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Global, regional, and national burden of falls among older adults: findings from the Global Burden of Disease Study 2021 and Projections to 2040

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Yang Chen[1,4], Feifei Dai[2,4], Shulun Huang[1], Daoda Qi[1], Chengyi Peng[1], Aijia Zhang[1], Yuan Wang[3], Yan Gu[1] ✉ & Jingjing Guo[1] ✉

Falls are a significant cause of injury-related morbidity and mortality among older adults worldwide, with a rising incidence in recent decades. Using data from the Global Burden of Disease Study 2021, we analyzed incidence, mortality, and disability-adjusted life years (DALYs) related to falls in individuals aged 65 years and older from 1990 to 2021. In 2021, there were approximately 45,657,816 new falls globally, reflecting a 182% increase since 1990. While the incidence rate rose, mortality and DALY rates remained relatively stable. Higher incidence was observed in women, but men had higher mortality rates. Regional differences were notable, with Australasia and South Asia showing the highest incidence and mortality burdens, respectively. Low bone mineral density emerged as the leading risk factor. Projections indicate a continued rise in incidence through 2040. These findings highlight the urgent need for targeted prevention strategies to reduce the health burden of falls among older adults.

Falls are the second leading cause of unintentional injury-related deaths worldwide, following only road traffic injuries[1,2]. Annually, falls account for about 684,000 deaths globally, exceeding deaths from other major injuries such as drowning and fire-related injuries[1]. Furthermore, an estimated 37.3 million fall-related incidents require medical intervention, posing a substantial burden on individuals, families, and healthcare systems[3]. In the United States, over 25% of adults aged 65 years and older experience falls annually, with approximately 37% of these falls resulting in injuries, about 9 million cases, that necessitate medical care or lead to activity limitations[4]. In terms of disability-adjusted life years (DALYs), the burden attributable to falls surpasses that of chronic respiratory diseases and several types of cancer in older age groups[5]. Beyond their physical consequences, falls are also frequently associated with psychological effects such as fear of falling, which can significantly impair autonomy and quality of life. With the aging population, the incidence and burden of falls among older adults are expected to rise[2,6], underscoring an urgency to investigate the epidemiological patterns, risk factors, and societal impact of falls in the aging population.

Most of the previous related epidemiological research focuses on incidence rates, identification of risk factors, and the evaluation of intervention measures for the falls among older adults[7]. Systematic reviews indicate that the annual fall incidence among individuals aged 60 and older worldwide is approximately 26%, but regional variations are significant, and data from developing countries are particularly scarce[3]. Moreover, previous studies are often limited in specific countries or regions, and have short time frames, making it difficult to fully capture global and long-term trends[3,8–11]. Many risk factors have been identified, including advanced age, female gender, osteoporosis, visual impairment, depressive symptoms, and medication[12]. In particular, growing evidence highlights that malnutrition and sarcopenia are critical contributors to increased fall risk by impairing strength, balance, and gait stability[13]. Osteoporosis is especially prevalent in older adults and contributes to fall-related fractures and mortality[14]. Furthermore, environmental hazards such as poor lighting, uneven flooring, and a lack of assistive devices also significantly elevate fall risk, particularly in low-resource settings[15]. However, there still lack studies that systematically compare all risk factors across countries at different socio-economic

[1]Department of Geriatrics, The Second Hospital of Nanjing, Nanjing University of Chinese Medicine, Nanjing, PR China. [2]Medical Insurance Office, The Second Hospital of Nanjing, Nanjing University of Chinese Medicine, Nanjing, PR China. [3]Clinical Research Center, The Second Hospital of Nanjing, Affiliated to Nanjing University of Chinese Medicine, Nanjing, PR China. [4]These authors contributed equally: Yang Chen, Feifei Dai. ✉e-mail: guyan703@foxmail.com; guojingjing0017@126.com

development levels, as well as analyze how these factors influence disease burden[16].

The Global Burden of Disease (GBD) database, led by the Institute for Health Metrics and Evaluation (IHME) at the University of Washington, provides global, territorial, and national data on diseases and injuries from 1990 to 2021[17]. These data cover the disease incidence, mortality, and DALYs across 204 countries and territories from 1990 to 2021, and are stratified by age, sex, and the Socio-demographic Index (SDI). Additionally, the GBD database reports fall-related risk factors, such as low bone density and alcohol use[6]. Therefore, the GBD database may be an ideal tool allowing a systematic evaluation of the disease burden and trend of falls and fall-related events among older adults, thus providing a scientific basis for the development of effective prevention and intervention strategies.

Considering the rising burden of falls among older adults, the complex distribution of risk factors, and the current lack of systematic and forward-looking studies, here we based on the GBD 2021 data to conduct a comprehensive study integrating trend analysis, predictive modeling, and risk attribution methods, aiming to provide evidence-based support for designing prevention and control strategies for falls among older adults.

Results

Global, regional, and national incidence

In 2021, an estimated 45,657,816 new falls (95% UI: 35,693,807–57,216,793) occurred among adults aged 65 years and older, representing a 182.09% increase from the 16,185,684 cases (95% UI: 12,256,022–20,850,252) in 1990. After age standardization, the global ASIR of falls rose from 5472.52 per 100,000 population in 1990 (95% UI: 4174.00–7025.05) to 6198.42 per 100,000 population in 2021 (95% UI: 4862.87–7753.18). The EAPC in ASIR over this period was 0.38% (95% CI: 0.33%–0.43%) (Table 1).

Among the 21 GBD regions, Western Europe (10,134,329 cases, 95% UI: 8,824,435–11,699,921) reported the highest number of fall-related incidents among older adults in 2021, followed by East Asia (9,381,366 cases, 95% UI: 6,743,859– 12,537,250) (Table S2). After age standardization, Australasia exhibited the highest ASIR (13,400.98 per 100,000 population, 95% UI: 11,593.60–15,527.26), whereas the lowest ASIR was observed in Southern Sub-Saharan Africa (944.24 per 100,000 population, 95% UI: 711.55 –1219.93) (Table S3).

From 1990 to 2021, three regions demonstrated statistically significant declines in ASIR (EAPC < 0): Central Europe (EAPC = −1.13%, 95% CI: −1.22% to −1.04%), Central Latin America (EAPC = −0.78%, 95% CI: −0.92% to −0.64%), and Southern Sub-Saharan Africa (EAPC = −0.46%, 95% CI: −0.59% to −0.33%). In contrast, most other regions exhibited increasing trends, with the most marked rise observed in North Africa and the Middle East (EAPC = 2.09%, 95% CI: 1.96%–2.21%) (Table S4 and Fig. 1a).

Among the 204 countries, China, India, the United States, Germany, and France reported the highest numbers of new falls among older adults in 2021, collectively accounting for more than half of the global total (Table S5). After age standardization, the highest ASIR was observed in Andorra (18,972.97 per 100,000 population, 95% UI: 15,675.88–22,567.12), followed by Croatia (17,649.07 per 100,000, 95% UI: 15,169.77–20,430.68), and Slovenia (16,260.21 per 100,000, 95% UI: 13,909.04–18,827.42) (Table S6 and Fig. 2a).

From 1990 to 2021, Türkiye exhibited the most substantial increase in ASIR among older adults, with an EAPC of 4.48% (95% CI: 4.10%–4.86%). Conversely, the steepest decline was observed in Czechia, with an EAPC of −2.80% (95% CI: −2.98% to −2.62%) (Table S7 and Fig. 2b).

Global, regional, and national mortality

From 1990 to 2021, the global number of fall-related deaths among older adults increased by 174.08%, reaching 555,539 in 2021 (95% UI: 446,578–619,898). The ASMR showed a slight increase from 77.20 per 100,000 population in 1990 (95% UI: 66.23–85.63) to 78.36 per 100,000 in 2021 (95% UI: 62.89– 87.54), with an EAPC of 0.25% (95% CI: 0.18%–0.33%) (Table 1).

Table 1 | Global new case number, death number, and DALYs of falls among older adults from 1990 to 2021

Year	Total	Male	Female
1990			
Incidence (95% UI)	16,185,684 (12,256,022– 20,850,252)	4,486,727 (3,323,481– 5,871,225)	11,698,957 (8,932,431–14,974,434)
Deaths (95% UI)	202,694 (174,402 –224,710)	89,660 (76,931– 104,644)	113,034 (90,695–128,647)
DALYs (95% UI)	6,812,382 (5,660,270– 8,209,984)	2,829,582 (2,357,918– 3,381,242)	3,982,800 (3,244,575– 4,849,350)
ASIR/100,000 persons (95% UI)	5472.52 (4174.00 –7025.05)	3527.04 (2641.19 –4592.96)	6680.73 (5118.61 –8540.26)
ASMR/100,000 persons (95% UI)	77.20 (66.23– 85.63)	85.75 (73.57– 99.46)	71.14 (57.26–80.83)
ASDR/100,000 persons (95% UI)	2300.76 (1917.86 –2765.40)	2252.01 (1887.56–2677.82)	2296.80 (1875.69– 2789.29)
2021			
Incidence (95% UI)	45,657,816 (35,693,807– 57,216,793)	15,118,062 (11,729,054– 19,071,515)	30,539,754 (23,968,235– 38,096,447)
Deaths (95% UI)	555,539 (446,578 –619,898)	254,451 (207,618 –286,918)	301,088 (225,035 –350,890)
DALYs (95% UI)	16,952,767 (13,899,084– 20,380,594)	7,335,102 (6,069,124– 8,690,125)	9,617,664 (7,759,210– 11,770,414)
ASIR/100,000 persons (95% UI)	6198.42 (4862.87 –7753.18)	4683.36 (3657.31 –5886.71)	7285.12 (5720.49 –9085.61)
ASMR/100,000 persons (95% UI)	78.36 (62.89– 87.54)	87.96 (71.77– 99.03)	71.52 (53.49– 83.34)
ASDR/100,000 persons (95% UI)	2296.74 (1885.13 –2759.42)	2278.58 (1892.81 –2691.74)	2291.31 (1848.25 –2803.74)
1990–2021			
Incidence (%)	182.09	236.95	161.05
Deaths (%)	174.08	183.80	166.37
DALYs (%)	144.85	159.23	141.48
EAPC in the ASIR (%, 95% CI)	0.38 (0.33–0.43)	0.89 (0.84–0.95)	0.26 (0.21–0.32)
EAPC in the ASMR (%, 95% CI)	0.25 (0.18–0.33)	0.25 (0.17–0.33)	0.25 (0.16–0.34)
EAPC in the ASDR (%, 95% CI)	0.03 (0.01–0.06)	0.05 (0.01–0.09)	0.06 (0.03–0.08)

DALYs disability-adjusted life-years, *ASIR* age-standardized incidence rate, *ASMR* age-standardized mortality rate, *ASDR* age-standardized disability-adjusted life year rate, *EAPC* estimated annual percentage change, *UI* uncertainty interval, *CI* confidence interval.

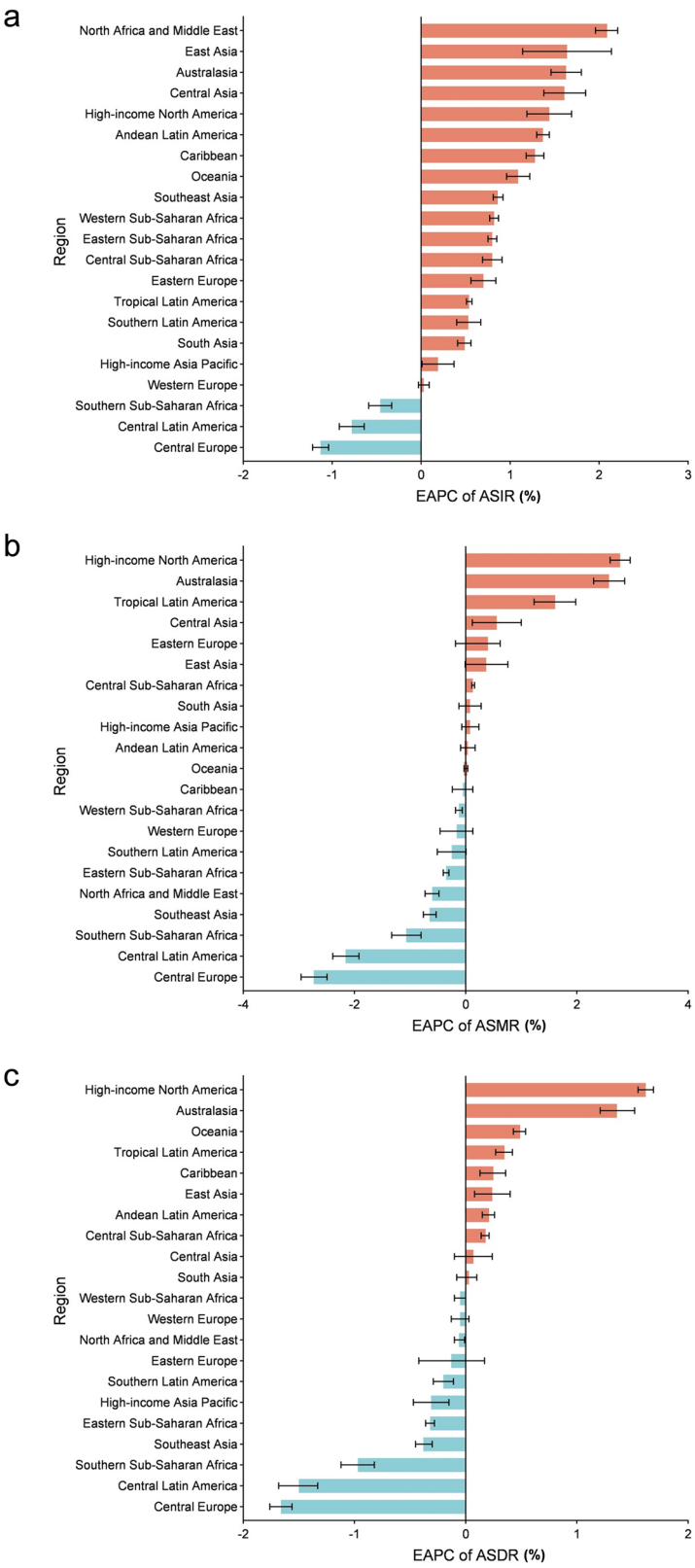


Fig. 1 | Trends in fall-related incidence, mortality, and disability burden among older adults across 21 global regions. EAPCs in the ASIR (**a**), ASMR (**b**), and ASDR (**c**) of falls among older adults across 21 GBD regions. EAPC estimated annual percentage change, ASIR age-standardized incidence rate, ASMR age-standardized mortality rate, ASDR age-standardized disability-adjusted life-year rate, GBD the Global Burden of Disease Study.

In 2021, South Asia reported the highest number of fall-related deaths among older adults, with 177,938 deaths (95% UI: 140,865–209,952), which accounted for 32.03% of global deaths, and also the highest ASMR among the 21 GBD regions (184.55 per 100,000 population, 95% UI: 146.20–219.11) (Table S3). Conversely, the lowest ASMR was observed in Central Asia, at 13.85 per 100,000 population (95% UI: 12.15–15.29). Over the 32-year period, the greatest increase in ASMR was noted in High-income North America (EAPC = 2.78%, 95% CI: 2.60%–2.96%), while the most pronounced decline occurred in Central Europe (EAPC = −2.73%, 95% CI: −2.96% to −2.49%) (Table S4 and Fig. 1b).

In 2021, India recorded the highest number of fall-related deaths among older adults, with an estimated 166,518 deaths (95% UI:

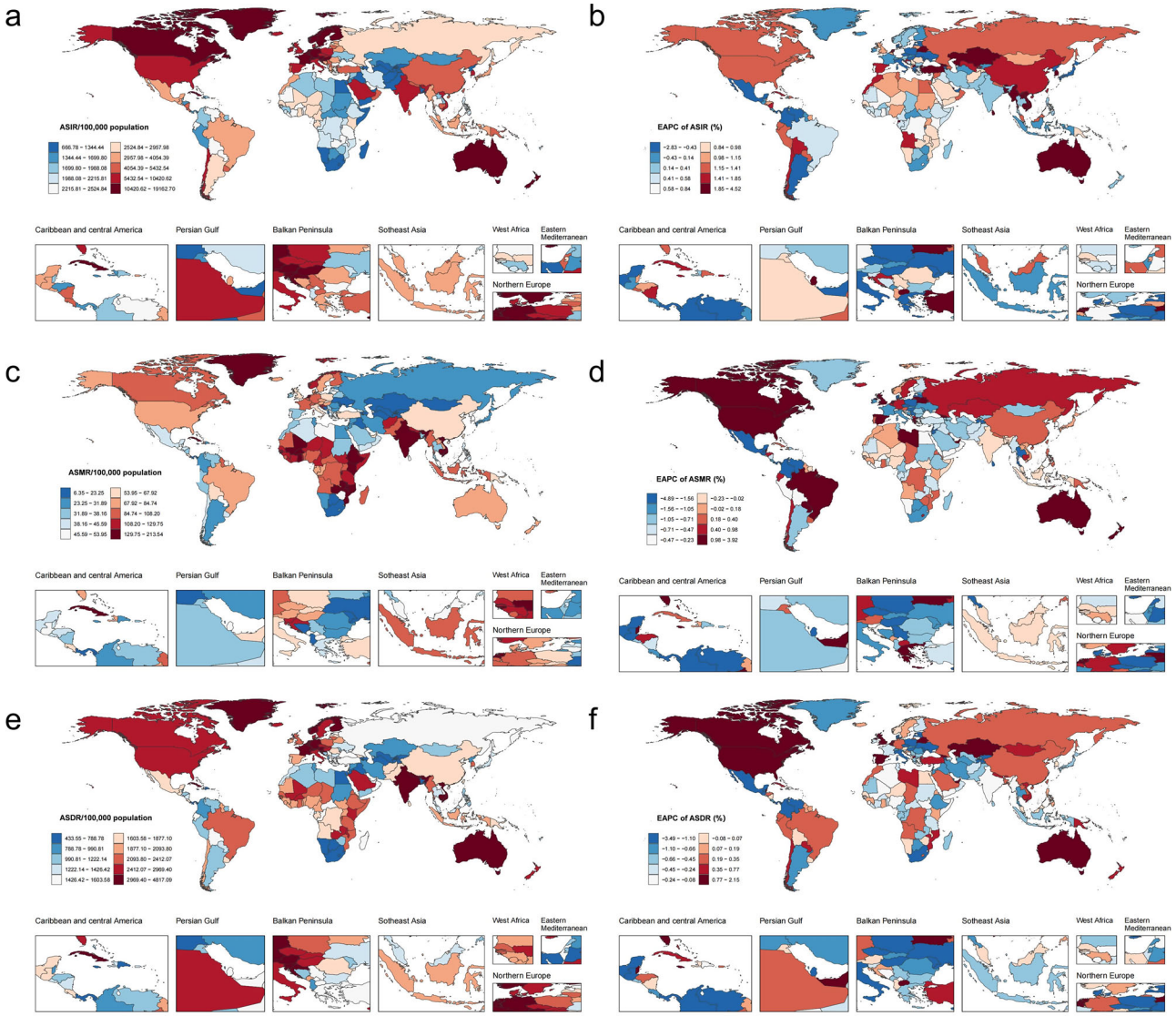


Fig. 2 | Geographic distribution and temporal trends in fall-related burden among older adults worldwide. ASIR (**a**), ASMR (**c**), and ASDR (**e**) of falls among older adults in 204 countries and territories in 2021. EAPCs in ASIR (**b**), ASMR (**d**), and ASDR (**f**) of falls among older adults from 1990 to 2021. ASIR age-standardized incidence rate, ASMR age-standardized mortality rate, ASDR age-standardized disability-adjusted life-year rate, EAPC estimated annual percentage change.

130,376–197,202), followed by China (93,378 deaths, 95% UI: 53,996–123,829), the United States (44,185 deaths, 95% UI: 36,467 to 48,318), and Germany (20,653 deaths, 95% UI: 16,540–23,680), all surpassing 20,000 deaths. India also exhibited the highest ASMR among the 204 countries, at 211.43 per 100,000 population (95% UI: 165.60 to 251.96), whereas the lowest ASMR was observed in Azerbaijan, at 6.41 per 100,000 population (95% UI: 4.27–9.10) (Tables S5 and S6 and Fig. 2c).

From 1990 to 2021, the largest increases in ASMR were observed in Georgia (EAPC = 3.88%, 95% CI: 2.73%–5.04%), the United States (EAPC = 2.95%, 95% CI: 2.76%–3.14%), and Australia (EAPC = 2.82%, 95% CI: 2.54%–3.11%). Conversely, the steepest declines in ASMR were reported in Hungary (EAPC = −4.84%, 95% CI: −5.19% to −4.50%), Czechia (EAPC = −3.95%, 95% CI: −4.35% to −3.54%), and Guam (EAPC = −3.26%, 95% CI: −3.78% to −2.74%) (Table S7 and Fig. 2d).

Global, regional, and national DALYs

In 2021, falls among older adults accounted for 16,952,767 DALYs globally (95% UI: 13,899,084–20,380,594), representing a 144.85% increase compared to that in 1990. Despite this absolute rise, the ASDR remained relatively stable over the study period, recorded at 2,300.76 per 100,000 population in 1990 (95% UI: 1917.86–2765.40) and 2296.74 per 100,000 in 2021 (95% UI: 1885.13–2759.42). The EAPC in ASDR was 0.03% (95% CI: 0.01%–0.06%) (Table 1).

In 2021, the highest burden of fall-related DALYs was observed in Asia, particularly in South Asia and East Asia, with India and China contributing the largest proportions. Combined, these two countries accounted for 42.71% of the global total. South Asia exhibited the highest ASDR (4,129.56 per 100,000 population, 95% UI: 3449.78–4826.17) (Tables S2 and S3), while the lowest regional ASDR was reported in Southern Sub-Saharan Africa (511.87 per 100,000, 95% UI: 420.78–629.75). From 1990 to 2021, Central Europe showed the greatest reduction in fall-related ASDR among older adults (EAPC = −1.66%; 95% CI: −1.76% to −1.56%), whereas High-income North America experienced the steepest increase (EAPC = 1.62%; 95% CI: 1.55%–1.69%) (Table S4 and Fig. 1c).

Mirroring mortality trends, India and Azerbaijan recorded the highest and lowest national ASDRs due to falls in 2021, at 4769.39 per 100,000 population (95% UI: 3955.49–5588.90) and 494.17 per 100,000 (95% UI: 371.49–637.95), respectively (Table S6 and Fig. 2e). Hungary demonstrated the most substantial decline in ASDR among all countries (EAPC = −3.46%; 95% CI: −3.67% to −3.24%), whereas the Netherlands exhibited the largest increase (EAPC = 2.13%; 95% CI: 1.56%–2.70%) (Table S7 and Fig. 2f).

Table 2 | EAPC in ASIR, ASDR, and ASMR of falls among older adults stratified by SDI from 1990 to 2021

Region and Year	ASIR/100,000 population (95% UI)	EAPC (%, 95% CI)	ASMR/100,000 population (95% UI)	EAPC (%, 95% CI)	ASDR/100,000 population (95% UI)	EAPC (%, 95% CI)
Low SDI		0.91 (0.87 to 0.96)		0.33 (0.09 to 0.56)		0.29 (0.17 to 0.41)
1990	2927.96 (2097.08 to 3936.94)		150.81 (120.52 to 186.13)		2851.83 (2385.43 to 3413.02)	
2021	3939.78 (2973.07 to 5051.05)		152.33 (123.66 to 190.13)		2965.78 (2491.03 to 3544.43)	
Low-middle SDI		0.52 (0.44 to 0.59)		0.30 (0.15 to 0.45)		0.16 (0.07 to 0.25)
1990	4340.79 (2982.70 to 6004.84)		126.14 (98.10 to 153.67)		2888.41 (2388.37 to 3411.59)	
2021	5183.66 (3823.94 to 6766.95)		133.37 (108.98 to 161.12)		3018.10 (2557.31 to 3539.25)	
Middle SDI		1.18 (0.98 to 1.38)		−0.16 (−0.28 to −0.05)		−0.01 (−0.06 to 0.04)
1990	3259.43 (2278.26 to 4477.71)		83.62 (65.84 to 96.43)		2019.02 (1693.25 to 2360.08)	
2021	4934.81 (3649.52 to 6455.22)		77.42 (55.79 to 90.66)		2053.25 (1655.84 to 2451.39)	
High-middle SDI		0.21 (0.10 to 0.33)		0.07 (−0.06 to 0.19)		−0.34 (−0.42 to −0.26)
1990	4747.57 (3544.56 to 6237.61)		54.82 (47.56 to 60.67)		1973.76 (1593.15 to 2435.20)	
2021	5285.53 (4116.59 to 6682.21)		52.04 (37.18 to 63.42)		1814.43 (1415.74 to 2280.40)	
High SDI		0.44 (0.38 to 0.50)		0.42 (0.27 to 0.57)		0.24 (0.20 to 0.28)
1990	7814.89 (6244.52 to 9675.93)		62.11 (54.38 to 66.46)		2369.85 (1891.06 to 2971.04)	
2021	8739.94 (7201.35 to 10516.32)		64.47 (54.01 to 70.22)		2447.50 (1946.55 to 3082.23)	

EAPC estimated annual percentage change, *ASIR* age-standardized incidence rate, *ASMR* age-standardized mortality rate, *ASDR* age-standardized disability-adjusted life year rate, *SDI* sociodemographic index, *UI* uncertainty interval, *CI* confidence interval.

Global disparities based on SDI

Among older adults, the highest ASIR of falls was observed in high SDI regions, while the ASMR remained relatively low. In contrast, high-middle SDI regions reported the lowest ASMR and ASDR. However, low SDI regions exhibited the lowest ASIR, but the highest ASMR and ASDR, a pattern that has persisted over the past 32 years. An analysis of EAPCs in ASRs from 1990 to 2021 showed that middle SDI regions experienced the greatest increase in ASIR, but a declining fall-related ASMR (EAPC < 0). The most substantial reduction in ASDR was noted in high-middle SDI regions (Tables 2, S8 and Fig. S2).

At the regional level, the ASIR among older adults was significantly positively correlated with the SDI across the 21 GBD regions from 1990 to 2021. Conversely, ASMR and ASDR were negatively correlated with SDI in low-middle SDI regions, but exhibited a positive correlation in high-middle SDI regions (Fig. 3).

Global variations by sex and age

In 2021, the global incidence, mortality, and DALY rates related to falls among older adults increased progressively with advancing age for both sexes, reaching their peaks among individuals aged 95 years and older. The ASIR and age-specific incidence rates were consistently higher in females across all age groups. In contrast, males exhibited higher ASMR and age-specific fall-related mortality rates. Among individuals under 75 years old, the fall-related DALY rate was slightly higher in males, whereas in those aged 75 years and older, females demonstrated significantly higher DALY rates, with a sex-specific disparity widening with age (Fig. S3).

From 1990 to 2021, the ASIR of falls among older adults showed an upward trend in both sexes, with a more pronounced increase in males (EAPC = 0.89%; 95% CI: 0.84%–0.95%) than in females (EAPC = 0.26%; 95% CI: 0.21%–0.32%). In contrast, the ASMR increased similarly in both males (EAPC = 0.25%; 95% CI: 0.17%–0.33%) and females (EAPC = 0.25%; 95% CI: 0.16%– 0.34%). The ASDR remained relatively stable, with slight increases in males (EAPC = 0.05%; 95% CI: 0.01%–0.09%) and females (EAPC = 0.06%; 95% CI: 0.03%–0.08%) (Table 1).

The analysis of fall-related ASR trends among elderly males and females across the five SDI categories over the past three decades revealed marked regional differences. In high SDI regions, the elderly males experienced the most pronounced increases in both ASMR and ASDR. In contrast, the elderly females in low SDI regions exhibited the greatest rises in ASMR and ASDR (Fig. S2).

Prediction of fall-related disease burden among older adults

To forecast future trends in the burden of falls among older adults, we applied a BAPC model to project ASRs over the next two decades. From 2022 to 2040, the global ASIR of falls among older adults was projected to increase from 6198.42 per 100,000 population in 2021 to 6460.83 per 100,000 in 2040 (95% UI: 5050.11–7871.54). In contrast, both the ASMR and ASDR were expected to decline, reaching 71.65 per 100,000 population (95% UI: 59.45–83.85) and 2120.02 per 100,000 population (95% UI: 1766.02–2474.03), respectively. These downward trends in ASMR and ASDR were projected to be more pronounced in males than in females (Fig. 4 and Table S9).

Risk analysis

According to the GBD database, the leading risk factors contributing to fall-related mortality and DALYs among older adults include alcohol use, low bone mineral density, occupational injuries, and smoking. Among these, low bone mineral density emerged as the predominant risk factor, accounting for 45.25% of fall-related deaths and 46.04% of DALYs globally in 2021. While the proportions of deaths and DALYs attributable to occupational injuries demonstrated a declining trend from 1990 to 2021, the contributions of other risk factors remained relatively stable (Figs. S4 and S5).

In 2021, the proportion of fall-related mortality and DALYs attributed to low bone mineral density and occupational injuries was notably higher in

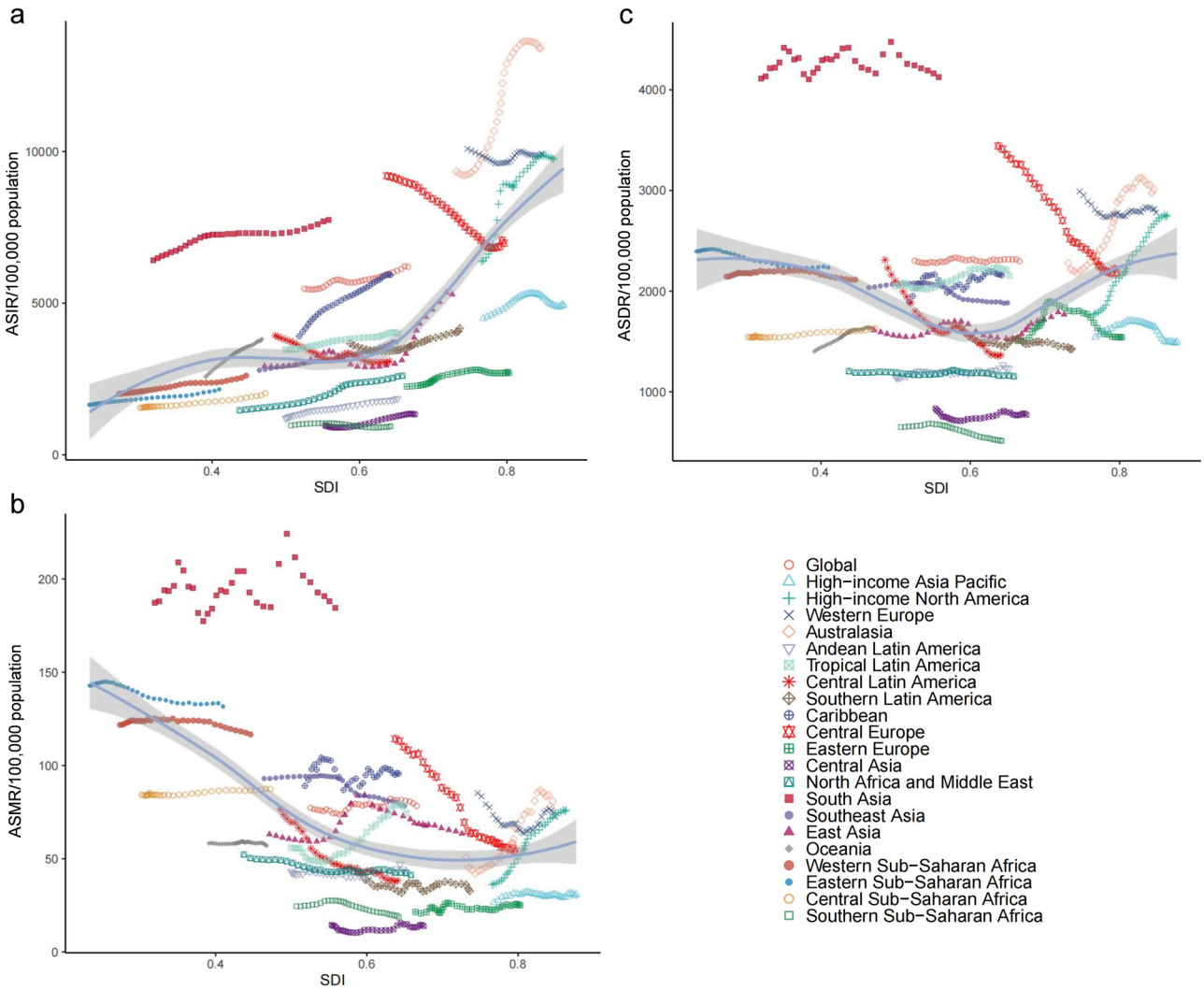


Fig. 3 | Trends in fall-related incidence, mortality, and disability burden by SDI level. ASIRs (**a**), ASMRs (**b**), and ASDRs (**c**) of falls among older adults across 21 GBD regions with varying SDI levels from 1990 to 2021. SDI socio-demographic index, ASIR age-standardized incidence rate, ASMR age-standardized mortality rate, ASDR age-standardized disability-adjusted life-year rate, GBD the Global Burden of Disease Study.

low and low-middle-SDI regions, compared to other SDI regions, with the highest burden observed in Central Sub-Saharan Africa (Fig. S5). Stratified analyses showed that the proportion of fall-related mortality and DALYs, due to low bone mineral density, increased significantly with advancing age among older men, while remaining consistently high across all age groups in older women. In contrast, the proportion attributable to occupational injuries declined markedly with age in both sexes. Additionally, among the older women, the proportion of fall-related deaths attributed to alcohol use increased substantially with age, a trend not observed in the older men (Figs. 5 and S6).

Discussion

In this study, we found that the global ASIR of falls among older adults increased from 5472.52 per 100,000 in 1990 to 6198.42 per 100,000 in 2021. However, the ASMR and ASDR associated with falls remained relatively stable over this period, showing no significant increase in line with the rising incidence, indicating that improvements in prevention and medical management have helped contain mortality and DALYs. These findings align with the conclusions of the World Health Organization's *Global Report on Falls Prevention in Older Age*[2]. Notably, in high-income countries, enhancements in healthcare infrastructure and emergency response capabilities have reduced fall-related mortality and DALY rates[18]. The BAPC model, which is widely used and considered reliable for forecasting long-term trends by accounting for age, period, and cohort effects, was employed to project future fall incidence and burden. Based on this model, a continued increase in fall incidence is predicted, albeit at a slower pace, likely reflecting progressive advances in global geriatric care and integrated health systems[19,20].

Regions with pronounced population aging, such as Australasia, Western Europe, and High-income North America, reported high ASIRs of falls among older adults. Countries like Croatia and Slovenia also showed the top three ASIRs of falls globally, potentially due to a higher proportion of rural residents and suboptimal housing conditions. Environmental hazards, such as deteriorating infrastructure, slippery surfaces, and inadequate stair safety, are prevalent in older houses, significantly increasing fall risk[21,22]. These results highlight the critical influence of the housing quality, particularly in rural areas where age-friendly architectural modifications are urgently needed[23,24].

Our findings also showed that high SDI regions tended to have higher ASIRs, but relatively lower ASMRs. This apparent paradox may stem from the longer life expectancy and higher level of physical activity among older adults, and their broader accesses to advanced healthcare, which increases fall risks but improves survival outcomes[25,26]. Simultaneously, a better chronic disease management has extended life spans, though often accompanied by physical frailty making falls more likely to occur[27]. Importantly, high SDI regions generally possess well-established healthcare

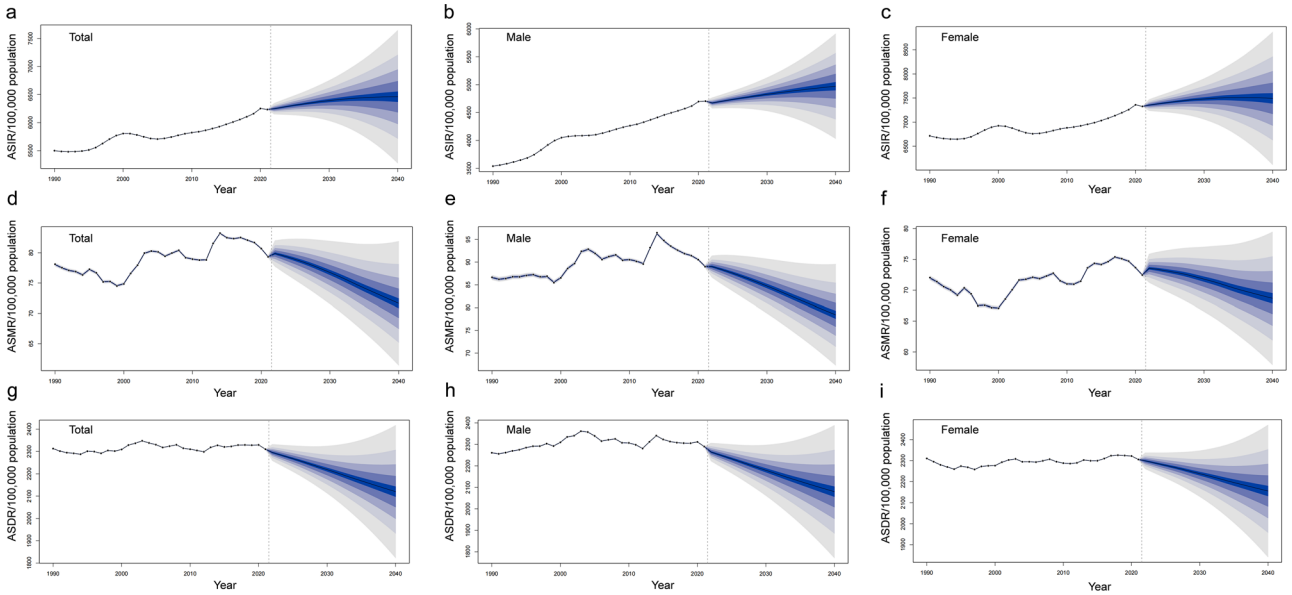


Fig. 4 | Projected global trends in fall-related burden among older adults by sex from 2022 to 2040. Projected global trends in the ASIR (**a**–**c**), ASMR (**d**–**f**), and ASDR (**g**–**i**) of falls among older adults by sex from 2022 to 2040. The dark blue line represents fitted projections beyond 2021, and the outermost light blue shaded area indicates the 95% UI. ASIR age-standardized incidence rate, ASMR age-standardized mortality rate, ASDR age-standardized disability-adjusted life-year rate, UI uncertainty intervals.

infrastructure, including timely emergency services, acute trauma care, and comprehensive rehabilitation systems, thus explaining the discordance between rising ASIR and stable ASMR[2,16]. In comparison, high-middle SDI countries such as South Korea, Singapore, and Spain reported moderately lower ASIRs, along with some of the world's lowest ASMRs and ASDRs. This may result from their mature public health infrastructures, relatively lower demographic aging pressures, and deeper family caregiving traditions that enable rapid response to falls[17]. Conversely, in low and lower-middle SDI regions, despite lower reported ASIRs, limited healthcare access, inadequate emergency services, and scarce rehabilitation resources lead to disproportionately high disability and mortality rates[28]. On the other hand, older adults in these regions are more vulnerable to osteoporosis, malnutrition, and hazardous living conditions, which compromises the negative outcomes of falls[29]. Therefore, differences between regions in healthcare capacity and post-fall treatment are important factors that affect the burden of falls. Strengthening primary healthcare capacity, along with the establishment of comprehensive fall prevention, emergency response, and rehabilitation systems, are therefore essential in reducing the fall-related burden, particularly in low SDI regions.

Globally, the burden of falls increases with advancing age, primarily due to physiological decline. Neuromuscular deterioration, sarcopenia, reduced balance, vision decline, and immunosenescence contribute to reduced mobility and an elevated fall risk[30]. Multimorbidity, including osteoporosis, cardiovascular disease, and cognitive impairment, along with multiple medications, further heightens this risk[31]. The incidence of falls is consistently higher among older women, likely due to postmenopausal declines in estrogen that accelerate bone loss and elevate fracture risk[16]. Women usually experience faster muscle deterioration and live longer, resulting in a greater lifetime exposure to falls. In contrast, although older men fall less often, they experience more serious outcomes, such as higher ASMR and DALYs, possibly due to increased rates of head trauma or complications like infections and cardiac events[32]. These differences are not only biological but also influenced by social and regional factors. In many low- and middle-income countries, older women may have limited access to healthcare services due to traditional gender roles, financial dependency, or lower health literacy, while older men may be less likely to seek medical care or receive rehabilitation after falls[33,34]. Such disparities may worsen fall outcomes in under-resourced regions. These findings suggest that fall prevention strategies must be tailored by sex and age, and should incorporate interventions targeting immune function, such as physical activity, nutritional support, and anti-inflammatory therapies[35]. Furthermore, understanding gender differences in both biological vulnerability and healthcare access is essential to design equitable and effective fall prevention strategies in different regions.

Notably, several well-established interventions have demonstrated effectiveness in reducing fall risk among older adults. These include: (1) balance and strength training programs (such as the Otago Exercise Programme or Tai Chi), (2) home safety assessments and modifications (e.g., installation of grab bars, improved lighting, and removal of tripping hazards), (3) regular medication reviews to reduce polypharmacy and avoid the use of psychotropic drugs where possible, (4) correction and management of visual impairments, and (5) appropriate use of assistive mobility devices when needed[36–39]. Multifactorial interventions that integrate these components and are tailored to individual risk profiles have consistently shown benefit in both clinical and community settings[40].

A significant portion of fall-related mortality and DALYs was attributed to low bone mineral density, underscoring osteoporosis as a major geriatric concern. Osteoporosis brings with complications such as fractures, immobility, chronic pain, and functional decline, all of which can increase the risk of falls[41,42]. To reduce the health burden of falls, particularly in low and low-middle-SDI countries, high-risk groups such as postmenopausal women, older men, and long-term corticosteroid users should be subjected to early diagnosis and individualized treatment plans incorporating medication, calcium, and vitamin D supplementation, and structured exercise programs[43].

As part of the GBD 2021 study, this research shares the widely acknowledged limitations reported in previous literature[44–46], while also presenting several additional constraints specific to our analysis. First, the analysis is restricted to fall events defined by ICD-9 codes E880-E886.99, E888-E888.9, E929.3, and ICD-10 codes W00-W19.9, potentially underestimating the true incidence, particularly in low SDI regions where falls without adverse consequences or causing minor injuries are often not recorded. This limitation may lead to an underestimation of the true prevalence and impact of falls among older adults, thereby overlooking their broader clinical and policy significance. Even seemingly minor falls can lead to psychological consequences, such as fear of falling and activity restriction,

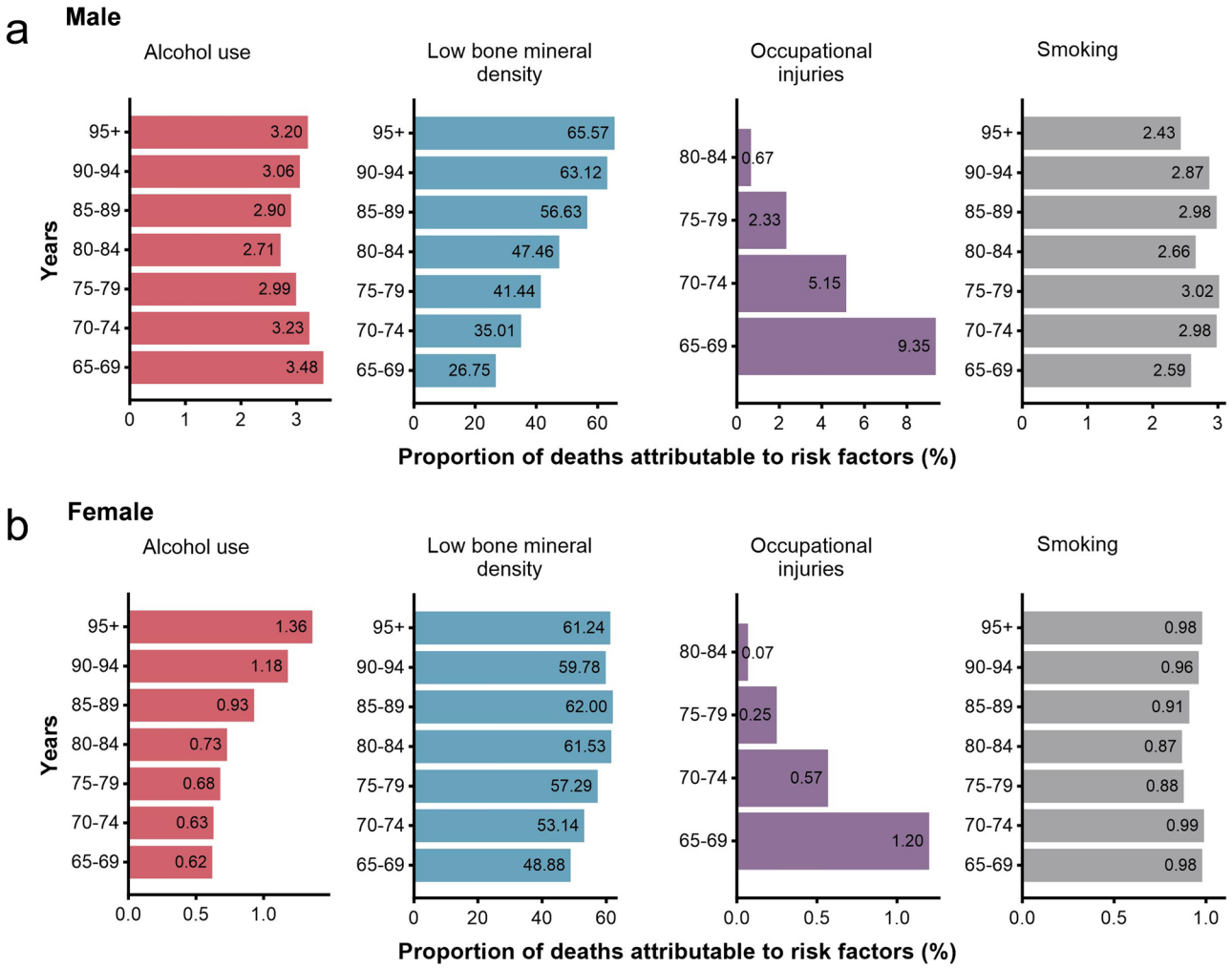


Fig. 5 | Risk factors contributing to fall-related deaths among older adults by sex in 2021. Proportion of fall-related age-standardized deaths among older adults attributable to specific risk factors in males (**a**) and females (**b**) in 2021.

that further increase future fall risk. Future studies should integrate community-based reporting mechanisms and wearable sensor data to better capture the full spectrum of fall events. Second, the consequences of falls are multifaceted, leading to challenges in the calculation of fall-related deaths and DALYs. While the GBD 2021 study uses standardized algorithms and expert-derived models to estimate fall-related DALYs, the approach remains limited in capturing the full spectrum of fall consequences, especially when comorbid conditions (e.g., osteoporosis, dementia) contribute to both fall risk and post-fall outcomes. Therefore, these estimates should be interpreted with caution, and future research incorporating longitudinal and clinical follow-up data may help address these methodological gaps. Third, although this study identifies major risk factors such as osteoporosis, alcohol use, and smoking, the GBD model does not fully capture contextual variables, like education, housing quality, and cultural practices, which may significantly influence both fall occurrence and severity.

Looking ahead, future research should focus on improving data quality and developing practical prevention strategies. Wearable devices and home sensors could help monitor falls in real time and support early intervention. In low-resource settings, building community-based systems and working with local health workers may improve fall reporting and care. It is also important to explore how policies, such as safer housing design and fall prevention programs in care facilities, can reduce risk. Studying the cost-effectiveness of these efforts can help health systems make better decisions. With population aging becoming a global trend, international cooperation is necessary to create affordable and culturally appropriate strategies for fall prevention across different regions.

In conclusion, this study provides a comprehensive assessment of the global burden of falls among older adults, including incidence, mortality, and DALYs, and reveals substantial variations across regions, sexes, and age groups. Although its global incidence is rising, the mortality and disability of falls in elderly adults have remained stable, likely due to improvements in health systems and prevention efforts. High and high-middle SDI countries benefit from well-developed infrastructures and targeted interventions, while low and low-middle SDI countries face elevating risks due to limited healthcare capacity. Age, sex, and osteoporosis remain key risk factors. These findings emphasize the need for early screening, health education, and context-specific strategies to reduce the fall-related burdens of falls and improve the quality of life for the elderly adults.

Methods

Data source

The Global Burden of Disease Study 2021 (GBD 2021) provides comprehensive estimates of the burden of more than 370 diseases and injuries across 204 countries and territories from 1990 to 2021. Relevant data were obtained from the GBD Results Tool available via the Global Health Data Exchange (GHDx) platform (http://ghdx.healthdata.org/gbd-results-tool)[17,47].

In this study, older adults were defined as individuals aged 65 years and older. According to GBD 2021, falls were defined as sudden downward displacements resulting from slipping, tripping, or other unintentional

movements, causing the individual to unintentionally rest on the ground, floor, or a lower level, or to strike an object, and potentially resulting in death, disability, or tissue injury[48].

The corresponding International Classification of Diseases (ICD) codes for falls included E880-E886.99, E888-E888.9, and E929.3 in ICD-9, and W00-W19.9 in ICD-10 [6,49,50]. Fall events were further classified into 47 mutually exclusive and collectively exhaustive injury categories (e.g., fractures, open wounds) to comprehensively capture the ranges of fall-related morbidity and mortality outcomes[51].

GBD 2021 employed a range of standardized indicators to quantify the epidemiological burden of falls, including incidence, mortality, and DALYs, along with their corresponding age-standardized rates, and all estimates were reported with 95% uncertainty intervals (UIs)[48]. Specifically, incidence and incidence rates were estimated using Bayesian meta-regression models, whereas mortality and mortality rates were derived from the Cause of Death Ensemble model (CODEm)[52,53].

Years of life lost (YLLs) quantify the burden of premature mortality. YLLs are calculated as the sum of the differences between the standard life expectancy and the actual age at death, multiplied by the number of deaths: $YLL = \sum(\text{standard life expectancy} - \text{age at death}) \times \text{number of deaths}$. Years lived with disability (YLDs) are estimated by multiplying the number of incident cases by the corresponding disability weight and the average duration of the condition until recovery or death. DALYs, a composite measure of overall disease burden, represent the total number of healthy years lost due to both premature death and disability, and are calculated as the sum of YLLs and YLDs[51,54,55].

The SDI is a composite metric reflecting regional development, based on the geometric mean of three normalized values: per capita income, mean years of education among individuals aged 15 years and older, and the total fertility rate among individuals younger than 25 years. All 204 countries and territories included in the GBD study are classified into five development categories: low, low-middle, middle, high-middle, and high[17].

The GBD Results Tool also provides the proportion of deaths and DALYs attributable to specific risk factors. For falls, the key risk factors include alcohol use, low bone mineral density, occupational injuries, and smoking[56], with detailed definitions provided in Supplementary Table S1.

Ethical compliance

This study was a cross-sectional analysis based on publicly available, anonymized data and did not involve identifiable personal information. All research procedures were conducted in accordance with the principles of the Declaration of Helsinki. The Ethics Committee of Nanjing Second Hospital approved the exemption from ethical approval and informed consent. Clinical trial registration was not applicable.

Statistical analysis

To adjust for population age structure, age-standardized rates (ASRs) were calculated per 100,000 population. The age-standardized rate (ASR) was calculated using the formula:

$$ASR = \frac{\sum_{i=1}^{A} a_i w_i}{\sum_{i=1}^{A} w_i} \times 100,000 \quad (1)$$

where A represents the number of age groups (seven groups ranging from 65–69 years to ≥95 years), i denotes the i-th age group, a_i is the rate to be standardized, and w_i is the weight or population size of the i-th age group in the standard population. This method was applied to calculate the ASIR, ASMR, and ASDR, each expressed per 100,000 population[57].

Percentage change (PC) was calculated to assess the relative changes in the number of incident cases, deaths, and DALYs due to falls among older adults from 1990 to 2021. PC was calculated using the formula:

$$PC = \frac{2021\,Value - 1990\,Value}{1990\,Value} \times 100\% \quad (2)$$

Temporal trends in the burden of falls were further evaluated using EAPC, derived by fitting a linear regression model to the natural logarithm of ASRs over time. In this model, β represents the slope of the linear regression line fitted to the natural logarithm of age-standardized rates over time. It serves as the basis for EAPC using the formula: $EAPC = (e^{\beta} - 1) \times 100\%$. A positive EAPC indicates an increasing trend, whereas a negative EAPC denotes a decreasing trend. Statistical significance was assessed based on the 95% confidence interval (CI) of β; if the CI did not include zero, the trend was considered statistically significant[58].

To forecast future trends in ASRs, we employed a Bayesian age-period-cohort (BAPC) model, which uses the integrated nested Laplace approximation (INLA) framework for Bayesian inference. This model disentangles the observed rates into distinct age, period, and cohort effects, which incorporates prior distributions and smoothing penalties to mitigate overfitting and stabilize estimates in regions with sparse data[59,60]. Projections assume continuity of past trends in the causes of falls and do not incorporate potential interventions or shocks.

The overall study design and workflow are illustrated in Fig. S1. All statistical analyses and visualizations were conducted using R software (version 4.4.1) and GraphPad Prism (version 10.2.0).

Data availability

The data from this study can be accessed openly through the Global Burden of Disease Study 2021 online database, as outlined in the Methods section.

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Author contributions

F.D. and Y.C.: Conceptualization, supervision, software, validation, writing—review and editing; S.H. and A.Z.: Investigation, writing-original draft; Y.W., D.Q. and C.P.: Investigation, data curation; J.G. and Y.G.: Writing—review & editing.

Competing interests

The authors declare no competing interests.

Additional information

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Correspondence and requests for materials should be addressed to Yan Gu or Jingjing Guo.

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