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RESEARCH

Burden of fall-related fracture among postmenopausal women: findings from the global burden of disease study 2021

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Abstract

Background Falls are a significant public health concern, especially among postmenopausal women. This study aims to evaluate the global, regional, and national burden of fall-related fractures among postmenopausal women using data from the Global Burden of Disease (GBD) Study 2021.

Methods This study assess the prevalence and incidence of fall-related fractures among women aged 55 and older from 1990 to 2021. The burden was evaluated by examining cases and rates of prevalence and incidence at the global level, stratified by age, region, nation, and socio-demographic index (SDI) levels. The estimated annual percentage change (EAPC) was utilized to assess temporal trends, while the Bayesian Age-Period-Cohort (BAPC) model was employed to forecast future trends. Additionally, the correlation between prevalence and incidence rates and SDI levels was analyzed across 21 GBD regions and 204 countries using locally estimated scatterplot smoothing (LOESS) regression.

Results In 2021, fall-related fractures among postmenopausal women had 25.42 million incident cases and 96.05 million prevalent cases, up 156.58% and 132.62% since 1990. The incidence rate rose from 2752.20 to 3231.91 per 100,000 populations and the prevalence rate from 11,471.72 to 12,213.33 per 100,000 populations, with EAPCs of 0.52 and 0.13. The incidence and prevalence rates increase with age and are highest in the 95 + age group. Between 1990 and 2021, among regions, the incidence rate of fall-related fractures among postmenopausal women rose most in North Africa, the Middle East, and Australasia, but fell most in Central Europe and Central Latin America. Meanwhile, the prevalence rate increased most in the Caribbean and High-income North America, while decreasing most in Southern Sub-Saharan Africa and Central Latin America. At the national level, the incidence and prevalence rates saw the most significant increases in Turkey and Bhutan. In contrast, United Arab Emirates and Czechia exhibited the lowest incidence rate, while Czechia and Latvia had the lowest prevalence rate. The correlation analysis showed that incidence and prevalence rates increased with SDI levels, reached an initial peak at approximately 0.38, subsequently declined to a nadir at approximately 0.62, then rose to their highest levels. Predictions indicate a substantial increase in both incident and prevalent cases, along with a modest rise in incidence and prevalence rates.

Conclusions The burden of fall-related fractures among postmenopausal women is substantial and increasing globally. Public health policies and resource allocation need to address this critical issue to improve the well-being of postmenopausal women and reduce the economic burden on healthcare systems.

Keywords Falls · Fractures · Postmenopausal women · Global Burden of Disease

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Introduction

Falls are a significant public health concern, particularly among the elderly population [1], and they pose a considerable threat to the well-being of postmenopausal women [2]. As women enter the postmenopausal stage, they experience a natural decline in estrogen levels, which contributes to a reduction in bone density and an increased susceptibility to fractures [2] This vulnerability is further exacerbated by age-related changes in balance, muscle strength, and overall physical function, making falls a leading cause of injury and hospitalization in this demographic [1, 3,4] The consequences of fall-related fractures are far-reaching, affecting not only the individual's quality of life but also imposing a substantial economic burden on healthcare systems and families. However, there is currently a lack of comprehensive research in this area, which is urgently needed to address these critical issues.

The Global Burden of Disease (GBD) Study 2021 offers a comprehensive and detailed analysis of the global health landscape, providing critical insights into the prevalence, incidence, and impact of various health conditions, including fall-related fractures [5, 6] This study aims to leverage the extensive data from the GBD 2021 to examine the global, regional, and national burden of fall-related fractures among postmenopausal women. By analyzing trends and patterns across different geographical regions, this research seeks to inform public health policies and guide the allocation of resources to address this critical issue. Ultimately, this study aims to contribute to the global effort to enhance the well-being of aging populations and reduce the burden of fall-related fractures on individuals, families, and healthcare systems worldwide.

Materials and methods

Study design and data sources

This research conducted an extensive, retrospective review to gauge the global, regional, and national prevalence and incidence of fall-related fracture among postmenopausal women from 1990 to 2021. Data were derived from the 2021 Global Burden of Disease (GBD) Study, a worldwide initiative involving hundreds of researchers focused on quantifying health loss from diseases, injuries, and risk factors. The GBD database amalgamates diverse data sources, including population-based surveys, hospital records, mortality registries, and academic literature, to provide a robust and comprehensive dataset for analysis [5–7].

Case definition

This study regards female individuals aged 55 and older as postmenopausal women. Age was stratified according to the standard GBD classification into the following groups: 55–59, 60–64, 65–69, 70–74, 75–79, 80–84, 85–89, 90–94, and 95 years and older. In the GBD classification system, falls are categorized as a level 3 cause, following injuries and unintentional injuries, which are ranked at levels 1 and 2 respectively. [8] Falls encompass fatalities or disabilities that arise from a sudden downward motion caused by slipping, tripping, or other accidental movements, leading to an individual landing at a lower level or colliding with an object [8] The definition of falls is based on specific International Classification of Diseases (ICD) codes related to falls (ICD-9: E880-E886.99, E888-E888.9, E929.3; ICD-10: W00-W19.9) [8, 9] Fractures encompass fatalities or disabilities resulting from a break in the continuity of the bone, which can be caused by various injury mechanisms such as falls, road injuries, or direct blows [10] The definition of fractures in the GBD study is based on a comprehensive set of ICD codes that specifically describe fracture diagnoses, rather than the external causes of injury. This study mainly focuses on fall-related fracture among postmenopausal women.

The socio-demographic index (SDI) serves as a comprehensive indicator of a nation's or region's development status, which is closely linked to health outcomes. It is calculated as the geometric mean of three indices ranging from 0 to 1, namely the total fertility rate among individuals under 25 years old, the average years of education for those aged 15 and above, and the lag-distributed income per capita. [11] The SDI ranges from 0, representing the lowest level of development, to 1, signifying the highest level of development. It is divided into five categories: low, low-middle, middle, high-middle, and high. [11] The World Health Organization (WHO) classifies nations into 21 GBD regions based on their geographic locations. For the purpose of comparative analysis, the 204 countries or territories and the 21 GBD regions are grouped into five quintiles according to their SDI levels: low (0–0.466), low-middle (0.466–0.619), middle (0.619–0.712), high-middle (0.712–0.810), and high SDI (0.810–1).

Statistical analysis

The burden of fall-related fracture among postmenopausal women was evaluated by examining the cases and rates of prevalence and incidence at the global level, with stratification by age, region, nation, and SDI levels. The 95% uncertainty intervals (UIs) were calculated through 1,000 simulations for each prevalence and incidence estimate, with the 2.5th and 97.5th percentiles defining the lower and

upper bounds of the 95% UIs, respectively. The cases and rates of prevalence and incidence were expressed as 95% UIs [5, 6]. To assess average trends over a specific period, the estimated annual percentage change (EAPC) in prevalence and incidence rates was calculated using a logarithmic regression model ($y = a + b\chi + \varepsilon$), where y represents the natural logarithm of prevalence and incidence rates, and χ denotes the calendar year. The EAPC was derived via the Eq. $100 \times (\exp(\beta) - 1)$, with the 95% confidence intervals (CIs) obtained from model parameters. An upward trend was confirmed if both the EAPC and its 95% CI exceeded zero, while a downward trend was established if they were both below zero. If the 95% CI included zero, the change in prevalence and incidence rates was deemed statistically insignificant [12] The Bayesian Age-Period-Cohort (BAPC) model was used to forecast the burden of fall-related fracture among postmenopausal women from 2022 to 2035. This model integrates age, period, and cohort effects multiplicatively through the Poisson distribution, with Markov Chain Monte Carlo (MCMC) for fitting and Integrated Nested Laplace Approximations (INLA) to address convergence issues [13, 14] Additionally, the correlation between prevalence and incidence rates of fall-related fracture among postmenopausal women and the SDI levels was analyzed across 21 GBD regions and 204 countries using locally estimated scatterplot smoothing (LOESS) regression. Data visualization and analysis were conducted using R version 4.2.2.

Results

Global trends

In 2021, fall-related fractures among postmenopausal women accounted for approximately 25.42 million (95% UI 21.97 to 29.08 million) incident cases and 96.05 million (95% UI 84.92 to 107.56 million) prevalent cases, representing increases of 156.58 % and 132.62 %, respectively, since 1990 (Figs. 1A-B and Tables 1–2). Over the same period, the corresponding incidence and prevalence rates increased from 2752.20 (95%UI 2346.98 to 3197.38) per 100,000 populations to 3231.91 (95% UI 2793.03 to 3697.13) per 100,000 populations and from 11,471.72 (95% UI 10,075.24 to 12,915.11) per 100,000 populations to 12,213.33 (95%UI 10,797.85 to 13,676.02) per 100,000 populations (Figs. 1A-B and Tables 1–2). The estimated EAPCs were 0.52 (95%CI 0.48 to 0.57) for incidence rate and 0.13 (95%CI 0.08 to 0.17) for prevalence rate (Tables 1–2).

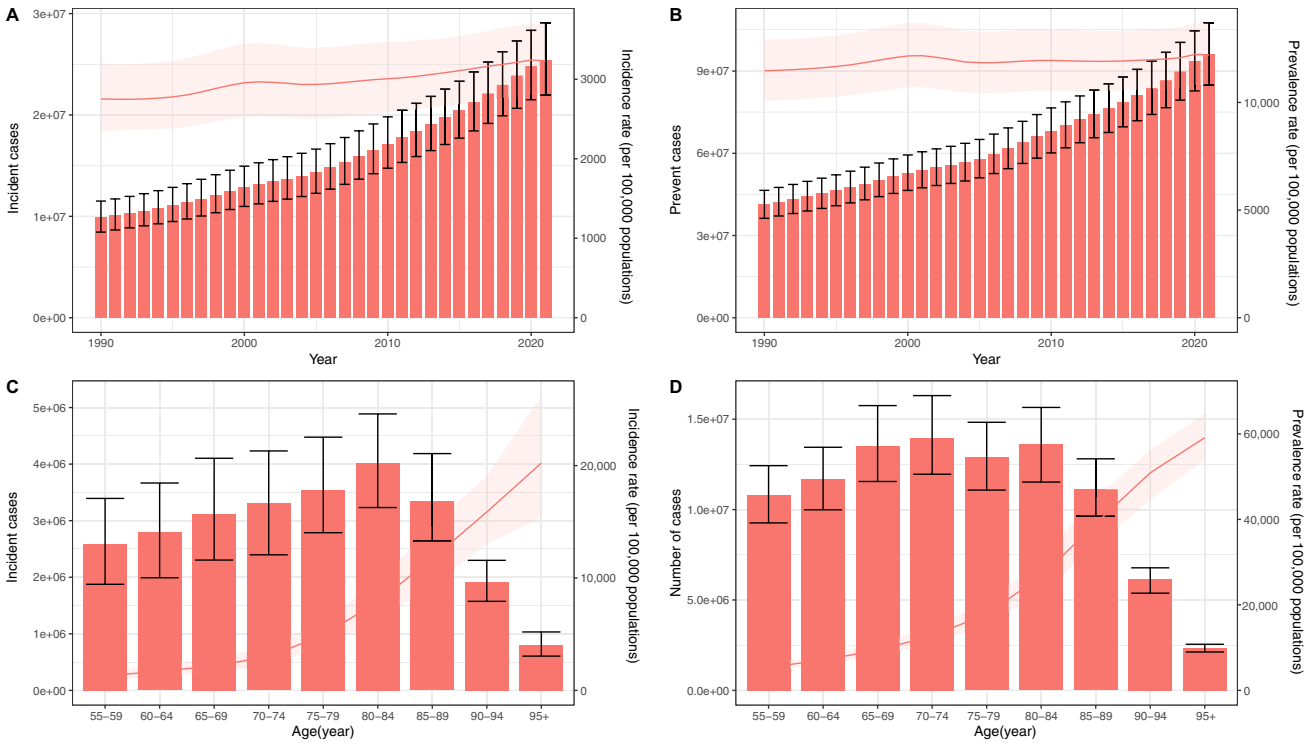

Fig. 1 Trends in cases and rates of incidence (**A**) and prevalence (**B**) for fall-related fractures among postmenopausal women at the global level, 1990–2021. The cases and rates of incidence (**C**) and prevalence (**D**) for fall-related fractures among postmenopausal women in the different age globally in 2021.

Table 1 Temporal trends and current status in the incidence of fall-related fractures among postmenopausal women by global, age, region, and SDI levels

Location	Incident cases (95%UI), 1990	Incidence rate (95%UI), 1990	Incident cases (95%UI), 2021	Incidence rate (95%UI), 2021	EAPC (95%CI),1990–2021
Global	9,906,336 (8,447,782 to 11,508,716)	2752.20 (2346.98 to 3197.38)	25,417,917 (21,966,263 to 29,076,783)	3231.91 (2793.03 to 3697.13)	0.52 (0.48 to 0.57)
Age(years)					
55–59	1,108,437 (774,697 to 1,473,357)	1200.75 (839.22 to 1596.06)	2,590,589 (1,875,281 to 3,393,448)	1288.83 (932.96 to 1688.25)	0.31 (0.27 to 0.35)
60–64	1,232,845 (866,423 to 1,680,407)	1502.31 (1055.8 to 2047.7)	2,791,734 (1,990,771 to 3,665,922)	1696.99 (1210.11 to 2228.38)	0.46 (0.41 to 0.5)
65–69	1,298,463 (932,444 to 1,752,177)	1959.11 (1406.86 to 2643.67)	3,121,610 (2,303,464 to 4,103,423)	2167.65 (1599.53 to 2849.42)	0.45 (0.39 to 0.5)
70–74	1,319,272 (905,024 to 1,759,965)	2804.42 (1923.84 to 3741.21)	3,303,895 (2,396,318 to 4,232,953)	3018.69 (2189.46 to 3867.55)	0.17 (0.11 to 0.24)
75–79	1,684,237 (1,305,207 to 2,157,668)	4636.87 (3593.37 to 5940.28)	3,539,516 (2,787,450 to 4,476,173)	4909.33 (3866.21 to 6208.48)	0.17 (0.07 to 0.28)
80–84	1,646,666 (129,5261 to 2,045,897)	7453.51 (5862.9 to 9260.6)	4,018,822 (3,232,196 to 4,887,386)	7890.69 (6346.2 to 9596.06)	0.16 (0.08 to 0.23)
85–89	1,086,491 (845,314 to 1,409,132)	10,814.07 (8413.58 to 14,025.38)	3,340,966 (2,642,565 to 4,185,668)	11,735.4 (9282.21 to 14,702.48)	0.18 (0.1 to 0.26)
90–94	415,812 (333,173 to 518,803)	13,740.28 (11,009.51 to 17,143.55)	1,914,138 (1,574,038 to 2,298,685)	15,870.64 (13,050.78 to 19,059.02)	0.44 (0.35 to 0.53)
95+	114,113 (81,560 to 160,509)	15,057.4 (10,761.99 to 21,179.32)	796,648 (605,946 to 1,033,001)	20,228.4 (15,386.11 to 26,229.83)	0.83 (0.66 to 1.00)
GBD regions					
Andean Latin America	10,418 (9,130 to 11,662)	604.95 (530.12 to 677.17)	47,766 (42,286 to 53,417)	923.42 (817.48 to 1032.66)	1.40 (1.33 to 1.47)
Australasia	108,427 (93,825 to 123,939)	5084.8 (4400.03 to 5812.24)	362,088 (318,499 to 406,101)	7815.52 (6874.68 to 8765.53)	1.74 (1.57 to 1.91)
Caribbean	45,662 (40,599 to 50,676)	2052.58 (1825.01 to 2277.99)	158,729 (139,776 to 175,781)	3233.04 (2847.01 to 3580.36)	1.38 (1.24 to 1.53)
Central Asia	26,464 (22,922 to 303,69)	556.23 (481.78 to 638.28)	49,742 (43,465 to 56,107)	609.38 (532.48 to 687.35)	0.81 (0.61 to 1.00)
Central Europe	655,813 (581,966 to 735,902)	4353.28 (3863.08 to 4884.9)	741,075 (660,570 to 824,613)	3555.06 (3168.86 to 3955.8)	-0.88 (-0.98 to -0.78)
Central Latin America	143,636 (122,278 to 168,219)	2042.39 (1738.69 to 2391.94)	353,690 (307,001 to 404,483)	1530.54 (1328.5 to 1750.34)	-0.86 (-1.01 to -0.71)
Central Sub-Saharan Africa	12,622 (11,014 to 14,476)	628.1 (548.08 to 720.35)	40,308 (35,528 to 45,438)	822.41 (724.9 to 927.08)	0.82 (0.80 to 0.84)
East Asia	1,061,493 (853,148 to 1,274,819)	1400.44 (1125.56 to 1681.88)	4,812,092 (4,022,792 to 5,636,465)	2377.18 (1987.26 to 2784.42)	1.62 (1.20 to 2.05)
Eastern Europe	401,090 (327,484 to 481,282)	1270.87 (1037.64 to 1524.96)	510,722 (433,693 to 595,699)	1338.37 (1136.51 to 1561.06)	0.10 (-0.07 to 0.27)
Eastern Sub-Saharan Africa	44,280 (37,478 to 51,769)	731.4 (619.04 to 855.09)	128,126 (111,030 to 146,084)	904.94 (784.2 to 1031.77)	0.60 (0.54 to 0.66)
High-income Asia Pacific	417,493 (344,977 to 506,257)	2133.35 (1762.79 to 2586.92)	1,191,722 (1,020,415 to 1,381,441)	3124.13 (2675.05 to 3621.49)	1.09 (0.99 to 1.19)
High-income North America	1,242,555 (1,026,895 to 1,507,130)	3782.88 (3126.32 to 4588.36)	3,647,156 (3,107,940 to 4,249,456)	6054 (5158.94 to 7053.77)	1.47 (1.22 to 1.73)
North Africa and Middle East	94,511(81,703 to 109,812)	681.3 (588.97 to 791.6)	437,039 (383,898 to 491,581)	1160.82 (1019.67 to 1305.69)	2.04 (1.88 to 2.19)
Oceania	3261 (2758 to 3825)	1410.94 (1193.09 to 1654.9)	12,796 (10,990 to 14,668)	2176.89 (1869.67 to 2495.36)	1.17 (0.99 to 1.36)
South Asia	1,552,732 (1,244,561 to 1,890,417)	3447.24 (2763.07 to 4196.94)	5,242,776 (4,351,774 to 6,197,413)	4140.85 (3437.11 to 4894.84)	0.55 (0.51 to 0.59)
Southeast Asia	318,781 (268,500 to 372,685)	1415.01 (1191.82 to 1654.28)	1,043,246 (907,878 to 1,190,933)	1701.28 (1480.53 to 1942.12)	0.46 (0.40 to 0.52)
Southern Latin America	86,479 (75,528 to 97,554)	1972.03 (1722.31 to 2224.58)	207,298 (181,769 to 231,651)	2547.47 (2233.74 to 2846.74)	0.94 (0.87 to 1.02)
Southern Sub-Saharan Africa	10,687 (8899 to 12,661)	424.23 (353.26 to 502.6)	22,098 (18,778 to 25,814)	388.06 (329.77 to 453.33)	-0.60 (-0.73 to -0.47)
Tropical Latin America	136,121 (110,553 to 163,889)	1687.5 (1370.54 to 2031.75)	512,403 (431,327 to 599,975)	2106.14 (1772.89 to 2466.09)	0.78 (0.73 to 0.82)

Table 1 (continued)

Location	Incident cases (95%UI), 1990	Incidence rate (95%UI), 1990	Incident cases (95%UI), 2021	Incidence rate (95%UI), 2021	EAPC (95%CI),1990–2021
Western Europe	3,466,176 (3,028,765 to 3,944,064)	6237.91 (5450.72 to 7097.94)	5,708,636 (5,055,914 to 6,362,564)	7119.54 (6305.5 to 7935.09)	0.56 (0.50 to 0.63)
Western Sub-Saharan Africa	67,633 (57,066 to 79,111)	972.05 (820.18 to 1137.01)	188,410 (163,694 to 216,087)	1102.77 (958.1 to 1264.76)	0.37 (0.33 to 0.41)
SDI levels					
Low SDI	260,211 (215,348 to 309,172)	1433.62 (1186.45 to 1703.36)	797,162 (675,607 to 934,061)	1905.32 (1614.79 to 2232.53)	0.94 (0.90 to 0.99)
Low-middle SDI	1,168,087 (944,648 to 1,412,372)	2359.17 (1907.9 to 2852.55)	3,384,708 (2,830,036 to 3,967,071)	2697.08 (2255.09 to 3161.13)	0.43 (0.37 to 0.49)
Middle SDI	1,429,876 (1,174,194 to 1,716,015)	1606.77 (1319.45 to 1928.31)	5,832,610 (4,933,010 to 6,811,371)	2369.82 (2004.31 to 2767.5)	1.15 (0.98 to 1.32)
High-middle SDI	2,256,119 (1,918,311 to 2,637,048)	2318.98 (1971.76 to 2710.53)	4,978,924 (4,294,622 to 5,719,477)	2649.74 (2285.56 to 3043.85)	0.37 (0.29 to 0.45)
High SDI	4,776,374 (4,142,348 to 5,483,906)	4524.08 (3923.55 to 5194.24)	10,400,709 (9,170,663 to 11,746,513)	5639.97 (4972.96 to 6369.76)	0.77 (0.72 to 0.82)

EAPC estimated annual percentage change, SDI socio-demographic index, GBD global burden of disease, UI uncertainty interval, CI confidence interval

Age trends

In 2021, Figs. 1C-D depict the age distribution of fall-related fractures among postmenopausal women. The global incident and prevalent cases of fall-related fractures among postmenopausal women was highest in the 80–84 and 70–74 age group, respectively. The incidence and prevalence rates associated with this condition rise steadily with advancing age, peaking in the 95+age group (Figs. 1C-D and Tables 1–2). From 1990 to 2021, the incidence and prevalence rates of fall-related fractures among postmenopausal women varied significantly across different age groups (Tables 1–2).

Geographic regional trends

In 2021, the Western Europe, Australasia, and High-income North America exhibited the highest incidence and prevalence rates of fall-related fractures among postmenopausal women across the 21 GBD regions. Conversely, Southern Sub-Saharan Africa demonstrated the lowest incidence and prevalence rates, as detailed in Tables 1–2. Between 1990 and 2021, the incidence rate of fall-related fractures among postmenopausal women increased most significantly in North Africa and the Middle East, as well as in Australasia. In contrast, Central Europe and Central Latin America saw the most substantial declines in incidence rate during this period (Table 1). During the same timeframe, the prevalence rate of fall-related fractures among postmenopausal women rose most markedly in the Caribbean and High-income North America. Conversely, Southern Sub-Saharan Africa and Central Latin America experienced the most notable decreases in prevalence rate (Table 2). Additionally, in 2021, the greatest incident and prevalent cases from fall-related fractures among postmenopausal women are observed in Western Europe, South Asia, and East Asia, as detailed in Tables 1–2.

National trends

In 2021, the highest incidence and prevalence rates of fall-related fractures among postmenopausal women were observed in Andorra and Belgium among the 204 countries and territories. Conversely, South Africa and Turkmenistan exhibited the lowest incidence rate, while Swaziland and South Africa had the lowest prevalence rate (Figs. 2A-B and Supplementary material Tables 1–2). Between 1990 and 2021, the incidence and prevalence rate of fall-related fractures among postmenopausal women saw the most significant increases in Turkey and Bhutan. In contrast, United Arab Emirates and Czechia exhibited the lowest incidence rate, while Czechia and Latvia had the lowest prevalence rate (Figs. 2C-D and Supplementary material Tables 1–2).

Table 2 Temporal trends and current status in the prevalence of fall-related fractures among postmenopausal women by global, age, region, and SDI levels

Location	Prevalent cases (95%UI), 1990	Prevalence rate (95%UI), 1990	Prevalent cases (95%UI), 2021	Prevalence rate (95%UI), 2021	EAPC(95%CI),1990–2021
Global	41,291,556 (36,265,056 to 46,486,922)	11,471.72 (10,075.24 to 12,915.11)	96,053,961 (84,921,707 to 107,557,545)	12,213.33 (10,797.85 to 13,676.02)	0.13 (0.08 to 0.17)
Age(years)					
55–59	5,361,957 (4,555,208 to 6,178,547)	5808.52 (4934.58 to 6693.12)	10,798,094 (9,262,616 to 12,429,256)	5372.09 (4608.19 to 6183.6)	-0.42 (-0.47 to -0.36)
60–64	6,109,774 (5,237,610 to 6,977,375)	7445.21 (6382.42 to 8502.45)	11,709,506 (9,987,683 to 13,447,257)	7117.77 (6071.14 to 8174.08)	-0.26 (-0.32 to -0.2)
65–69	6,367,932 (5,444,927 to 7,381,091)	9607.88 (8215.26 to 11,136.52)	13,517,592 (11,553,860 to 15,752,056)	9386.64 (8023.02 to 10,938.25)	-0.12 (-0.14 to -0.09)
70–74	5,718,096 (4,895,254 to 6,659,620)	12,155.13 (10,405.99 to 14,156.56)	13,978,059 (11,955,953 to 16,304,558)	12,771.44 (10,923.89 to 14,897.11)	0.01 (-0.04 to 0.07)
75–79	6,422,264 (5,534,198 to 7,395,819)	17,681.14 (15,236.2 to 20,361.43)	12,878,888 (11,078,230 to 14,829,940)	17,863.11 (15,365.58 to 20,569.23)	0.02 (-0.05 to 0.09)
80–84	5,839,268 (4,955,246 to 6,807,958)	26,431.01 (22,429.55 to 30,815.72)	13,595,965 (11,522,425 to 15,649,935)	26,694.77 (22,623.51 to 30,727.6)	0.01 (-0.02 to 0.05)
85–89	3,697,891 (3,194,884 to 4,234,768)	36,805.88 (31,799.35 to 42,149.53)	11,107,217 (9,633,580 to 12,807,997)	39,014.95 (33,838.69 to 44,989.07)	0.15 (0.09 to 0.22)
90–94	1,389,890 (1,217,834 to 1,544,484)	45,928.13 (40,242.67 to 51,036.61)	6,140,350 (5,376,236 to 6,779,411)	50,911.32 (44,575.84 to 56,209.94)	0.33 (0.25 to 0.41)
95+	384,484 (345,619 to 428,690)	50,733.18 (45,604.91 to 56,566.27)	23,28,290 (2,122,121 to 2,551,175)	59,119.65 (53,884.63 to 64,779.14)	0.41 (0.29 to 0.53)
GBD regions					
Andean Latin America	58,913 (52,166 to 66,602)	3420.9 (3029.12 to 3867.39)	239,448 (212,018 to 268,931)	4629.05 (4098.76 to 5199)	0.99 (0.89 to 1.08)
Australasia	430,350 (379,126 to 482,115)	20,181.62 (17,779.46 to 22,609.18)	1,170,564 (1,053,830 to 1,290,084)	25,266.18 (22,746.51 to 27,845.96)	0.87 (0.71 to 1.02)
Caribbean	125,919 (109,943 to 141,459)	5660.28 (4942.14 to 6358.86)	417,476 (370,307 to 463,153)	8503.27 (7542.52 to 9433.64)	1.25 (1.08 to 1.42)
Central Asia	258,437 (226,104 to 291,715)	5431.80 (4752.23 to 6131.24)	392,704 (343,182 to 443,084)	4810.91 (4204.23 to 5428.1)	-0.18 (-0.27 to -0.08)
Central Europe	2,415,255 (2,136,526 to 2,694,643)	16,032.42 (14,182.23 to 17,887)	2,998,025 (2,641,371 to 3,345,219)	14,382.02 (12,671.09 to 16,047.56)	-0.49 (-0.55 to -0.43)
Central Latin America	639,205 (556,986 to 718,097)	9088.98 (7919.89 to 10,210.76)	1,575,445 (1,371,027 to 1,766,167)	6817.50 (5932.91 to 7642.82)	-0.50 (-0.73 to -0.27)
Central Sub-Saharan Africa	47,651 (41,653 to 54,333)	2371.23 (2072.74 to 2703.71)	141,882 (124,287 to 158,985)	2894.87 (2535.87 to 3243.82)	0.63 (0.58 to 0.69)
East Asia	4,917,978 (4,296,061 to 5,628,853)	6488.32 (5667.82 to 7426.19)	18,236,530 (16,041,063 to 20,535,023)	9008.86 (7924.3 to 10,144.32)	0.63 (0.10 to 1.16)
Eastern Europe	3,537,350 (3,062,770 to 4,026,531)	11,208.20 (9704.48 to 12,758.18)	4,173,683 (3,648,462 to 4,713,802)	10,937.36 (9560.99 to 12,352.77)	-0.31 (-0.64 to 0.02)
Eastern Sub-Saharan Africa	170,352 (148,002 to 193,532)	2813.81 (2444.63 to 3196.68)	436,214 (381,111 to 487,965)	3080.94 (2691.75 to 3446.45)	0.21 (0.17 to 0.25)
High-income Asia Pacific	2,327,480 (2,047,803 to 2,647,991)	11,893.18 (10,464.07 to 13,530.96)	5,463,598 (4,863,524 to 6,081,267)	14,322.98 (12,749.87 to 15,942.22)	0.48 (0.32 to 0.63)

Table 2 (continued)

Location	Prevalent cases (95%UI), 1990	Prevalence rate (95%UI), 1990	Prevalent cases (95%UI), 2021	Prevalence rate (95%UI), 2021	EAPC(95%CI),1990–2021
High-income North America	5,387,686 (4,705,737 to 6,086,084)	16,402.48 (14,326.33 to 18,528.71)	14,136,772 (12,312,244 to 16,040,235)	23,465.95 (20,437.37 to 26,625.55)	1.10 (1.01 to 1.19)
North Africa and Middle East	589,358 (516,124 to 666,857)	4248.49 (3720.57 to 4807.16)	2,021,648 (1,780,523 to 2,279,599)	5369.71 (4729.26 to 6054.86)	0.79 (0.65 to 0.93)
Oceania	14,666 (12,930 to 16,390)	6345.58 (5594.17 to 7091.18)	51,642 (45,959 to 57,385)	8785.17 (7818.45 to 9762.24)	0.88 (0.73 to 1.03)
South Asia	4,954,652 (4,294,853 to 5,693,584)	10,999.89 (9535.06 to 12,640.41)	16,104,907 (14,025,406 to 18,504,867)	12,719.97 (11,077.54 to 14,615.5)	0.45 (0.42 to 0.49)
Southeast Asia	1,149,276 (1,003,189 to 1,303,557)	5101.41 (4452.96 to 5786.23)	3,397,468 (2,985,233 to 3,829,667)	5540.44 (4868.19 to 6245.26)	0.09 (0.02 to 0.17)
Southern Latin America	415,755 (366,306 to 467,981)	9480.77 (8353.13 to 10,671.71)	963,797 (854,916 to 1,076,908)	11,844.03 (10,506 to 13,234.05)	0.75 (0.64 to 0.87)
Southern Sub-Saharan Africa	58,475 (51,228 to 66,817)	2321.15 (2033.51 to 2652.3)	105,810 (92,822 to 120,795)	1858.14 (1630.04 to 2121.28)	-0.83 (-0.93 to -0.73)
Tropical Latin America	720,274 (628,438 to 820,090)	8929.29 (7790.8 to 10,166.72)	2,285,270 (2,010,166 to 2,576,894)	9393.21 (8262.44 to 10,591.87)	0.05 (-0.13 to 0.24)
Western Europe	12,834,274 (11,356,934 to 14,256,351)	23,097.22 (20,438.53 to 25,656.47)	21,132,622 (18,894,876 to 23,339,579)	26,355.62 (23,564.81 to 29,108.03)	0.53 (0.45 to 0.61)
Western Sub-Saharan Africa	238,251 (205,319 to 269,140)	3424.26 (2950.94 to 3868.2)	608,456 (529,594 to 682,849)	3561.29 (3099.71 to 3996.71)	0.12 (0.05 to 0.19)
SDI levels					
Low SDI	955,867 (832,668 to 1,085,159)	5266.29 (4587.53 to 5978.62)	2,651,820 (2,321,961 to 3,014,806)	6338.19 (5549.78 to 7205.77)	0.60 (0.54 to 0.66)
Low-middle SDI	4,084,373 (3,561,331 to 4,664,014)	8249.16 (7192.78 to 9419.86)	11,353,189 (9,921,890 to 12,946,508)	9046.7 (7906.18 to 10,316.32)	0.30 (0.23 to 0.36)
Middle SDI	5,857,127 (5,127,383 to 6,659,379)	6581.72 (5761.7 to 7483.22)	20,827,250 (18,265,466 to 23,583,368)	8462.24 (7421.37 to 9582.06)	0.60 (0.39 to 0.81)
High-middle SDI	11,133,799 (9,830,357 to 12,536,155)	11,444.03 (10,104.27 to 12,885.46)	21,786,254 (19,312,146 to 24,273,470)	11,594.44 (10,277.75 to 12,918.12)	-0.14 (-0.23 to -0.05)
High SDI	19,203,759 (16,952,306 to 21,462,497)	18,189.41 (16,056.88 to 20,328.84)	39,349,472 (34,864,182 to 43,768,964) 19,674,736 (17,432,091 to 21,884,482)	21,337.97 (18,905.74 to 23,734.52)	0.51 (0.46 to 0.57)

EAPC estimated annual percentage change, SDI socio-demographic index, GBD global burden of disease, UI uncertainty interval, CI confidence interval

Correlation with the SDI levels

The relationship between the incidence and prevalence rates of fall-related fractures among postmenopausal women and the SDI levels across 21 regions from 1990 to 2021 is illustrated in Figs. 3A-B. From 1990 to 2021, the incidence and prevalence rates of fall-related fractures among postmenopausal women rose with increasing SDI levels, reaching an initial peak of around 0.38. Subsequently, they dipped to a low of 0.62 before steadily climbing back up to their highest level. The incidence and prevalence rates in Western Europe, Australasia, and High-income North America exceeded the levels that would be expected based on their SDI. In 2021, the relationship between the incidence and prevalence rates of fall-related fractures among postmenopausal women and the SDI levels across 204 countries and territories is depicted in Figs. 3C-D. The incidence and prevalence rates initially rose slowly with increasing SDI levels, eventually reaching 0.68, after which they increased sharply. The incidence and prevalence rates in Andorra, Belgium, Croatia, Norway, and Switzerland exceeded the levels that would be expected based on their SDI.

Projection trends

The future projections of fall-related fractures among postmenopausal women are illustrated in Fig. 4. The projection trends suggest that the incident cases of fall-related fractures among postmenopausal women will steadily climb each year, beginning with 26.55 million cases in 2022 and escalating to 41.57million cases by 2035. Likewise, the prevalent cases of fall-related fractures among postmenopausal women are projected to increase annually, rising from 99.63 million cases in 2022 to 153.79 million cases by 2035. In the upcoming 14 years, the incidence and prevalence rates of fall-related fractures among postmenopausal women are projected to undergo a slight uptick. The incidence rate is projected to climb from 3227.15 per 100,000 populations in 2022 to 3346.60 per 100,000 populations by 2035. Meanwhile, the prevalence rate is set to grow from 12,120.87 per 100,000 populations in 2022 to 12,584.49 per 100,000 populations by 2035.

Discussion

This comprehensive analysis of data from the GBD Study 2021 reveals a substantial and growing global burden of fall-related fractures among postmenopausal women. Between 1990 and 2021, both the absolute number of incident and prevalent cases and the corresponding rates increased worldwide. The burden demonstrates clear demographic and geographic disparities, being strongly associated with advancing age and varying considerably across regions and nations with different socioeconomic development levels. Our projections indicate that this public health challenge is set to intensify in the coming decades, underscoring the urgent need for targeted interventions.

The findings of this study underscore the substantial and increasing burden of fall-related fractures among postmenopausal women globally. The significant rise is mainly due to the combined impact of aging and a lack of estrogen, which greatly increase the risk of osteoporosis-related fractures and ensuing issues [15, 16] This upward trend is concerning, as it suggests that the problem is not only persistent but also worsening over time. Even after accounting for population aging through the incidence and prevalence rates have shown a persistent upward trend (EAPC of 0.52 and 0.13, respectively). This suggests that other factors beyond demographic shifts are at play. To address this growing public health concern, it is crucial to implement comprehensive strategies that include early screening for osteoporosis, promoting bone health through diet and exercise, and providing hormone replacement therapy where appropriate. Additionally, public health campaigns should focus on raising awareness about fall prevention and the importance of maintaining bone density to reduce the incidence of fractures in postmenopausal women.

The age-specific pattern we observed, where rates escalate dramatically with age and peak in the 95 + group, is consistent with the well-established pathophysiology of postmenopausal osteoporosis [17] and age-related declines in muscle mass (sarcopenia), balance, and cognitive function [18–20], all of which synergistically increase the risk of falls and fragility fractures. Furthermore, some research highlights the potential significance of early exposure to environmental factors (primarily dietary factors, physical activity, and comorbidities), as etiological factors could have an impact earlier in the life course, resulting in an elevated rate of fractures in later life. [21, 22] Given these findings, targeted interventions such as fall prevention programs, strength and balance training, and nutritional support for older adults, especially those aged 95 and above, are essential. Public health initiatives should also focus on early detection and management of osteoporosis to mitigate the risk of fragility fractures in this vulnerable population.

The regional and national variations in the incidence and prevalence of fall-related fractures highlight the complexity of this public health issue. Western Europe, Australasia, and High-income North America had the highest rates in 2021, while Southern Sub-Saharan Africa had the lowest. These differences may be attributed to various factors, including lifestyle, calcium intake, the plasma level of vitamin D, osteoporosis medication, healthcare infrastructure,

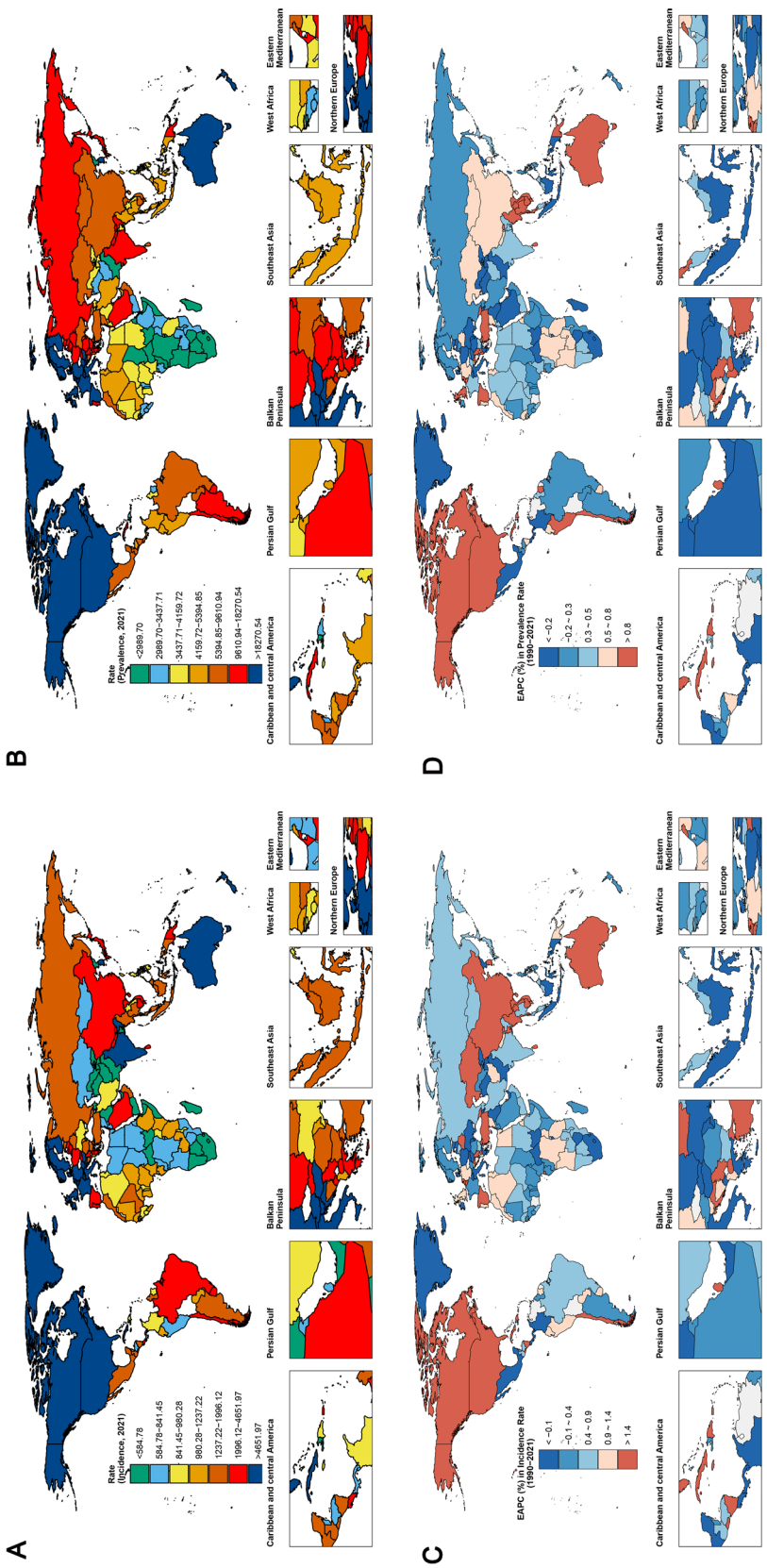

Fig. 2 Global distribution of fall-related fractures among postmenopausal women. Incidence rate (Per 100,000 populations), in 2021 (**A**); Prevalence rate (Per 100,000 populations), in 2021 (**B**); EAPC for incidence rate, 1990–2021 (**C**); EAPC for prevalence rate, 1990–2021 (**D**). EAPC, Estimated Annual Percentage Change

environmental and/or intrinsic factors, and socioeconomic conditions [23–25] For instance, high-income regions benefit from superior acute care and a wider range of improved therapies and preventive strategies. This has led to a higher survival rate among postmenopausal women who suffer fractures caused by falls. However, a considerable proportion of these individuals require long-term care due to different extents of disability [26–28] In contrast, low-income countries face higher mortality rates among the elderly who experience fractures due to falls because of limited acute care and lack of access to advanced therapies and preventive measures [29]. The analysis of trends from 1990 to 2021 offers further insights. The most significant increases in incidence rates in regions like North Africa and Middle East, and Australasia may signal rapid demographic transitions and changing lifestyles in these regions. Meanwhile, the declines observed in Central Europe and Central Latin America could be the result of successful public health initiatives focused on fracture prevention, improved nutrition, or the wider availability of osteoporosis treatment. The correlation analysis shows that the incidence and prevalence rates of fall-related fractures among postmenopausal women increase with the SDI levels, reaching a peak at around 0.38, then dipping to 0.62 before rising again. This suggests a complex relationship between socioeconomic development and the burden of fall-related fractures [28–30]. Regions with moderate levels of development may experience higher rates of fall-related fractures due to factors such as rapid urbanization, changes in lifestyle, and increased life expectancy. In contrast, regions with very high levels of development may have better healthcare infrastructure and preventive measures in place, which can help mitigate the risk of falls and fractures. At the national level, the stark contrasts between countries like Turkey and Bhutan (showing the largest increases) and the United Arab Emirates and Czechia (showing the largest decreases) highlight the critical role of national-level policies and healthcare infrastructure. Countries like Andorra and Belgium, whose rates exceeded the expected level based on their SDI, should be prioritized for further investigation into specific risk factors and healthcare delivery models. To address the complexity of fall-related fractures, countries should tailor public health strategies based on their specific socioeconomic and healthcare contexts. High-income countries should focus on improving long-term care and rehabilitation services for the postmenopausal women, while low-income countries should prioritize enhancing acute care and expanding access to basic fracture prevention and treatment measures. Additionally, countries with significant increases in fracture incidence, such as Turkey and Bhutan, should invest in targeted interventions like exercise programmes [31, 32], calcium and vitamin D supplementation [33–35], safe environment modifications [36], and osteoporosis screening, while those with declines, like the United Arab Emirates and Czechia, should continue to strengthen their successful public health initiatives and share best practices.

Strengths and limitations

This study benefits from the use of comprehensive data from the GBD Study 2021, which integrates a wide range of sources to provide a robust and detailed dataset. The inclusion of both global, regional and national analyses allows for a nuanced understanding of the burden of fall-related fractures among postmenopausal women. Additionally, the application of rigorous statistical methods, such as the EAPC and the BAPC model, ensures accurate trend assessments and reliable future projections. The use of LOESS regression further enhances the analysis by capturing nonlinear relationships between the incidence and prevalence rates and SDI levels.

Despite these strengths, the study is subject to limitations inherent in the data sources. The reliance on existing health records and surveys may introduce underreporting and inaccuracies, particularly in regions with less developed healthcare infrastructure [25]. Additionally, the study assumes that current trends will persist, which may not account for future changes in healthcare practices or public health interventions [37]. The analysis also does not consider individual-level factors, such as genetic predisposition, lifestyle choices, and comorbid conditions, which could influence fracture risk. Future research should focus on addressing these limitations by improving data collection and incorporating individual-level data to enhance the accuracy and applicability of the findings.

Conclusion

The burden of fall-related fractures among postmenopausal women is substantial and increasing globally. This study highlights the need for public health policies and resource allocation to address this critical issue, with a focus on improving bone health, preventing falls, and enhancing healthcare services for older women. By taking proactive measures, we can improve the well-being of postmenopausal women and reduce the economic burden on healthcare systems worldwide.

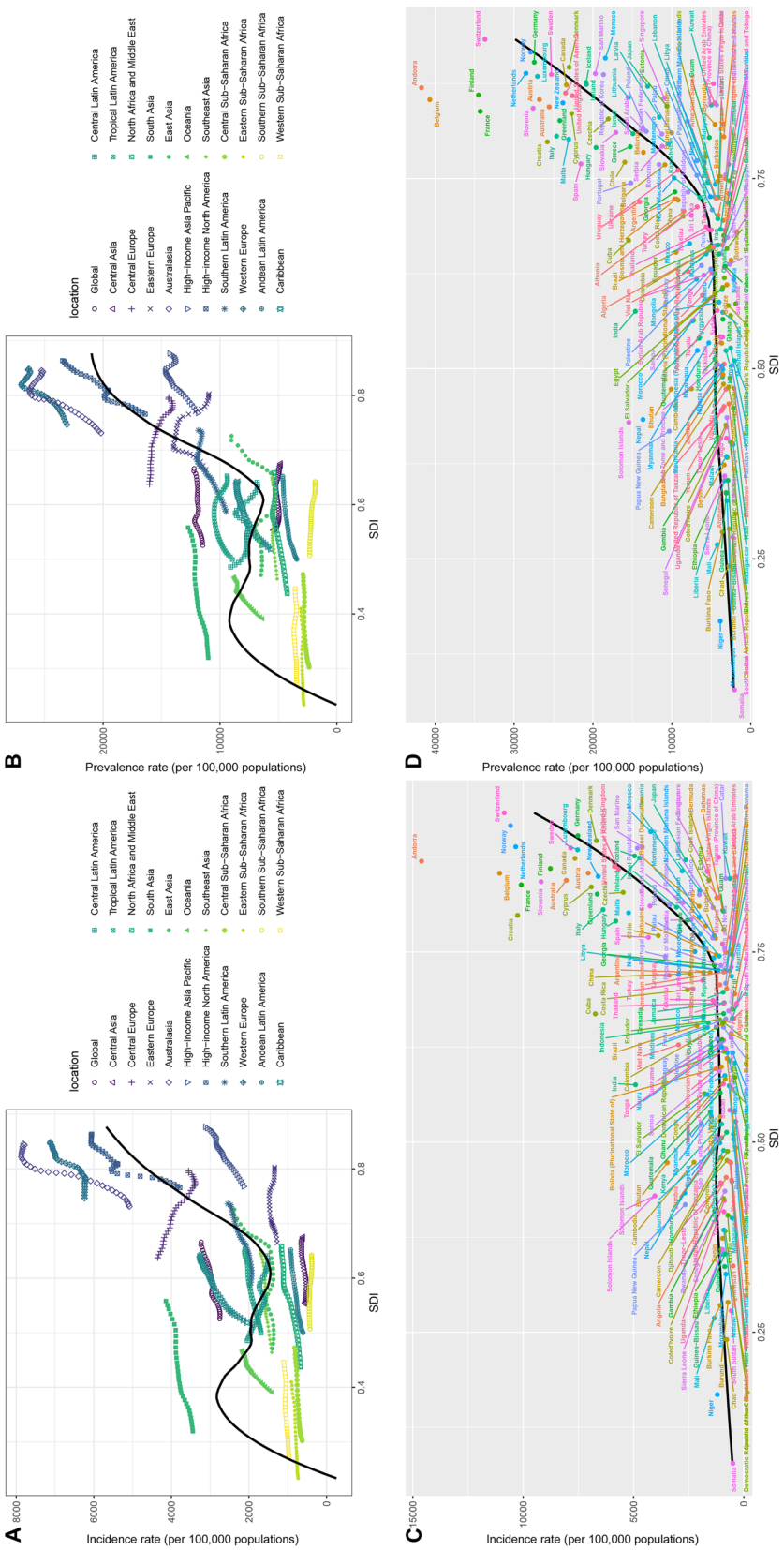

Fig. 3 Incidence (**A**) and prevalence (**B**) rates for fall-related fractures among postmenopausal women across the 21 Global Burden of Disease regions by sociodemographic index, 1990–2021, and incidence (**C**) and prevalence (**D**) rates for fall-related fractures among postmenopausal women across the 204 countries/territories by sociodemographic index, by 2021

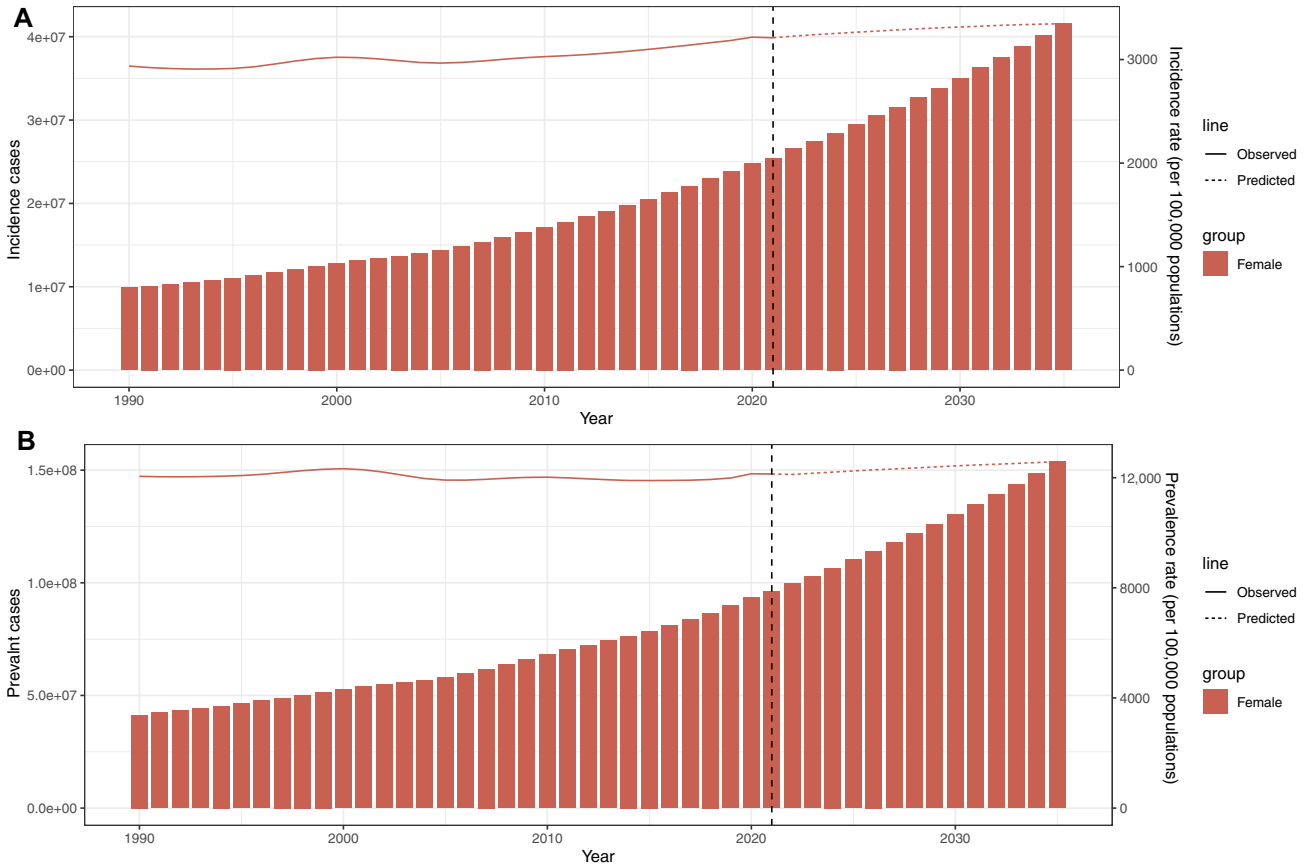

Fig. 4 Predicted cases and rates of Incidence (**A**) and prevalence (**B**) from 2022 to 2035 for fall-related fractures among postmenopausal women

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Data availability The data resources for the GBD 2021 study were accessible online through the Global Health Data Exchange (GHDx) query tool (http://ghdx.healthdata.org/gbd-results-tool).

Declarations

Competing interests The authors declare no competing interests.

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