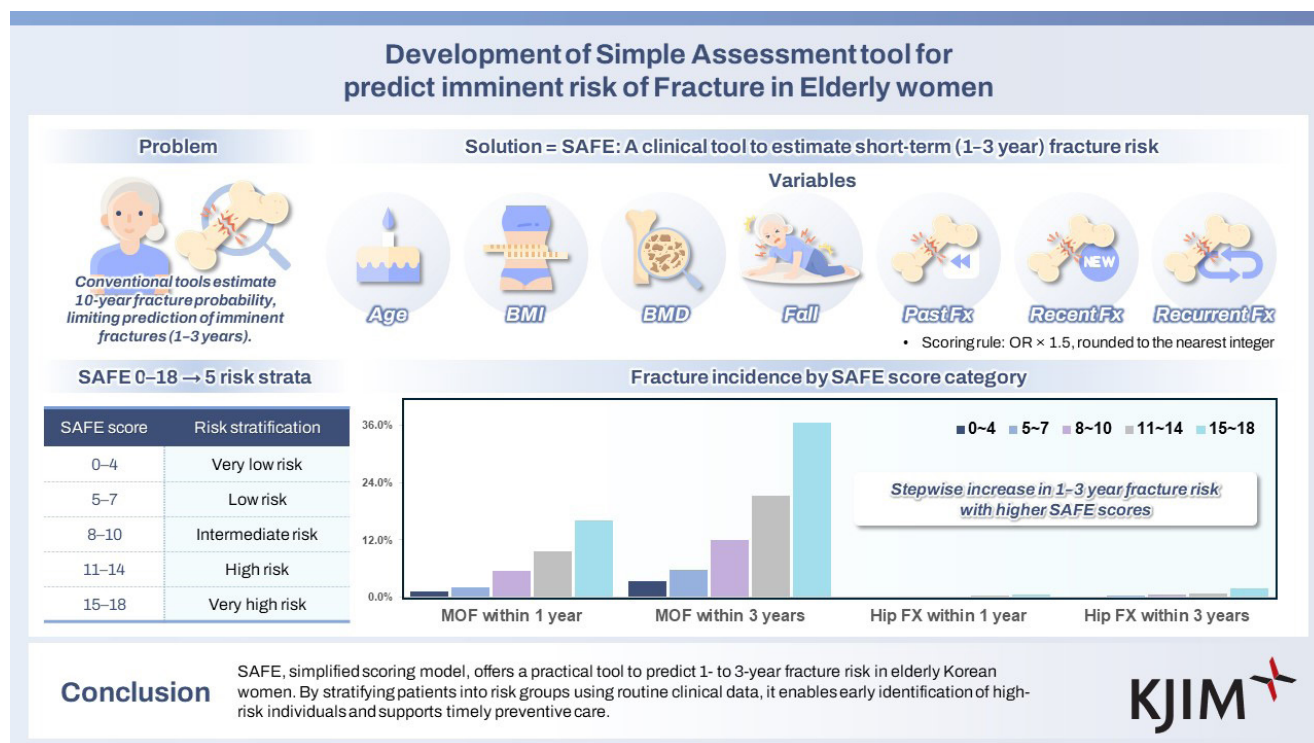




Development of Simple Assessment tool for predict imminent risk of Fracture in Elderly women

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Background/Aims: Previously developed fracture risk prediction models primarily estimate long-term risk and are limited in their ability to predict imminent fractures. We developed a simplified and practical model to predict the short-term fracture risk (1- to 3-year risk) in elderly Korean women.

Methods: We included 1,440,988 women who underwent a national life-transition health examination at age 66 between 2011 and 2017. The participants were followed-up for 3 years to identify major osteoporotic fractures (MOFs) and hip fractures. Clinical risk factors such as body mass index, bone mineral density, fall history within 6 months, prior fractures within 3

years, recent fractures within 1 year, and recurrent fractures were analyzed. Multivariate logistic regression was used to estimate the odds ratios (ORs) for these risk factors. Each OR was converted into a risk score, and the total scores were stratified into five groups: 0–4, 5–7, 8–10, 11–14, and 15–18 points.

Results: Higher scores were associated with a significantly increased risk of fractures. At 3 years, the incidences of MOF were 3.4%, 5.8%, 12.0%, 21.3%, and 36.6%, and the hip fracture incidences were 0.13%, 0.26%, 0.59%, 0.73%, and 1.82% across the five groups, respectively.

Conclusions: This simplified scoring model is a practical tool for predicting the 1- to 3-year fracture risk in elderly Korean women. By stratifying patients into risk groups based on routine clinical data, it enables the early identification of high-risk individuals and facilitates timely preventive care.

Keywords: Osteoporosis; Postmenopause; Osteoporotic fractures; Risk assessment; Korea

INTRODUCTION

Because osteoporotic fractures are associated with high morbidity and mortality [1,2], it is important to prevent fractures through the early detection of high fracture risk and appropriate treatment. Low bone mineral density (BMD) is the strongest predictor of osteoporotic fractures [3]. However, combining BMD with clinical risk factors yields better fracture risk prediction than BMD alone [4,5]. Accordingly, algorithms that combine clinical risk factors with BMD have been developed to better estimate fracture risk and several studies have compared the efficacies, strengths, and limitations of numerous predictive models for osteoporotic fractures [6]. Among the prediction models for osteoporotic fractures, the World Health Organization Fracture Risk Assessment Tool (FRAX) algorithm [7], Qfracture algorithm [8], and Garvan Fracture Risk Calculator (Garvan) [9] are the most commonly used. Because FRAX is the most externally validated model [6], several international guidelines recommend its use for fracture risk assessment. As the risk and incidence of osteoporotic fractures vary widely between populations [10], it is necessary to develop ethnicity-specific predictive models for osteoporotic fracture risk; however, Asian-specific prediction models for estimating the individual risk of osteoporotic fractures remain rare. Therefore, a Korean fracture risk prediction model based on clinical risk factors was developed in previous study [11]. However, previously developed fracture risk assessment tools are limited in the clinical practice because they are too complicated and involve many risk factors. Additionally, because they are dependent on the recall of family history and past history of

fractures, their accuracy can be limited in elderly populations. Moreover, because they assess the 10-year fracture risk, they cannot be applied to predict the imminent risk of fractures. This study aimed to develop a simpler and more practical fracture risk prediction model to predict the imminent risk of fractures in elderly Korean women.

METHODS

Study population

Data from postmenopausal women aged 66 years who underwent a national life-transition examination in Korea between January 2011 and December 2017 were reviewed using the Korean National Health Insurance (KNHI) claims database, covering the period from 2009 to 2019. The KNHI claims database contains information on diagnoses, drug prescriptions, and procedures according to the International Classification of Diseases, 10th revision (ICD-10). Briefly, in the 66-year-old national life-transition examination, a physical examination, BMD tests, vision and hearing tests, depression screening tests, chest radiography, and blood tests are performed, and drinking and smoking histories are recorded. Fall history within the previous 6-months is also recorded. Among eligible participants who underwent a BMD test ($n = 1,041,223$), participants were excluded if there were no data on fall history or body mass index (BMI). Individuals with BMD measured using peripheral DXA, peripheral quantitative computed tomography, or quantitative ultrasonography were also excluded. Finally, 778,696 women with BMD measured using dual-energy X-ray absorptiometry (DXA) were included in the study cohort. Considering that

health examinations are conducted for each person every two years, their repeated health examination data between 2011 and 2017 were collected using the KNHI claims database ($n = 2,515,727$). The number of health examinations conducted annually is shown in Figure 1. After excluding missing and outlier data, 1,440,988 cases were ultimately included (Fig. 1). The index date was defined as the date of the health examination. An example of the collection process in one individual is shown in Supplementary Figure 1.

Clinical risk factors

Clinical data, including BMD test results, age at the time of health examination, BMI, history of falls in the last 6 months, history of past or recent fractures, and recurrent fractures, were collected. Based on the BMD results, the participants were classified as normal, osteopenia, or osteoporosis. They were additionally divided by age into two groups: ≥ 65 and < 70 years, ≥ 70 years. For BMI, the most recent value from a health examination administered every 2 years was used. Missing or outlier BMI data were imputed by calculating

the mean BMI values from health examinations performed more than three times. Participants were divided into five BMI groups: < 20 , ≥ 20 and < 23 , ≥ 23 and < 25 , ≥ 25 and < 27.5 , and ≥ 27.5 kg/m^2 . A past fracture was defined as any fracture that occurred within 3 years prior to the index date. A recent fracture was defined as a fracture that occurred within 1 year prior to the index date. A recurrent fracture was defined as two or more fractures of any type that occurred 6 months apart within 3 years prior to the index date. The sites of past, recent, and recurrent fractures were defined as hip, spine, distal radius, and proximal humeral fractures.

Study outcomes

The primary outcome was the incidence of major osteoporotic fractures (MOFs) within 3 years of the index date. Secondary outcomes included hip fractures within 3 years or MOFs or hip fractures within 1 year of the index date. MOFs involve the hip, spine, distal radius, and proximal humerus, and are defined using the following ICD-10 diagnosis and

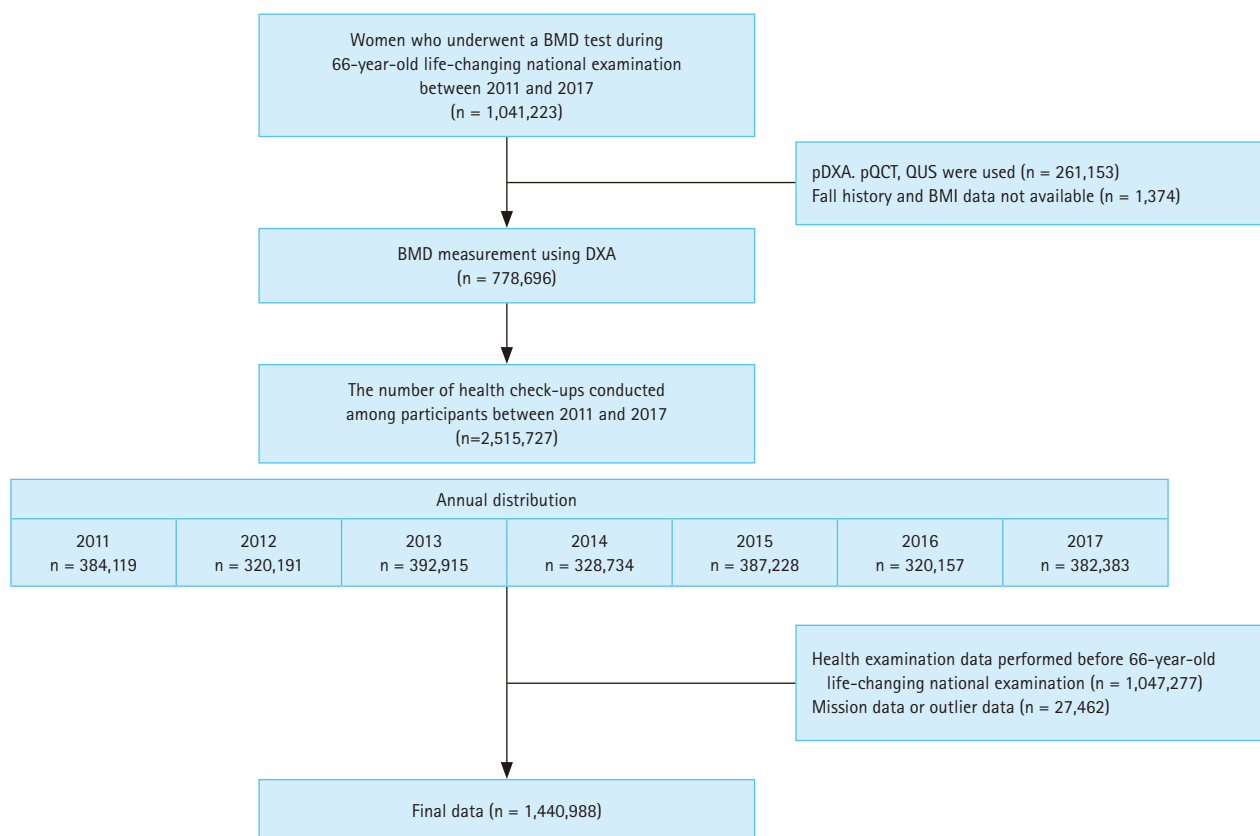


Figure 1. Study design. BMD, bone mineral density; DXA, dual-energy X-ray absorptiometry; pDXA, peripheral dual-energy X-ray absorptiometry; pQCT, peripheral quantitative computed tomography; QUS, quantitative ultrasound; BMI, body mass index.

procedure codes: hip fracture (S72.0, S72.1), vertebral fracture (S22.0, S22.1, S32.0, T080, M48.4, M48.5, M49.5), humeral fracture (S42.2, S42.3), and distal radial fracture (S52.5, S52.6).

Statistical analysis and development of the Simple Assessment tool for predict imminent risk of Fracture in Elderly women (SAFE)

Baseline characteristics are expressed as the mean $\pm$ standard deviation for continuous variables and as number (%) for categorical variables. The rates of primary and secondary outcomes were calculated as percentages. To develop a simple assessment tool, logistic regression analyses were first performed for MOF at 3 years using covariates of age group, BMI group, BMD value at 66 years of age and history of falls, past fractures, recent fractures, and recurrent fractures. To calculate the score for each covariate, the odds ratio (OR) of each risk factor was multiplied by 1.5 and scored by rounding up. The MOF risk was predicted by summing the scores for each risk factor. This fracture risk assessment tool was named Simple Assessment tool for predict imminent risk of Fracture in Elderly women (SAFE). According to the summed SAFE scores, the patients were divided into five groups (0–4, 5–7, 8–10, 11–14, and 15–18 points), with a higher score indicating a higher risk of fracture. After developing the SAFE score for MOF, we applied the SAFE score to other secondary outcomes to validate whether it would also be suitable for those. The incidence of fractures was analyzed according to the SAFE score. Statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA), and a p value < 0.05 was considered statistically significant.

Ethics statement

This study was approved by the Institutional Review Board (IRB) of Yongin Severance Hospital (IRB number: 9-2022-0095). Informed consent was not required from the patients because of the nature of the public data from the KNHI claims database.

RESULTS

Baseline characteristics of study participants

The baseline characteristics of the participants are summarized in Table 1. The mean age was 67.4 years, and 82.8%

Table 1. Baseline characteristics of study participants

Variable	Value (n = 1,440,988)
Age (y)	67.4 $\pm$ 1.7
65–70	1,192,451 (82.8)
≥ 70	248,537 (17.2)
BMI (kg/m ²)	24.5 $\pm$ 3.2
< 20	82,760 (5.7)
20 $\leq$ BMI < 23	374,295 (26.0)
23 $\leq$ BMI < 25	384,375 (26.7)
25 $\leq$ BMI < 27.5	362,523 (25.2)
≥ 27.5	237,035 (16.4)
BMD	
Normal	290,098 (20.1)
Osteopenia	632,129 (43.9)
Osteoporosis	546,223 (37.9)
History of fall	123,557 (8.6)
Past fracture	57,587 (4.0)
Recent fracture	25,045 (1.7)
Recurrent fracture	5,379 (0.4)

Values are presented as mean $\pm$ standard deviation or number (%). BMI, body mass index; BMD, bone mineral density

of the participants were between 65 and < 70 years of age. The mean BMI was 24.5 kg/m². Most patients (77.9%) had a BMI of ≥ 20 and < 27.5 kg/m². The normal BMD group included 290,098 (20.1%), the osteopenia group included 632,129 (43.9%), and the osteoporosis group included 546,223 (37.9%) participants. A history of falls within the last 6 months was reported in 8.6% of the analyzed cohort, with a history of past fractures in 4.0%, recent fractures in 1.7%, and recurrent fractures in 0.4%.

The incidence of fracture

The mean follow-up duration was 1.4 $\pm$ 0.7 years. The incidence rates of MOFs and hip fractures within 1 year were 1.7% and 0.1%, respectively (Fig. 2). The incidence rates of MOFs and hip fractures within 3 years were 4.6% and 0.2%, respectively (Fig. 2).

The association between clinical risk factors and MOF within 3 years

Table 2 presents the association between clinical risk factors and MOF within 3 years. The risk of MOF increased with old age, underweight and obesity, osteoporosis, history of

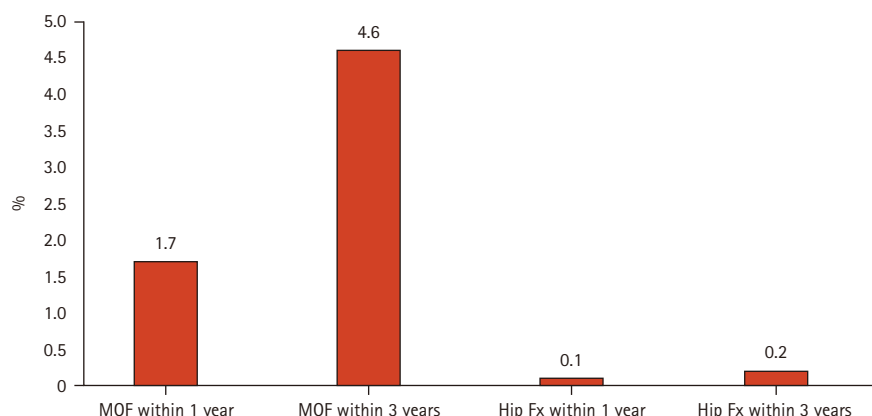


Figure 2. Fracture incidence during study period. MOF, major osteoporotic fracture; Fx, fracture.

Table 2. Association between risk factors and major osteoporotic fracture within 3 years

Variable	OR (95% CI)
Age (y)	
65–70	Reference
≥ 70	1.31 (1.29–1.34)
BMI (kg/m ²)	
< 20	1.04 (1.01–1.08)
20 ≤ BMI < 23	0.98 (0.69–1.00)
23 ≤ BMI < 25	Reference
25 ≤ BMI < 27.5	1.05 (1.03–1.07)
≥ 27.5	1.11 (1.09–1.14)
BMD	
Normal	Reference
Osteopenia	1.5 (1.47–1.54)
Osteoporosis	2.19 (2.14–2.25)
History of fall	
No	Reference
Yes	1.29 (1.25–1.32)
Past fracture	
No	Reference
Yes	2.28 (2.19–2.36)
Recent fracture	
No	Reference
Yes	1.64 (1.56–1.72)
Recurrent fracture	
No	Reference
Yes	2.51 (2.35–2.69)

By multivariate logistic test.

OR, odds ratio; CI, confidence interval; BMI, body mass index; BMD, bone mineral density.

falls, and history of previous and recurrent fractures: The OR for MOF within 3 years was 1.31 (95% confidence interval [CI] 1.29–1.34) in those aged 70 years compared with those aged ≥ 65 years and < 70 years. The ORs for MOF within 3 years were 1.04 (95% CI 1.01–1.08) for BMI < 20 kg/m², 0.98 (95% CI 0.69–1.00) for BMI ≥ 20 and < 23 kg/m², 1.05 (95% CI 1.03–1.07) for BMI ≥ 25 and < 27.5 kg/m², and 1.11 (95% CI 1.09–1.14) for BMI ≥ 27.5 kg/m² compared with BMI ≥ 23 and < 25 kg/m². The ORs for MOF within 3 years were 1.5 (95% CI 1.47–1.54) for osteopenia and 2.19 (95% CI 2.14–2.25) for osteoporosis compared with normal BMD. A history of falls increased the risk of MOF within 3 years by 1.29-fold (95% CI 1.25–1.32). The ORs for the occurrence of MOF for past, recent, and recurrent fractures were 2.28 (95% CI 2.19–2.36), 1.64 (95% CI 1.56–1.72), and 2.51 (95% CI 2.35–2.69), respectively.

SAFE score and risk of fractures in 1 or 3 years

The SAFE score ranges from 0 to 18 points, according to the risk factors. The presence of all the risk factors results in a score of 18 points (Table 3). The incidence of fractures was analyzed according to the SAFE score (Supplementary Table 1). The higher the score, the higher the fracture incidence for both MOF and hip fractures. Fracture incidence according to the SAFE score is shown in Figure 3. There were clear increasing trends in fracture incidence with higher SAFE scores. The incidences of MOF within 3 years were 3.4%, 5.8%, 12.0%, 21.3%, and 36.6% in participants with scores of 0–4, 5–7, 8–10, 11–14, and 15–18 points, respectively. The SAFE score was also suitable for hip fractures at 3 years; the incidences of hip fractures within 3 years were 0.13%, 0.26%, 0.59%, 0.73%, and 1.82%

Table 3. Development of Simple Assessment tool for predict imminent risk of Fracture in Elderly women (SAFE)

Variable	Score (round [odds ratio*1.5])
Age (y)	
65–70	0
≥ 70	2
BMI (kg/m ²)	
< 20	2
20 ≤ BMI < 23	1
23 ≤ BMI < 25	0
25 ≤ BMI < 27.5	2
≥ 27.5	2
BMD	
Normal	0
Osteopenia	2
Osteoporosis	3
History of fall	
No	0
Yes	2
Past fracture	
No	0
Yes	3
Recent fracture	
No	0
Yes	2
Recurrent fracture	
No	0
Yes	4
Total score	18

BMI, body mass index; BMD, bone mineral density.

in those with scores of 0–4, 5–7, 8–10, 11–14, and 15–18 points, respectively. The SAFE score predicted the imminent risk of fracture within 1 year, and the incidence of MOF within 1 year was 1.2%, 2.1%, 5.6%, 9.7%, and 16.2% in those with scores of 0–4, 5–7, 8–10, 11–14, and 15–18 points, respectively. The incidences of hip fractures within 1 year were 0.04%, 0.10%, 0.24%, 0.25%, and 0.68% in participants with scores of 0–4, 5–7, 8–10, 11–14, and 15–18 points, respectively.

DISCUSSION

We developed a new and simple fracture risk prediction model, SAFE, to predict the imminent risk of fractures in elderly Korean women using a nationwide retrospective cohort of Korean women over the age of 66 years. SAFE was developed using seven clinical risk factors that are well-known simple covariates for osteoporosis and fracture, including age, BMI, BMD, history of falls within 6 months, history of past fractures within 3 years, recent fractures within 1 year, and recurrent fractures. The SAFE score can predict the imminent fracture risk, within 1 or 3 years, for both MOF and hip fractures.

Previous fracture prediction models, including FRAX, QFracture, and Garvan Fracture Risk Calculator, included many risk factors, and specific tools were required to use them. Previous studies using these models evaluated 10-year and 5-year fracture probabilities. Therefore, it was difficult to calculate fracture risk easily and quickly in actual clinical practice and to predict the imminent fracture risk.

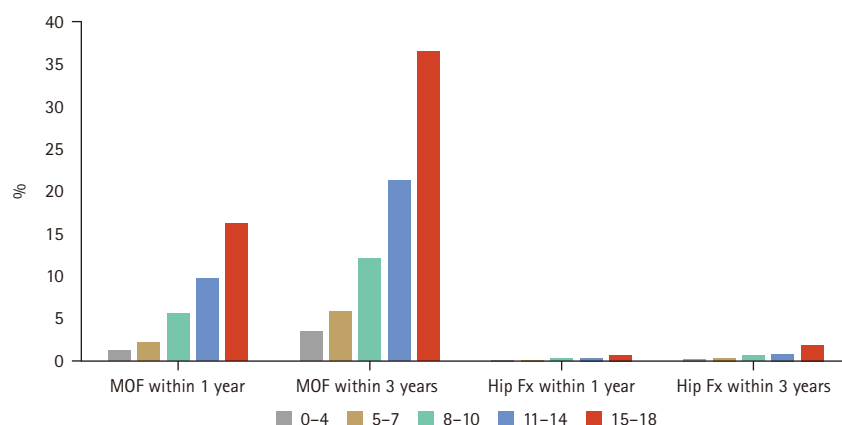


Figure 3. Fracture incidence according to Simple Assessment tool for predict imminent risk of Fracture in Elderly women (SAFE) score group. MOF, major osteoporotic fracture; Fx, fracture.

In contrast, SAFE can easily, quickly, and intuitively calculate fracture risk by including only the major clinical risk factors related to fractures and osteoporosis. In addition, unlike previous fracture prediction models, SAFE can improve the accuracy of fracture prediction because it includes the history of falls, recurrent fractures, and recent fracture history within 12 months. Moreover, in the elderly, predicting imminent fracture risk may be more important than predicting 10-year fracture risk; thus, SAFE's 1-year and 3-year imminent fracture risk prediction is a significant strength.

When developing SAFE, we attempted to make it as simple as possible, with the fewest clinical risk factors. Among the various clinical risk factors, only the critical factors that strongly influence fracture incidence were selected. Bone loss increases with age and, in combination with intrinsic and extrinsic factors, accelerates the decline in bone quantity and quality, leading to osteoporosis and fracture [12]. Low BMI or body weight is associated with low BMD and is therefore a risk factor for osteoporotic fractures [13,14]. Even the simplest fracture risk assessment tool, the Osteoporosis Self-assessment Tool (OST), includes age and weight [15]. Because low BMD is a well-known and strong predictor of osteoporotic fracture risk [3], fracture risk prediction models that do not include BMD have limited prediction accuracy. A previous study compared the predictive rates of FRAX with and without BMD [16]. The 10-year probability of hip fracture calculated using FRAX scores with and without BMD was concordant in 83.8% of the patients; however, BMD data may be required for younger age, higher BMI, and lower BMD to facilitate accurate risk assessment [16]. Previous studies have suggested that falls are independent risk factors of fractures [17,18]. In our study, falls increased the risk of fractures by 29.0%. This was similar to the OR in the elderly (1.31, 95% CI 1.29–1.34). Unlike QFracture and the Garvan Fracture Risk Calculator, FRAX does not include fall history. Considering the strong association between falls and fractures, Kanis et al. [19] proposed adjusting the conventional FRAX to estimate the fracture probability according to the number of falls in the preceding year. In their study, the 10-year fracture probability progressively increased as the number of reported falls increased [19]. Thus, for the probability of MOF, the FRAX value was multiplied by 1.2, 1.3, and 1.7 for a history of one, two, and three or more reported falls, respectively. For the probability of hip fracture, the FRAX value was multiplied by 1.2, 1.5, and 2.0 for a history of one, two, and three or more report-

ed falls, respectively [19]. In SAFE, only fall history within 6 months was included, and the number of falls was not considered. However, because fall-related risk factors depend on a patient's memory, the exact number of falls may not be accurate. Even if only a history of a fall is identified, it is possible to calculate the fracture risk quickly and efficiently in clinical practice. Prior fractures increase the risk of subsequent fractures [20]. In a meta-analysis, a previous history of fracture conferred an increased risk of fracture of substantial importance beyond that explained by BMD [21]. The risk of subsequent fractures is higher during the first year after the initial fracture [22]. Thus, recently published guidelines for postmenopausal osteoporosis management defined the very high fracture risk group as those with recent fractures, multiple fractures, very low BMD, or several other clinical factors [23,24]. More active and rapid osteoporosis treatment is recommended in the very-high-risk group. In our study, the ORs for past fracture history (OR 2.28, 95% CI 2.19–2.36) and recurrent fractures (OR 2.51, 95% CI 2.35–2.69) were higher than that for osteoporosis (OR 2.19, 95% CI 2.14–2.25). Considering the importance of recent fractures, the scores for recent fractures within 12 months were added to the SAFE score.

Most fracture prediction models have been developed and validated in United States, the United Kingdom, and China; however, models for the Korean population are insufficient. The Korean Fracture Risk Score (KFRS), which was previously developed and validated for the Korean population, did not include BMD; therefore, the SAFE score supplemented the KFRS. Kong et al. [25] developed a novel fracture prediction model using CatBoost, a machine-learning method in a prospective Korean community-based cohort. The CatBoost model predicted total and hip fractures better than the FRAX model. However, the CatBoost model may not be easy to apply in a real-world setting because it includes the top 20 predictive factors.

This study has some limitations. First, the SAFE is difficult to generalize because men and women under the age of 66 were excluded. Second, the SAFE score was not validated. Follow-up studies are underway to validate the clinical usefulness of SAFE scores in different populations and ethnicities. Additionally, a comparative study with other fracture risk prediction models is required to evaluate the fracture prediction accuracy of the SAFE score. Third, fractures may have been underestimated because the definition of fractures used ICD-10 codes and the fractures were not con-

firmed radiologically. Finally, owing to data limitations, our study was restricted to the history of previous fractures and recurrent fractures within 3 years. However, if more large-scale prospective studies are conducted in the future and the definition of past fracture history and repeated fractures could be included more broadly, it may be more convenient for real-world use.

In conclusion, we developed a novel, simple fracture risk prediction model, SAFE, to better predict the imminent fracture risk in elderly Korean women using age, BMI, BMD, history of falls within 6 months, history of past fractures within 3 years, recent fractures within 1 year, and recurrent fractures. The SAFE score can predict the imminent risk of fractures that may occur within 1 or 3 years. The SAFE score may help identify patients at higher risk of imminent fractures with the need for immediate therapeutic intervention.

KEY MESSAGE

1. We developed a simple and practical tool, SAFE to predict 1- to 3-year fracture risk in elderly Korean women.
2. SAFE includes clinical risk factors such as age, BMI, BMD, history of falls within 6 months, past fractures within 3 years, recent fractures within 1 year, and recurrent fractures.
3. SAFE demonstrates a strong dose-response relationship with future fracture incidence and may support early identification and timely intervention for high-risk individuals.

REFERENCES

1. Hopkins RB, Burke N, Von Keyserlingk C, et al. The current economic burden of illness of osteoporosis in Canada. *Osteoporos Int* 2016;27:3023-3032.
2. Haentjens P, Magaziner J, Colón-Emeric CS, et al. Meta-analysis: excess mortality after hip fracture among older women and men. *Ann Intern Med* 2010;152:380-390.
3. Johnell O, Kanis JA, Oden A, et al. Predictive value of BMD for hip and other fractures. *J Bone Miner Res* 2005;20:1185-1194.
4. Aspray TJ. Fragility fracture: recent developments in risk assessment. *Ther Adv Musculoskelet Dis* 2015;7:17-25.
5. Kanis JA, Oden A, Johnell O, et al. The use of clinical risk factors enhances the performance of BMD in the prediction of hip and osteoporotic fractures in men and women. *Osteoporos Int* 2007;18:1033-1046.
6. Sun X, Chen Y, Gao Y, et al. Prediction models for osteoporotic fractures risk: a systematic review and critical appraisal. *Aging Dis* 2022;13:1215-1238.
7. Kanis JA, Johnell O, Oden A, Johansson H, McCloskey E. FRAX and the assessment of fracture probability in men and women from the UK. *Osteoporos Int* 2008;19:385-397.
8. Hippisley-Cox J, Coupland C. Predicting risk of osteoporotic fracture in men and women in England and Wales: prospective derivation and validation of QFractureScores. *BMJ* 2009;339:b4229.
9. Nguyen ND, Frost SA, Center JR, Eisman JA, Nguyen TV. Development of prognostic nomograms for individualizing 5-year and 10-year fracture risks. *Osteoporos Int* 2008;19:1431-1444.
10. Barrett-Connor E, Siris ES, Wehren LE, et al. Osteoporosis and fracture risk in women of different ethnic groups. *J Bone Miner Res* 2005;20:185-194.
11. Kim HY, Jang EJ, Park B, et al. Development of a Korean Fracture Risk Score (KFRS) for predicting osteoporotic fracture risk: analysis of data from the Korean National Health Insurance Service. *PLoS One* 2016;11:e0158918.
12. Demontiero O, Vidal C, Duque G. Aging and bone loss: new insights for the clinician. *Ther Adv Musculoskelet Dis* 2012;4:61-76.
13. De Laet C, Kanis JA, Odén A, et al. Body mass index as a predictor of fracture risk: a meta-analysis. *Osteoporos Int* 2005;16:1330-1338.
14. Yi SW, Bae JH, Kim YM, Won YJ, Kim SH. Relationship between body mass index and fracture risk at different skeletal sites: a nationwide cohort study. *Arch Osteoporos* 2022;17:99.
15. Koh LK, Sedrine WB, Torralba TP, et al.; Osteoporosis Self-Assessment Tool for Asians (OSTA) Research Group. A simple tool to identify Asian women at increased risk of osteoporosis. *Osteoporos Int* 2001;12:699-705.
16. Teeratakulpisarn N, Charoensri S, Theerakulpisut D, Pongchaiyakul C. FRAX score with and without bone mineral density: a comparison and factors affecting the discordance in osteoporosis treatment in Thais. *Arch Osteoporos* 2021;16:44.
17. Kaptoge S, Benevolenskaya LI, Bhalla AK, et al. Low BMD is less predictive than reported falls for future limb fractures in women across Europe: results from the European Prospective Osteoporosis Study. *Bone* 2005;36:387-398.

18. Gillespie LD, Gillespie WJ, Robertson MC, Lamb SE, Cumming RG, Rowe BH. Interventions for preventing falls in elderly people. *Cochrane Database Syst Rev* 2003;(4):CD000340.
19. Kanis JA, Johansson H, Harvey NC, et al. Adjusting conventional FRAX estimates of fracture probability according to the number of prior falls in the preceding year. *Osteoporos Int* 2023;34:479-487.
20. Lindsay R, Silverman SL, Cooper C, et al. Risk of new vertebral fracture in the year following a fracture. *JAMA* 2001;285:320-323.
21. Kanis JA, Johnell O, De Laet C, et al. A meta-analysis of previous fracture and subsequent fracture risk. *Bone* 2004;35:375-382.
22. van Geel TA, Huntjens KM, van den Bergh JP, Dinant GJ, Geusens PP. Timing of subsequent fractures after an initial fracture. *Curr Osteoporos Rep* 2010;8:118-122.
23. Eastell R, Rosen CJ, Black DM, Cheung AM, Murad MH, Shoback D. Pharmacological management of osteoporosis in postmenopausal women: an Endocrine Society* clinical practice guideline. *J Clin Endocrinol Metab* 2019;104:1595-1622.
24. Camacho PM, Petak SM, Binkley N, et al. American Association of Clinical Endocrinologists/American College of Endocrinology clinical practice guidelines for the diagnosis and treatment of postmenopausal osteoporosis—2020 update Executive Summary. *Endocr Pract* 2020;26:564-570.
25. Kong SH, Ahn D, Kim BR, et al. A novel fracture prediction model using machine learning in a community-based cohort. *JBMR Plus* 2020;4:e10337.

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Credit authorship contributions

So Young Park: investigation, data curation, writing - original draft, writing - review & editing; Sujin Kwon: methodology, investigation, data curation, formal analysis, validation; Kyoung Jin Kim: investigation, writing - review & editing; Seong Hee Ahn: investigation, writing - review & editing; Ha Young Kim: writing - review & editing; Kyoung Min Kim: conceptualization, investigation, data curation, validation, writing - review & editing, supervision

Conflicts of interest

The authors disclose no conflicts.

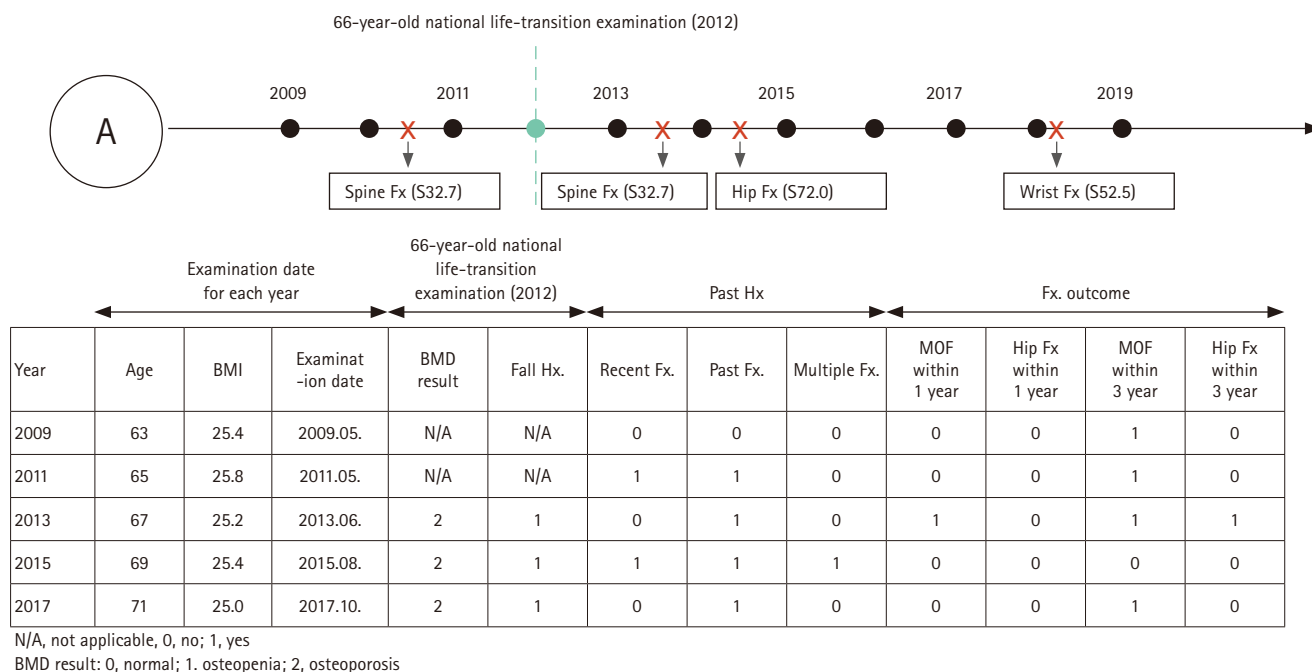
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None

Supplementary Table 1. The incidence of Fx according to SAFE score

Score	Major osteoporotic Fx						Hip Fx					
	Within 1 year			Within 3 year			Within 1 year			Within 3 year		
	No Fx (n)	Fx (n)	Incidence (%)	No Fx (n)	Fx (n)	Incidence (%)	No Fx (n)	Fx (n)	Incidence (%)	No Fx (n)	Fx (n)	Incidence (%)
0	53,450	426	1	52,634	1,242	2	53,859	17	0	53,826	50	0
1	40,405	347	1	39,829	923	2	40,726	26	0	40,703	49	0
2	254,359	2,673	1	249,291	7,741	3	256,919	113	0	256,709	323	0
3	227,336	3,336	1	220,973	9,699	4	230,571	101	0	230,335	337	0
4	402,848	5,816	1	391,555	17,109	4	408,412	252	0	407,932	732	0
5	225,165	4,229	2	217,130	12,264	5	229,206	188	0	228,886	508	0
6	106,933	2,231	2	102,898	6,266	6	109,053	111	0	108,854	310	0
7	62,901	1,906	3	59,749	5,058	8	64,718	89	0	64,568	239	0
8	15,611	716	4	14,701	1,626	10	16,287	40	0	16,234	93	1
9	12,129	790	6	11,283	1,636	13	12,894	25	0	12,850	69	1
10	6,482	540	8	5,925	1,097	16	6,999	23	0	6,970	52	1
11	3,848	364	9	3,470	742	18	4,201	11	0	4,179	33	1
12	2,702	283	9	2,359	626	21	2,979	6	0	2,963	22	1
13	1,137	148	12	935	350	27	1,282	3	0	1,280	5	0
14	879	121	12	703	297	30	996	4	0	991	9	1
15	433	85	16	324	194	37	515	3	1	510	8	2
16	259	49	16	202	106	34	306	2	1	302	6	2
17	29	5	15	20	14	41	33	1	3	32	2	6

Fx, fracture; SAFE, Simple Assessment tool for predict imminent risk of Fracture in Elderly women.



Supplementary Figure 1. Example of subject data collection process. Subject A underwent the 66-year-old national life-transition examination in 2012, and data on bone mineral density test results and fall history were collected. Subject A underwent five health examinations between 2009 and 2019. Fracture history and fracture outcome data were collected using each health examination date as the index date. Because only data after the 66-year-old national life-transition examination is extracted, three cases can be collected from subject A after 2012. BMI, body mass index; BMD, bone mineral density; Hx, history; Fx, fracture; MOF, major osteoporotic fracture.