CRP, alcohol consumption status, and history of fracture. The association between secondhand smoke and fractures persisted when all of these covariates were included in the full model (exposed vs non-exposed: aHR: 1.27, 95% CI, 1.03–1.56, $P = 0.027$; high-level exposed vs non-exposed, aHR: 1.33, 95% CI, 1.04–1.70, $P = 0.023$).

Additionally, we examined whether the association varied according to the fracture site. The analysis focused on the fracture site at the initial occurrence of a fracture. Compared with the unexposed group, the exposed group exhibited an increased risk of non-vertebral (aHR: 1.37, 95% CI, 1.08–1.73) and non-vertebral non-hip fractures (aHR: 1.31, 95% CI, 1.03–1.67), as well as overall fractures (aHR: 1.27, 95% CI, 1.03–1.56) (Table 5). No significant difference was observed in the risk of vertebral and hip fractures based on the level of secondhand smoke exposure.

Table 3. Hazard ratios of incident fracture risk in the low and high exposure groups.

	Basic model		Full model	
	Hazard ratio (95% CI)	*P*-value	Hazard ratio (95% CI)	*P*-value
Level of exposure to secondhand smoke				
Low exposure group (vs unexposed)	1.17 (0.88–1.55)	.288	1.18 (0.89–1.57)	.253
High exposure group (vs unexposed)	1.37 (1.08–1.75)	.010	1.33 (1.04–1.70)	.025
Age, per 1 yr increase	1.05 (1.04–1.07)	<.001	1.04 (1.02–1.06)	<.001
Women	1.98 (1.35–2.89)	<.001	1.73 (1.13–2.63)	.011
BMI, per 1 kg/m^2 increase	1.01 (0.98–1.04)	.644	1.00 (0.97–1.03)	.946
Income level				
Low (vs high)			1.61 (1.14–2.26)	.007
Middle (vs high)			1.58 (1.11–2.23)	.011
SoS, per 1 SD increase			0.90 (0.80–1.01)	.076
CRP, per 1 log increase			0.99 (0.91–1.08)	.824
High alcohol intake			1.02 (0.44–2.36)	.966
History of fracture			1.32 (0.77–2.29)	.316

Abbreviations: CRP, C-reactive protein; SoS, speed of sound

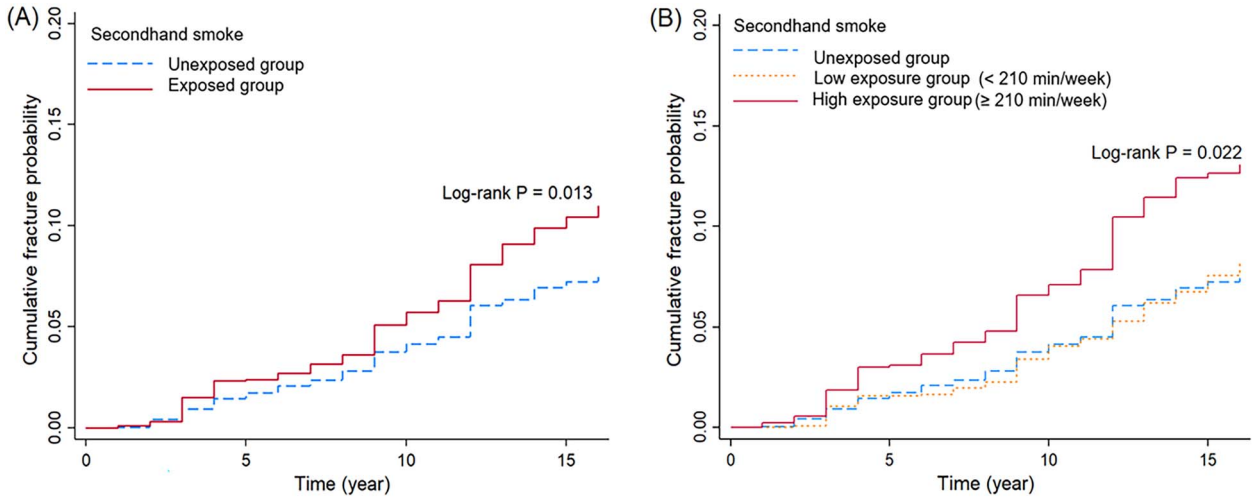


Figure 2. Kaplan–Meier curves of incident fracture according to the exposure status to secondhand smoke (A) and level of exposure (B).

Table 4. Hazard ratios of incident fracture risk in the secondhand smoke exposure group adjusted for FRAX scores.

	Adjusted hazard ratio (95% CI)	*P*-value
Exposure to secondhand smoke		
Exposure group (vs unexposed)	1.24 (1.01–1.52)	.038
FRAX score per 1% point increase	1.12 (1.08–1.16)	<.001
Level of exposure to secondhand smoke		
Low exposure group (vs unexposed)	1.11 (0.84–1.47)	.450
High exposure group (vs unexposed)	1.34 (1.05–1.69)	.017
FRAX score per 1% point increase	1.12 (1.08–1.16)	<.001

Abbreviation: FRAX, fracture risk assessment tool.

Table 5. Hazard ratios of incident fracture risk in the secondhand smoke exposure group stratified by fracture site.

Fracture sites	Adjusted hazard ratio (95% CI)	*P*-value
Overall fracture	1.27 (1.03–1.56)	.028
Vertebral fracture	1.02 (0.65–1.62)	.920
Hip fracture	1.04 (0.45–2.37)	.930
Non-vertebral fracture	1.37 (1.08–1.73)	.009
Non-vertebral non-hip fracture	1.31 (1.03–1.67)	.028

Adjusted for age, sex, BMI, income, speed of sound at midshaft tibia, C-reactive protein, high alcohol intake, and history of fracture.

Discussion

This prospective cohort study demonstrated that secondhand smoke was associated with a 27% increased risk of fracture after adjusting for age, sex, and BMD assessed by QUS. The association was robust and independent of the FRAX score. Additionally, the association exhibited a dose-dependent pattern, with a more pronounced effect observed in cortical bone fractures.

The association between smoking and bone health has been extensively documented. A study including 41 pairs of twins demonstrated that with every additional 10 pack-years of smoking, the twin who smoked more heavily demonstrated a 2.0% lower bone density at the lumbar spine and a 1.4% lower bone density at the femoral shaft.[6] The impact of smoking on bone health accumulates over time, resulting in additional bone loss of 4%, 6%, and 8% by age 70, 80, and 90 yr, respectively.[12] Compared with nonsmoking, current smoking is associated with a 25% higher risk of any fracture and an 84% higher risk of hip fracture, regardless of BMD.[13] Meta-analyses have further confirmed the heightened fracture risk among both male and female smokers.[12-14]

However, the harmful effects of secondhand smoke on bone health remain less understood. Previous animal models have shown that exposure to secondhand smoke is associated with low bone mass, delayed fracture healing, and impaired callus formation.[15,16] In humans, exposure to secondhand smoke during childhood has been linked to lower peripheral quantitative CT-derived bone sum index, lower heel ultrasound–estimated BMD in adulthood, and increased risk of low-energy fractures.[17] A cohort study involving postmenopausal Korean women who had never smoked demonstrated that the presence of active smokers among family members was associated with a 3.68-fold increased risk of femoral neck osteoporosis compared to those not exposed to secondhand smoke. Despite these findings, studies specifically investigating the association between secondhand smoke and fracture risk are limited. In this study, we included 4843 individuals without a smoking history and evaluated their fracture risk based on their level of exposure to secondhand smoke within a median follow-up of 8 yr. We observed that secondhand smoke was associated with an increased risk of incident fractures even after adjusting for multiple covariates.

The mechanism by which smoking adversely affects bone health involves increased bone resorption caused by toxic chemicals in tobacco. Specifically, the binding of nicotine to its receptors in osteoblasts and chondrocytes, as well as the activation of the RANKL pathway in osteoclasts, has been suggested as plausible mechanisms.[18] Previous animal models have shown that smoking inhibits osteogenesis and osseointegration, while nicotine exposure hinders bone matrix synthesis and differentiation in human growth plate chondrocytes.[18,19] In smokers, the expression of bone markers is altered, with significantly low levels of osteoprotegerin, a marker of bone formation.[20] Considering the compositional similarity between secondhand smoke and active smoke, it is conceivable that secondhand smoke might also impact bone metabolism similarly.[21] Compared with control mice (unexposed to smoke), mice exposed to smoke have demonstrated lower yield load, stiffness, yield stress, and flexural modulus, indicating the deleterious effects of smoke on structural strength, material properties, and bone mass.[22] The toxic compounds found in secondhand smoke might induce similar detrimental effects on bone health, potentially resulting in outcomes comparable to those observed in active smokers.

In our study, we observed a dose-dependent association between secondhand smoke exposure and fractures. Individuals in the high exposure group exhibited a significantly higher risk of incident fracture, whereas those in the low exposure group did not exhibit a notable increase in fracture risk. These findings are in line with those of previous studies that investigated the dose-dependent harmful effects of smoking. This dose-dependent association between smoke exposure and adverse health outcomes extends beyond respiratory events and heart disease[23-25] and is also evident in bone health outcomes. Previous studies conducted among Korean women reported that higher urinary cotinine levels, a marker of increased smoke exposure, are associated with significantly lower BMD at the femur neck, total femur, and lumbar spine.[26] Furthermore, a previous meta-analysis confirmed that dose-dependent bone loss is associated with smoking exposure.[27] These findings emphasize the importance of avoiding secondhand smoke to protect bone health.

Additionally, our study revealed that secondhand smoke was associated with an increased risk of non-vertebral and non-vertebral non-hip fractures, as well as overall fractures. This finding aligns with that of previous studies, indicating detrimental effects of smoking on cortical bones. In a study involving rabbits that underwent midshaft tibia osteotomies, the groups receiving nicotine exhibited reduced callus formation and a notable delay in the formation of cortical continuity.[28] Furthermore, young male smokers exhibited reduced cortical thickness compared with that of nonsmokers.[29] Considering the current challenges in pharmacological interventions for preventing non-vertebral or non-hip fractures, our results emphasize the importance of avoiding secondhand smoke exposure as a preventive measure for fractures occurring at such sites.

Surgeon General reports indicate that no threshold has been established for the adverse health outcomes of secondhand smoking exposure, and even brief exposure can cause harmful effects on health.[30] In line with the findings of previous studies, which demonstrated an elevated circulatory inflammatory marker and a higher risk of new-onset hypertension even in exposure levels of 60–180 min/wk,[31,32] the risk of incident fracture was higher in high exposed group, defined using the median (210 min/wk) or highest quartile (840 min/wk), than that of the unexposed group. Hence, an optimal threshold for defining a high exposed group in terms of fracture risk needs to be explored further.

Our study has several limitations. The study was conducted in participants who were able to visit the examination center, potentially introducing a bias toward healthy volunteers. Furthermore, smoking history and fracture outcomes were assessed using a self-reported questionnaire. Specifically, relying on self-reported fracture outcomes may lead to the underreporting of certain fractures, particularly vertebral fractures, potentially compromising the statistical power of the study. As it was not possible to trace back to the time of initiation of secondhand smoke in this study, we compared exposed and unexposed groups in this study using the information collected at the time of entry to the cohort. This might lead to depletion of susceptible subjects particularly in the exposed group, resulting in underestimation of the risk.[33] BMD was assessed using QUS, which is considered less accurate than DXA BMD. The lack of DXA BMD and history of osteoporosis represents

a notable limitation of this study, although attempts have been made to address this by adjusting mid-shaft tibia SoS as a surrogate for BMD information and history of fracture in the statistical model. The FRAX score was calculated without DXA BMD. It would be crucial to determine whether the association between secondhand smoking and fracture risk remains robust after adjusting for FRAX score with DXA BMD. Our study was conducted in specific geographic areas (Ansung and Ansan, Korea), which may limit the generalizability of our findings to other regions. The exposed group had a younger mean age and higher proportion of women compared with those of the unexposed group. Although this was an inherent limitation owing to the exclusion of individuals with smoking history according to the study scheme, efforts were made to adjust for differences between the groups using a multivariable model. This model demonstrated a robust association between secondhand smoking and higher fracture risk even after adjusting for age and sex.

Despite the incidence rate of osteoporotic fractures plateauing in Korea since 2013,[34] a substantial population of patients with osteoporosis and related fractures remains, necessitating appropriate management to mitigate future fracture risk. However, the treatment adherence and compliance rates among these patients remain suboptimal. Thus, identifying modifiable prognostic factors that can significantly affect bone health and actively addressing them in older and osteoporotic individuals is crucial. Our study demonstrated that exposure to secondhand smoke independently increases the risk of fractures, regardless of clinical predictors. These findings highlight the importance of recognizing and addressing the impact of secondhand smoke on fracture risk. Implementing preventive measures and raising awareness about the harmful effects of secondhand smoke could potentially help reduce the burden of fractures and improve bone health outcomes in vulnerable populations.

Author contributions

Junyeong Ahn (Data curation, Formal analysis, Investigation, Methodology, Validation, Writing—original draft [contributed equally] [shared first authorship]), Hye-Sun Park (Formal analysis, Investigation, Validation, Writing—original draft, Writing—review & editing [contributed equal] [shared first authorship]), Sung Joon Cho (Investigation, Writing—review & editing), Seungjin Baek (Data curation, Formal analysis, Writing—review & editing), Yumie Rhee (Conceptualization, Formal analysis, Methodology, Supervision, Writing—review & editing), and Namki Hong (Conceptualization, Data curation, Formal analysis, Investigation, Supervision, Validation, Writing—review & editing)

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Conflicts of interest

None declared.

Data availability

The data are accessible through the Korea Disease Control and Prevention Agency (KDCA). Permission to access the data can be obtained from the KDCA (http://www.kdca.go.kr).

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