Lei et al.
Journal of Orthopaedic Surgery and Research (2025) 20:480
https://doi.org/10.1186/s13018-025-05915-9

Journal of Orthopaedic Surgery and Research

RESEARCH Open Access

Global burden of vertebral fractures from 1990 to 2021 and projections for the next three decades

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Abstract

Background Vertebral fractures are linked to significant disability and mortality risks. Yet, existing studies on their global burden are outdated and lack predictive foresight.

Methods Public data from the 2021 GBD study were analyzed to assess the global burden and epidemiological trends of vertebral fractures. The annual percentage change (EAPC) was calculated to represent temporal trends from 1990 to 2021. Machine learning was used to predict the global burden of vertebral fractures over the next 30 years.

Results From 1990 to 2021, the global burden of vertebral fractures significantly decreased. The age-standardized incidence rates (ASIR) showed the largest decline in Eastern Sub-Saharan Africa (EAPC: -1.5; 95% CI: -2.0 to -1.0), while North Africa and the Middle East were the only regions to report an increase (EAPC: 0.3; 95% CI: 0.1 to 0.5). For age-standardized prevalence rates (ASPR), High-income Asia Pacific saw the steepest decline (EAPC: -1.4; 95% CI: -1.5 to -1.2), while the Caribbean experienced the largest increase (EAPC: 0.8; 95% CI: 0.4 to 1.3). Similarly, in terms of age-standardized years lived with disability rates (ASYR), the most substantial reduction occurred in High-income Asia Pacific (EAPC: -1.4; 95% CI: -1.5 to -1.3), with the Caribbean again showing the greatest rise (EAPC: 0.8; 95% CI: 0.3 to 1.2). Males generally exhibited higher age-standardized rates (ASRs) than females, although females aged 65–70 years old surpassed males. Predictive models suggest continued declines in global ASIR, ASPR, and ASYR by 2050.

Conclusions Our study shows a steady reduction in the global burden of vertebral fractures from 1990 to 2021. Nevertheless, disparities remain across regions, with a positive correlation between ASRs with SDI.

Key points

1. In 2021, there were approximately 7.5 million incidence cases, 5.4 million prevalence cases, and 0.55 million YLD cases globally. ASPR, ASIR, and ASYR all showed a downward trend.

2. From 1990 to 2021, incidence, prevalence, and YLDs increased with time. The gap between males and females gradually narrowed, with males consistently exhibiting higher ASRs.

3. SDI is positively correlated with ASIR, ASPR, and ASYR.

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Keywords Global burden of disease study, Vertebral fractures, Epidemiological science

Introduction

Spinal injuries refer to disruptions in the continuity, integrity, and stability of the spinal structure, primarily caused by motor vehicle accidents, falls, violence, and sports injuries [1]. Severe cases may result in spinal cord damage, leading to neurological dysfunction [2]. Vertebral fractures are the most common type of spinal injury, often overlooked during the clinical latency period until chronic back pain or impaired daily activities arise [3]. Studies show that vertebral fracture patients may experience reduced quality of life due to immobility, depression, and social isolation [4]. Moreover, these fractures are associated with increased mortality, highlighting their significance as a public health concern [5, 6].

From 1990 to 2019, global prevalence, incidence, and years lived with disability (YLDs) due to vertebral fractures declined [3]. From the perspective of the sociodemographic index (SDI), high-SDI countries exhibited lower age-standardized incidence rate (ASIR), prevalence rate (ASPR), and YLD rate (ASYR) than low-SDI countries, underscoring the link between spinal injuries and socioeconomic factors [3]. Generally, the incidence of vertebral fractures rose with age and was initially higher in men. However, postmenopausal osteoporosis significantly elevated fracture risk in elderly women, leading to a higher prevalence and YLD burden compared to men in later life [3, 7]. There is still a lack of recent studies on the global burden of vertebral fractures, and predictive analyses in this field remain unreported.

This study utilized Global Burden of Disease (GBD) 2021 data to analyze global prevalence, incidence, and YLDs of vertebral fractures from 1990 to 2021 across 204 countries and 21 regions. We dissected the contributions of population growth, aging, and epidemiological change to the disease burden and examined 30-year trends by age, gender, and SDI. Using ARIMA modeling, we projected the disease burden to 2050, providing insights to guide preventive strategies and healthcare resource allocation.

Method

Data source and injury definition

The incidence, prevalence, and attributable burden of vertebral fractures were estimated using GBD 2021 data (https://vizhub.healthdata.org/gbd-results/). Vertebral fractures encompassed various etiologies, with the definition anchored in the International Classification of Diseases (ICD) codes (ICD-9 and ICD-10).

Measurements

We examined the incidence, prevalence, and age-standardized burden rates of vertebral fractures, including ASIR, ASPR, and ASYR, between 1990 and 2021, disaggregated by gender, age, and SDI.

Incidence refers to the number of new cases within a specific population and timeframe, while prevalence indicates the proportion affected within a given period and region. YLD measures years lived with disability due to vertebral fractures. SDI reflects socio-economic conditions impacting health outcomes, integrating mean educational attainment (age 15+), total fertility rate (under 25), and lag-distributed per capita income, modeled after the United Nations' Human Development Index.

The estimation for incidence, prevalence, and YLD

The methodology for estimating the injury burden in GBD 2021 has been well-documented [8, 9]. It relies primarily on data from hospital records, insurance claims, and civil registries. Given the temporal span of these datasets, variations in ICD coding may introduce bias, necessitating prior adjustments [10]. After correcting coding discrepancies, injury incidence was estimated using the Bayesian tool DisMod-MR 2.1. Injuries are categorized by external causes (e.g., falls, road traffic accidents) and nature of injury (e.g., vertebral fractures). Incidence, prevalence, and YLDs are estimated based on the nature of injury. Short-term disability prevalence is calculated as the product of incidence and injury duration, while long-term disability is adjusted by DisMod-MR 2.1 to account for temporal variations. Ultimately, prevalence estimates are integrated with disability weights to quantify YLDs, as detailed in relevant literature [11, 12]. Final estimates (means with 95% uncertainty intervals (UIs)) were derived from 500 draws from the estimate's distribution, with 95% UIs defined as the 2.5 th to 97.5 th percentile range of outcomes [8, 9].

Statistical analysis

In this study, we estimated the incidence, prevalence, and YLDs of vertebral fractures, along with their 95% UI, using the Bayesian-based DisMod-MR 2.1 tool. After obtaining annual estimates, temporal trends were assessed by calculating the estimated annual percentage change (EAPC) in ASIR, ASPR, and ASYR from 1990 to 2021. The EAPC was modeled via least squares linear regression on log-transformed rates: $\ln(y)=\alpha+\beta x+\epsilon$, where y represents the age-standardized rate (ASR), x denotes the year, and β is the regression coefficient [3]. The EAPC was derived as $(\exp(\beta)-1)\times 100\%$, with its 95% confidence interval (95% CI) obtained by applying this same formula to the lower and upper bounds of β's 95% CI ($\beta\pm 1.96\times SE$). Specifically, the EAPC's 95% CI was calculated as $[(\exp(\beta-1.96\times SE)-1)\times 100\%, (\exp(\beta+1.96\times SE)-1)\times 100\%]$. A significant increasing ASR trend was defined when the EAPC's 95% CI entirely exceeded zero (lower bound>0), while a decreasing trend required the upper bound<0; otherwise, trends were considered stable. Regression analyses were implemented using the broom package in R.

Global maps were generated using the ggmap, maps, and dplyr packages in R to visualize and compare the disease burden across the world and 21 regions. Age- and sex-stratified analyses were conducted by constructing dual-axis, dual-panel, and line charts using ggplot2, reshape2, and dplyr to depict the distribution of disease burden across population groups. The association between the Socio-demographic Index (SDI) and vertebral fracture burden was further explored, with SDI categories (low, low-middle, middle, high-middle, and high) used to compare burdens across different socioeconomic strata [13]. Data processing and visualization were performed using reshape, ggrepel, and ggplot2 packages.

Decomposition analysis, stratified by sex and SDI, quantified the contributions of population ageing, growth, and epidemiological changes to the variation in vertebral fracture burden from 1990 to 2021. Each factor's contribution is depicted by black dots, with positive values indicating an increase and negative values a decrease in disease burden [14].

Future trends were projected using autoregressive integrated moving average (ARIMA), Extreme Gradient Boosting (XGBoost), and Long Short-Term Memory (LSTM) models. ARIMA, an established time-series method, predicted baseline values through the equation: $Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \ldots + \phi_P Y_{t-P} + \varepsilon_t - \theta_1\varepsilon_{t-1} - \ldots - \theta_q\varepsilon_{t-q}$, where φ and θ are autoregressive and moving average parameters, Y_t is the differenced series, and ε_t denotes stochastic error at period t [15]. Optimal ARIMA parameters were selected via"auto.arima()". Residuals were refined using XGBoost to capture nonlinearities, followed by LSTM for long-range dependencies. The final forecast combined ARIMA predictions, XGBoost refinements, and LSTM corrections.

All analyses were performed in R (version 4.3.2), with statistical significance set at p<0.05.

Result

Global and regional burden of vertebral fractures

In 2021, the global prevalence of vertebral fractures was estimated at 5.4 (95% UI: 4.7–6.2) million, with an annual incidence of 7.5 (95% UI: 5.8–9.7) million equally affecting males and females (Table 1). The YLDs attributed to these fractures totaled 0.5 (95% UI: 0.4–0.8) million. ASRs were recorded at 65.2 (95% UI: 56.9–75.3) cases per 100,000 population for ASPR, 92.8 (95% UI: 72.1–120.0) cases per 100,000 population for ASIR, and 6.6 (95% UI: 4.4–9.2) cases per 100,000 population for ASYR. Among 21 global regions, Australasia exhibited the highest ASRs, with an ASIR of 232.2 (95% UI: 174.3–303.6) cases per 100,000 population, ASPR of 182.3 (95% UI: 158.1–208.9) cases per 100,000 population, and ASYR of 18.6 (95% UI: 12.5–25.8) cases per 100,000 population. Between 1990 and 2021, all global vertebral fracture metrics demonstrated negative EAPC, signaling a worldwide decline. For ASIR trends, North Africa and the Middle East demonstrated a slight increase (EAPC: 0.3; 95% CI: 0.1 to 0.5), while Southeast Asia (EAPC: 0.1; 95% CI: −0.4 to 0.6) and the Caribbean (EAPC: 0.4; 95% CI: −0.4 to 1.2) showed stable trends. In contrast, other regions exhibited declining ASIRs, with Eastern Sub-Saharan Africa experiencing the steepest decrease (EAPC: −1.5; 95% CI: −2.0 to −1.0). Regional ASPR trends varied, with the Caribbean experiencing the largest increase (EAPC: 0.8; 95% CI: 0.4 to 1.3), whereas High-income Asia Pacific saw the sharpest decline (EAPC: −1.4; 95% CI: −1.5 to −1.2). ASYR trends followed a similar pattern, with the Caribbean recording the most pronounced rise and High-income Asia Pacific the most significant reduction. Across different SDI regions, ASRs generally declined, except in Middle SDI and Low SDI regions, where ASPR and ASYR remained stable. The High-middle SDI group experienced the sharpest decline, while High SDI regions had the highest ASRs and Low SDI regions the lowest.

The dual-axis plots of temporal trends in global disease burden

Figure 1 illustrates the GBD and ASRs of vertebral fractures in males and females from 1990 to 2021. The ASIR, ASPR, and ASYR exhibited a downward trend in both sexes, with the gender gap narrowing and reaching its lowest point in 2021. In contrast, incidence, prevalence, and YLDs in both sexes increased over time, with males consistently experiencing higher rates than females.

The global disease burden across different age groups

Figure 2 illustrated the prevalence, incidence, and YLD of vertebral fractures across age groups in 2021 (Fig. 2 a, c, e), along with their ASRs (Fig. 2 b, d, f). Overall, the number of individuals with vertebral fracture-related

Table 1 Trends in the incidence, prevalence, and YLDs of vertebral fractures from 1990 to 2021

Location	Incidence			Prevalence			YLD		
	number in 2021 (95% UI)	ASIR per 100,000 (95% UI)	EAPC from 1990 to 2019 (95% CI)	number in 2021 (x 1000) (95% UI)	ASPR per 100,000 (95% UI)	EAPC from 1990 to 2019 (95% CI)	number in 2021 (x 1000) (95% UI)	ASYR per 100,000 (95% UI)	EAPC from 1990 to 2019 (95% CI)
Global	7497446 (5834963,9737255)	92.75 (72.12,119.99)	−0.77 (−0.81 to −0.72)	5371438 (4703837,6196132)	65.19 (56.89,75.28)	−0.79 (−0.83 to −0.75)	545923 (366571,757099)	6.62 (4.43,9.2)	−0.81 (−0.85 to −0.77)
High SDI	2141941 (1580376,2884480)	157.17 (119.04,207.76)	−0.68 (−0.70 to −0.65)	2469882 (2144431,2817433)	131.65 (114.84,149.24)	−0.61 (−0.63 to −0.59)	245574 (163359,339966)	13.36 (8.95,18.51)	−0.64 (−0.66 to −0.62)
High-middle SDI	1531877 (1165619,2014820)	109.16 (83.64,142.31)	−0.89 (−0.97 to −0.81)	1086362 (953352,1244962)	64.26 (55.8,74.54)	−1.01 (−1.10 to −0.92)	111095 (75248,154768)	6.63 (4.46,9.32)	−1.00 (−1.09 to −0.91)
Low SDI	640628 (493996,832902)	63.4 (49.74,80.95)	−0.41 (−0.64 to −0.17)	246714 (190571,325486)	33.49 (27.67,41.42)	−0.04 (−0.15 to 0.07)	26118 (17629,38250)	3.44 (2.39,4.87)	−0.06 (−0.18 to 0.05)
Low-middle SDI	1265742 (996257,1631788)	69.74 (54.83,90.51)	−0.62 (−0.74 to −0.49)	567486 (471693,669476)	36.65 (31.13,42.92)	−0.26 (−0.33 to −0.18)	59226 (40462,84059)	3.76 (2.56,5.27)	−0.28 (−0.36 to −0.21)
Middle SDI	1910369 (1474209,2500467)	76.23 (58.96,99.58)	−0.23 (−0.30 to −0.16)	996724 (846944,1163380)	39.57 (33.59,46.45)	−0.05 (−0.15 to 0.04)	103474 (69771,145983)	4.09 (2.76,5.74)	−0.08 (−0.17 to 0.01)
GBD 21 regions									
Andean Latin America	48851 (38490,62399)	73.08 (57.51,93.44)	−0.38 (−0.49 to −0.27)	20589 (16961,25108)	32.29 (26.87,39.16)	−0.21 (−0.27 to −0.15)	2181 (1450,3098)	3.41 (2.28,4.81)	−0.23 (−0.28 to −0.17)
Australasia	82214 (60157,109852)	232.18 (174.33,303.58)	−0.22 (−0.31 to −0.13)	86326 (74702,98843)	182.32 (158.11,208.92)	−0.10 (−0.18 to −0.01)	8616 (5703,11844)	18.56 (12.45,25.78)	−0.13 (−0.21 to −0.05)
Caribbean	41527 (33084,53030)	85.96 (68.43,109.85)	0.43 (−0.36 to 1.21)	21949 (18704,25857)	42.64 (36.12,50.54)	0.81 (0.37 to 1.25)	2262 (1567,3155)	4.42 (3.04,6.15)	0.76 (0.30 to 1.23)
Central Asia	86933 (68675,113052)	90.11 (71.1,117.03)	−0.90 (−1.10 to −0.70)	34439 (27868,42185)	37.62 (30.74,45.71)	−0.73 (−0.84 to −0.61)	3667 (2411,5236)	3.98 (2.64,5.66)	−0.74 (−0.86 to −0.63)
Central Europe	202041 (153511,270779)	163.9 (123.54,221.11)	−1.06 (−1.13 to −0.99)	116959 (100857,137786)	71.09 (58.61,87.02)	−1.05 (−1.12 to −0.98)	11981 (8062,16770)	7.44 (4.81,10.66)	−1.04 (−1.11 to −0.97)
Central Latin America	226974 (176349,291985)	89.37 (69.36,114.98)	−0.72 (−0.94 to −0.49)	103659 (87349,124125)	40.95 (34.49,49.06)	−0.77 (−0.94 to −0.60)	10874 (7365,15275)	4.29 (2.9,6.02)	−0.76 (−0.94 to −0.59)
Central Sub-Saharan Africa	60232 (47863,74329)	47.93 (37.98,58.52)	−1.18 (−1.91 to −0.45)	23216 (18095,29626)	25.97 (21.33,32.14)	−0.34 (−0.71 to 0.03)	2477 (1667,3610)	2.69 (1.87,3.82)	−0.38 (−0.77 to 0.01)
East Asia	1219234 (908987,1625137)	75.19 (56.5,100.88)	−0.61 (−0.86 to −0.35)	732220 (632696,852696)	39.83 (33.85,46.73)	−0.32 (−0.44 to −0.21)	75654 (50869,106460)	4.13 (2.73,5.86)	−0.35 (−0.47 to −0.22)
Eastern Europe	355895 (275645,470575)	168.73 (130.9,221.27)	−1.05 (−1.34 to −0.76)	190639 (162961,224778)	72.13 (59.51,87.22)	−0.95 (−1.27 to −0.64)	19785 (13361,27689)	7.6 (4.98,10.83)	−0.96 (−1.27 to −0.65)
Eastern Sub-Saharan Africa	178286 (139448,228457)	46.21 (36.44,58.42)	−1.50 (−2.00 to −0.99)	69295 (52053,95131)	25.57 (20.56,33.54)	−0.69 (−0.93 to −0.45)	7361 (4815,10978)	2.64 (1.82,3.73)	−0.73 (−0.98 to −0.48)
High-income Asia Pacific	304508 (226180,407850)	130.33 (99.13,170.3)	−1.42 (−1.54 to −1.31)	402262 (355326,451412)	107.14 (95.11,121.49)	−1.36 (−1.48 to −1.24)	40341 (26946,55606)	11.06 (7.51,15.2)	−1.37 (−1.48 to −1.25)
High-income North America	757555 (564304,997819)	158.96 (122.41,206.63)	−0.41 (−0.52 to −0.29)	948836 (822350,1080753)	157.6 (138.08,178.17)	−0.01 (−0.08 to 0.07)	93496 (62165,128945)	15.76 (10.54,21.65)	−0.08 (−0.16 to 0.00)

Table 1 (continued)

Location	Incidence			Prevalence			YLD		
	number in 2021 (95% UI)	**ASIR per 100,000 (95% UI)**	**EAPC from 1990 to 2019 (95% CI)**	**number in 2021 (x 1000) (95% UI)**	**ASPR per 100,000 (95% UI)**	**EAPC from 1990 to 2019 (95% CI)**	**number in 2021 (x 1000) (95% UI)**	**ASYR per 100,000 (95% UI)**	**EAPC from 1990 to 2019 (95% CI)**
North Africa and Middle East	617361 (486189,785817)	98.91 (77.9,125.93)	0.31 (0.11 to 0.50)	258874 (204786,333164)	46.08 (37.31,57.72)	0.17 (0.08 to 0.25)	27310 (18500,39366)	4.8 (3.3,6.87)	0.15 (0.06 to 0.25)
Oceania	7692 (5963,9984)	61 (46.98,79.4)	−0.03 (−0.36 to 0.31)	3015 (2451,3632)	31.39 (26.72,36.65)	0.17 (−0.12 to 0.47)	321 (212,459)	3.24 (2.16,4.53)	0.14 (−0.15 to 0.43)
South Asia	1317848 (1008026,1757072)	75.77 (57.31,101.33)	−0.45 (−0.57 to −0.34)	625367 (518858,748472)	42.04 (35.53,50.11)	−0.08 (−0.15 to −0.02)	64644 (43185,92519)	4.26 (2.85,6)	−0.11 (−0.18 to −0.04)
Southeast Asia	418745 (331267,531579)	60.26 (47.65,76.78)	0.12 (−0.38 to 0.61)	202255 (170360,239427)	31.12 (26.53,36.58)	0.40 (0.15 to 0.66)	21193 (14577,29974)	3.22 (2.22,4.53)	0.38 (0.11 to 0.64)
Southern Latin America	104148 (80434,133864)	149.29 (115.32,191.82)	−0.06 (−0.19 to 0.06)	91462 (82273,102207)	114.53 (101.87,129.44)	−0.02 (−0.10 to 0.07)	9371 (6339,12904)	11.82 (7.96,16.34)	−0.03 (−0.12 to 0.06)
Southern Sub-Saharan Africa	42218 (33535,52630)	52.06 (41.43,65.02)	−1.20 (−1.33 to −1.08)	18239 (15229,21548)	25.56 (21.8,29.61)	−1.27 (−1.41 to −1.12)	1925 (1290,2677)	2.66 (1.83,3.68)	−1.28 (−1.42 to −1.14)
Tropical Latin America	249486 (191127,326516)	106.31 (81.32,139.24)	−0.73 (−0.87 to −0.59)	120349 (101926,142082)	49.15 (41.4,58.44)	−0.62 (−0.71 to −0.52)	12532 (8310,17771)	5.12 (3.39,7.31)	−0.63 (−0.73 to −0.53)
Western Europe	979713 (696247,1351596)	177.62 (128.55,243.91)	−0.76 (−0.82 to −0.70)	1232001 (1066030,1413658)	151.43 (131.99,172.21)	−0.75 (−0.80 to −0.71)	122477 (81287,171373)	15.45 (10.37,21.43)	−0.76 (−0.81 to −0.72)
Western Sub-Saharan Africa	195986 (156081,244567)	44.76 (35.81,56.18)	−0.23 (−0.35 to −0.12)	69487 (55451,85899)	22.6 (19.2,26.36)	0.02 (−0.04 to 0.09)	7456 (4895,10680)	2.35 (1.6,3.3)	0.02 (−0.05 to 0.08)

Abbreviations: *UI* uncertainty interval, *CI* confidence interval, *YLD* years lived with disability, *EAPC* estimated annual percentage change, *ASIR* age standardized incidence rate, *ASPR* age standardized prevalence rate, *ASYR* age standardized YLD rate

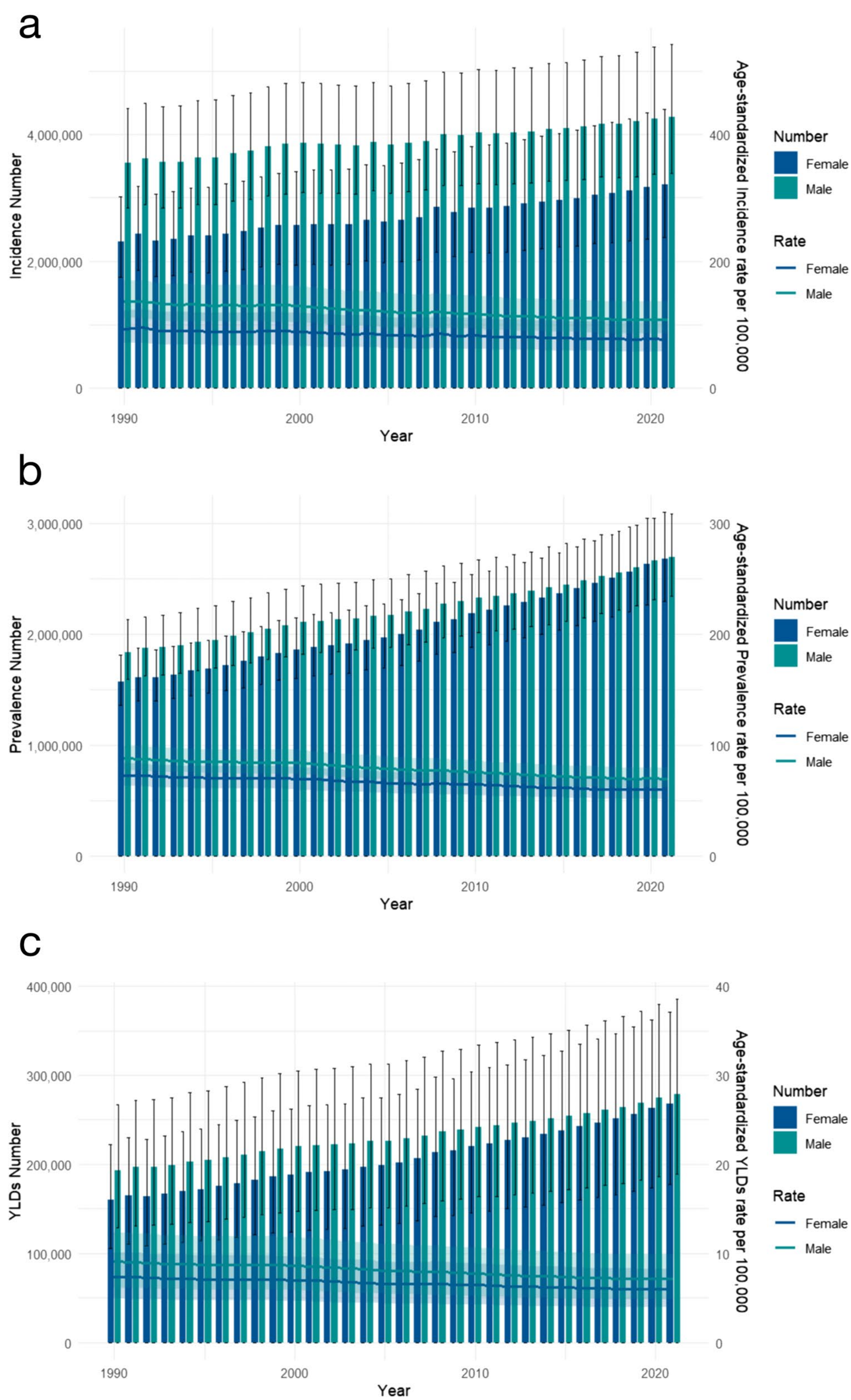

Fig. 1. The all-age cases, age-standardized incidence, prevalence, and YLDs from 1990 to 2021. **a** Incident cases and age standardized incidence rate; (**b**) Prevalent cases and age standardized prevalence rate; (**c**) YLD cases and age standardized YLD rate. YLD, years lived with disability.

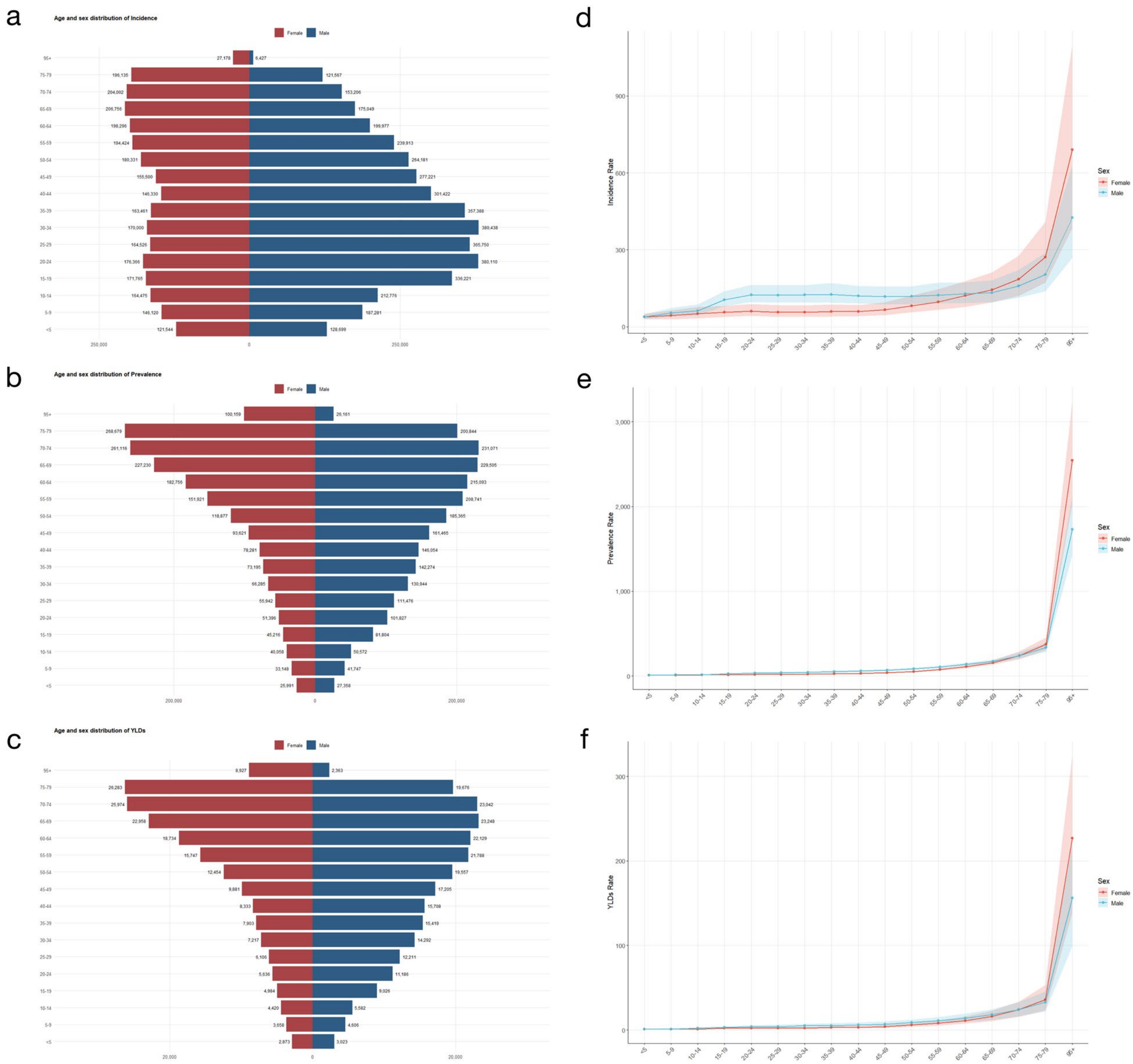

Fig. 2. The incidence, prevalence, and YLDs of vertebral fractures across different age groups in 2021. **a** Incidence; (**b**) Prevalence; (**c**) YLDs; (**d**) Age standardized incidence rate; (**e**) Age standardized prevalence rate; (**f**) Age standardized YLD rate. YLD, years lived with disability.

disabilities increased with age. Among males, prevalence peaked between 15 and 50 years old, whereas in females, incidence and disability rose sharply between 50 and 80 years old. In individuals under 65 years old, the ASIR was higher in males than in females, but the trend reversed between 65 and 70 years. A similar trend was observed in incidence and YLD. Among individuals under 75 years old, males exhibited higher ASPR and ASYR than females, whereas in those over 75 years old, females surpassed males in both metrics.

Causes of vertebral fractures

Multiple factors contributed to the ASIR, ASPR, and ASYR of vertebral fractures in GBD 2021 (Fig. 3). Globally, falls were the leading cause, with an ASIR of 57.9 (95% UI: 38.2–84.5) per 100,000, an ASPR of 44.7 (95% UI: 37.4–53.1) per 100,000, and an ASYR of 4.5 (95% UI: 2.9–6.3) per 100,000. Road injuries and mechanical forces also exhibited relatively high risk rates.

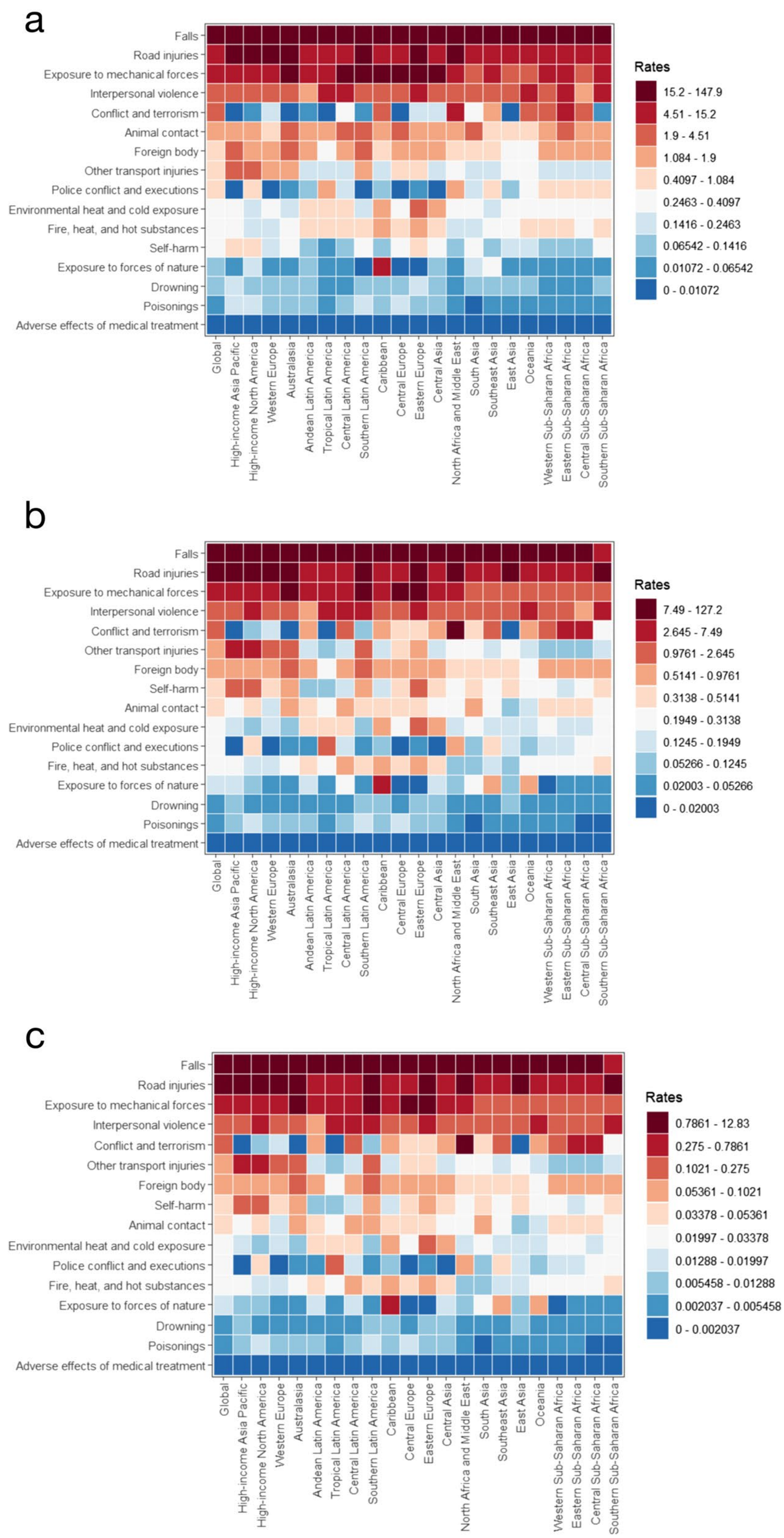

Fig. 3. The causes associated with the incidence, prevalence and burden of vertebral fractures**. a** Age standardized incidence rate; (**b**) Age standardized prevalence rate; (**c**) Age standardized YLD rate. YLD, years lived with disability.

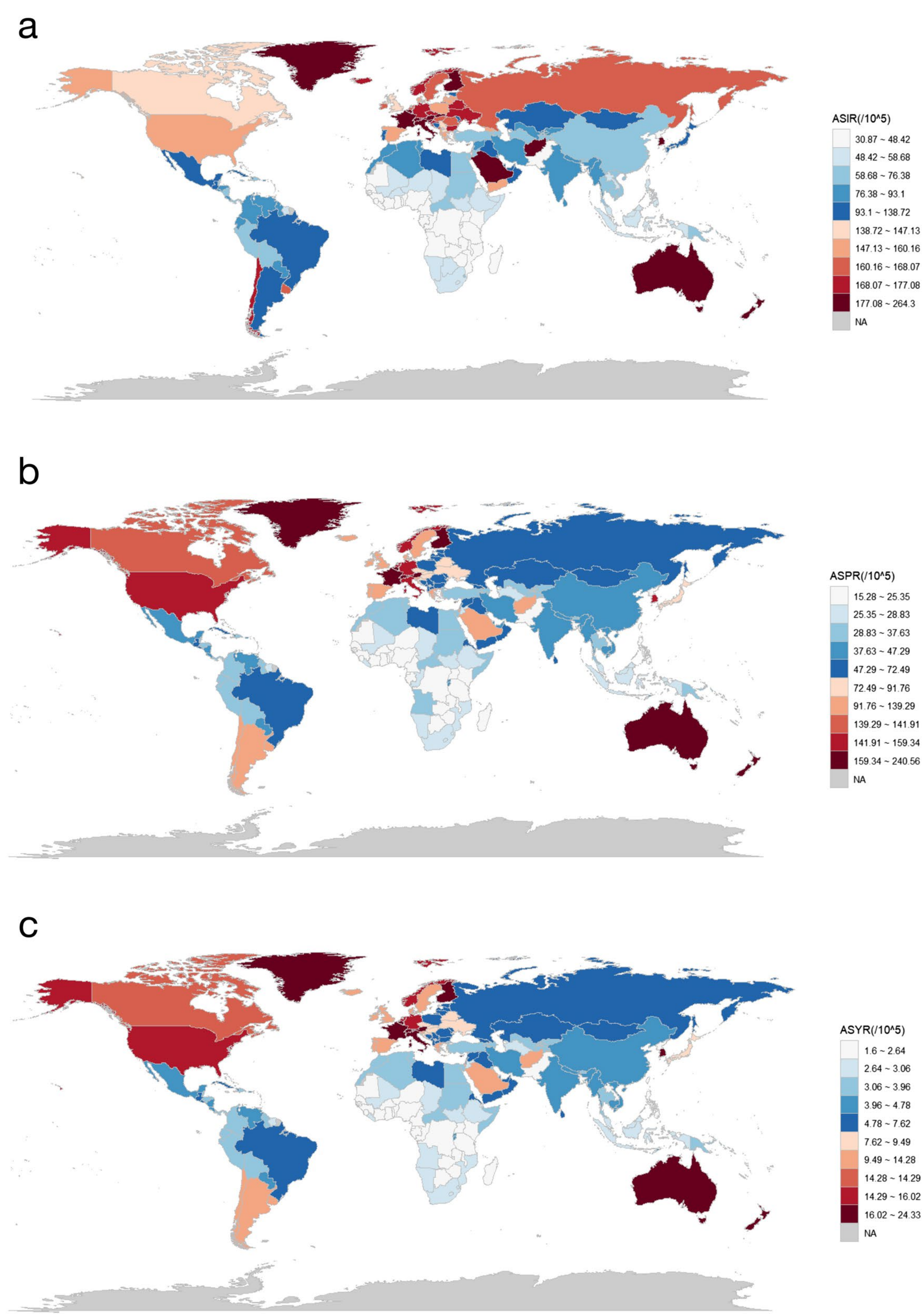

Fig. 4. Global burden of vertebral fractures across 204 countries and territories in 2021. **a** Age-standardized incidence; (**b**) Age-standardized prevalence; (**c**) Age-standardized YLDs. YLD, years lived with disability.

The global map of 204 countries and the relationship between the burden of vertebral fractures and the SDI

Figure 4 displayed the ASIR, ASPR, and ASYR of vertebral fractures in 2021 at the national level. Geospatially, high ASIR was mainly seen in developed regions. Andorra had the highest ASIR of 264.3 (95% UI: 189.7–367.1) per 100,000, followed by New Zealand and Finland (Fig. 4A). Similarly, Andorra exhibited the highest ASPR of 240.6 (95% UI: 207.3–276.9) per 100,000, with other developed nations, including Belgium and Finland, also reporting elevated rates (Fig. 4B). The ASYR distribution mirrored that of ASPR, with Andorra again recording the highest ASYR of 24.3 (95% UI: 16.0–33.7) per 100,000 (Fig. 4C).

Fig. 5 depicted the global and regional variations in ASRs of vertebral fractures relative to the SDI. Globally, when SDI was below 0.8, the ASIR rose sharply with increasing SDI, but beyond this threshold, it declined. A similar trend was observed for the ASPR and ASYR, which peaked at the SDI of 0.8 before decreasing. Between 1990 and 2021, the most pronounced reductions in ASRs occurred in High-income Asia Pacific, followed by Western Europe, while other regions experienced more gradual declines.

Results of the decomposition analysis for vertebral fractures

The decomposition analysis revealed consistent global patterns in how population growth, aging, and epidemiological changes had influenced the disease burden of vertebral fractures (Fig. 6). Population growth and aging contributed to higher prevalence, incidence, and YLD, while epidemiological changes partially offset these increases. In men, population growth was the dominant factor behind rising prevalence, incidence, and YLD. Whereas, in women, aging primarily fuelled the increase in incidence and YLD, and population growth contributed most to prevalence. Across SDI regions, aging was the principal driver of rising ASPR and ASYR, followed by population growth. However, in Low, High-middle, and High SDI regions, population growth was the primary determinant of increasing ASIR. The epidemiological changes had led to a decline in ASYR in High-Middle and High SDI regions, alongside reductions in ASPR across High-Middle, High, and Low-Middle SDI regions, and a decrease in ASIR in Low, Low-Middle, High-Middle, and High SDI regions. In contrast, other SDI regions had experienced a rising disease burden as a consequence of this shift.

Forecast analysis results for vertebral fractures

Predictive analytics indicated that by 2050, the global ASPR of vertebral fractures would decline to 49.3 (95% CI: 45.9–53.8) per 100,000 (Fig. 7a), while the ASIR and ASYR would drop to 68.5 (95% CI: 62.2–78.3) and 4.9 (95% CI: 4.6–5.4) per 100,000 (Fig. 7d, g). Gender-specific projections suggested a decrease in ASPR to 53.0 (95% CI: 46.8–59.6) per 100,000 in men and 46.7 (95% CI: 43.2–51.5) per 100,000 in women (Fig. 7b, c). Correspondingly, ASIR was expected to reach 78.7 (95% CI: 68.3–92.0) per 100,000 in men and 60.4 (95% CI: 51.6–70.2) in women (Fig. 7e, f), while ASYR would decline to 5.4 (95% CI: 4.8–6.0) per 100,000 in men and 4.7 (95% CI: 4.3–5.2) per 100,000 in women (Fig. 7h, i).

Discussion

This study analyzed the global prevalence, incidence, and YLDs of vertebral fractures from 1990 to 2021, along with their temporal trends. For the first time, we also provided projections extending from 2022 to 2050. Although ASRs declined over the study period, the absolute number of affected individuals rose from 5.9 (95% UI: 4.6–7.4) million in 1990 to 7.5 (95% UI: 5.8–9.7) million in 2021. Age-stratified analyses revealed that ASRs increased with advancing age, with male rates exceeding female rates until women surpassed men between the ages of 60 and 70. A decomposition analysis identified population growth and aging as primary drivers of the rising burden, whereas epidemiological changes mitigated its impact. Falls emerged as the predominant cause across all age groups, followed by road injuries. Looking ahead, our projections indicated a global decline in vertebral fracture burden for both sexes by 2050, highlighting the efficacy of current preventive measures.

Vertebral fractures are a global health concern, contributing significantly to disability and mortality. Vertebral fractures are more frequently observed in young and middle-aged men compared to women, largely attributable to their broader participation in high-energy physical activities and lifestyles encompassing behavioral risk factors such as smoking [16, 17]. Moreover, the screening rate for osteoporosis is significantly higher among women than men [18], potentially leading to underdiagnosis of fractures in the male population. Intriguingly, a reversal in age-standardized rates (ASRs) is observed among women aged 65–70 years, highlighting the complexity of sex-specific differences—a finding consistent with previous studies [3]. Decomposition analyses in the present study further indicate that population ageing serves as a principal driver of the increased incidence and years lived with disability (YLD) among women. This may be attributed to the precipitous decline in estrogen levels following menopause, which accelerates bone loss through an elevated annual rate of bone mineral density reduction, thereby heightening the risk of osteoporosis and

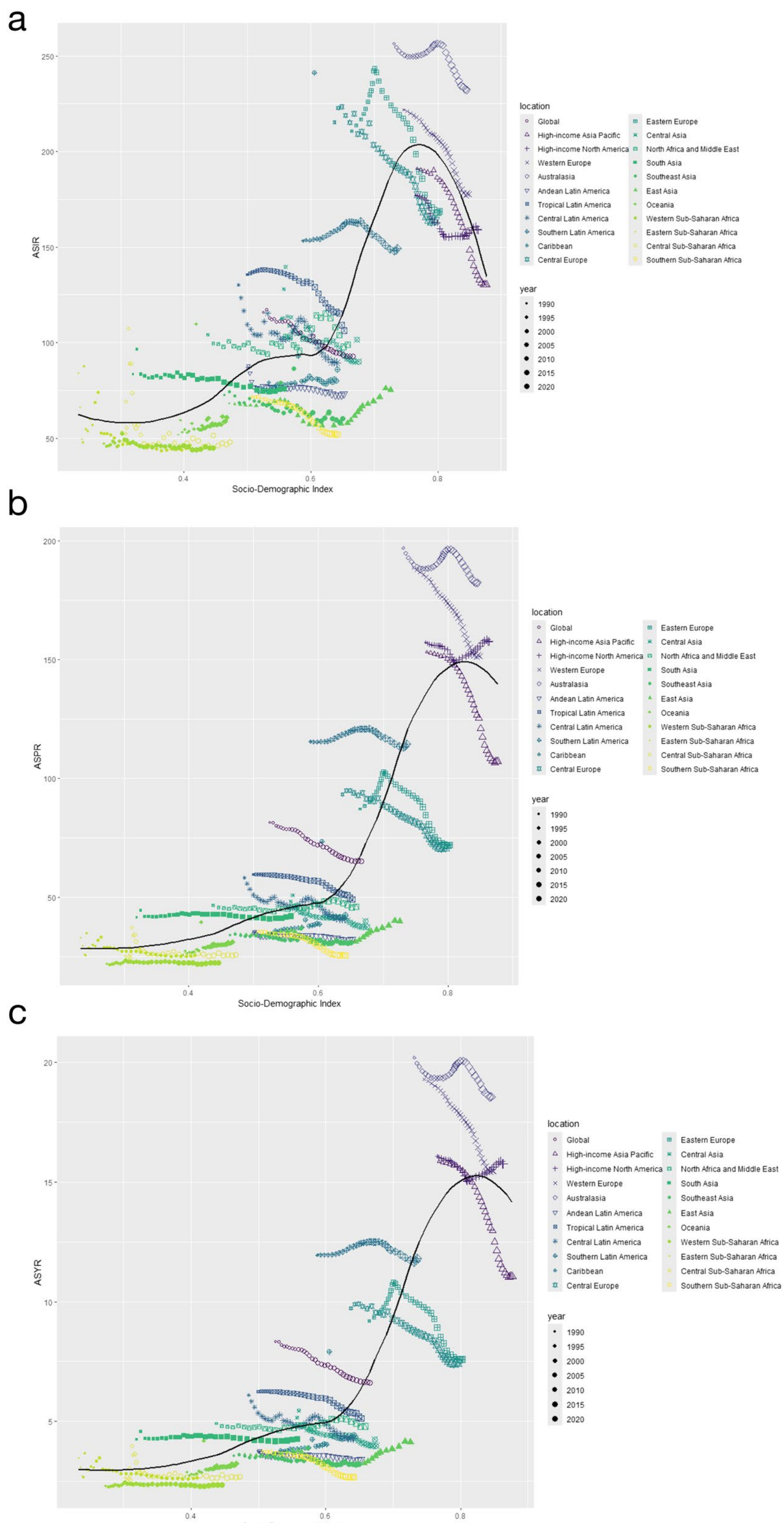

Fig. 5. SDI analysis results. **a** Incidence across 21 regions; (**b**) Prevalence across 21 regions; (**c**) YLDs across 21 regions. YLD, years lived with disability.

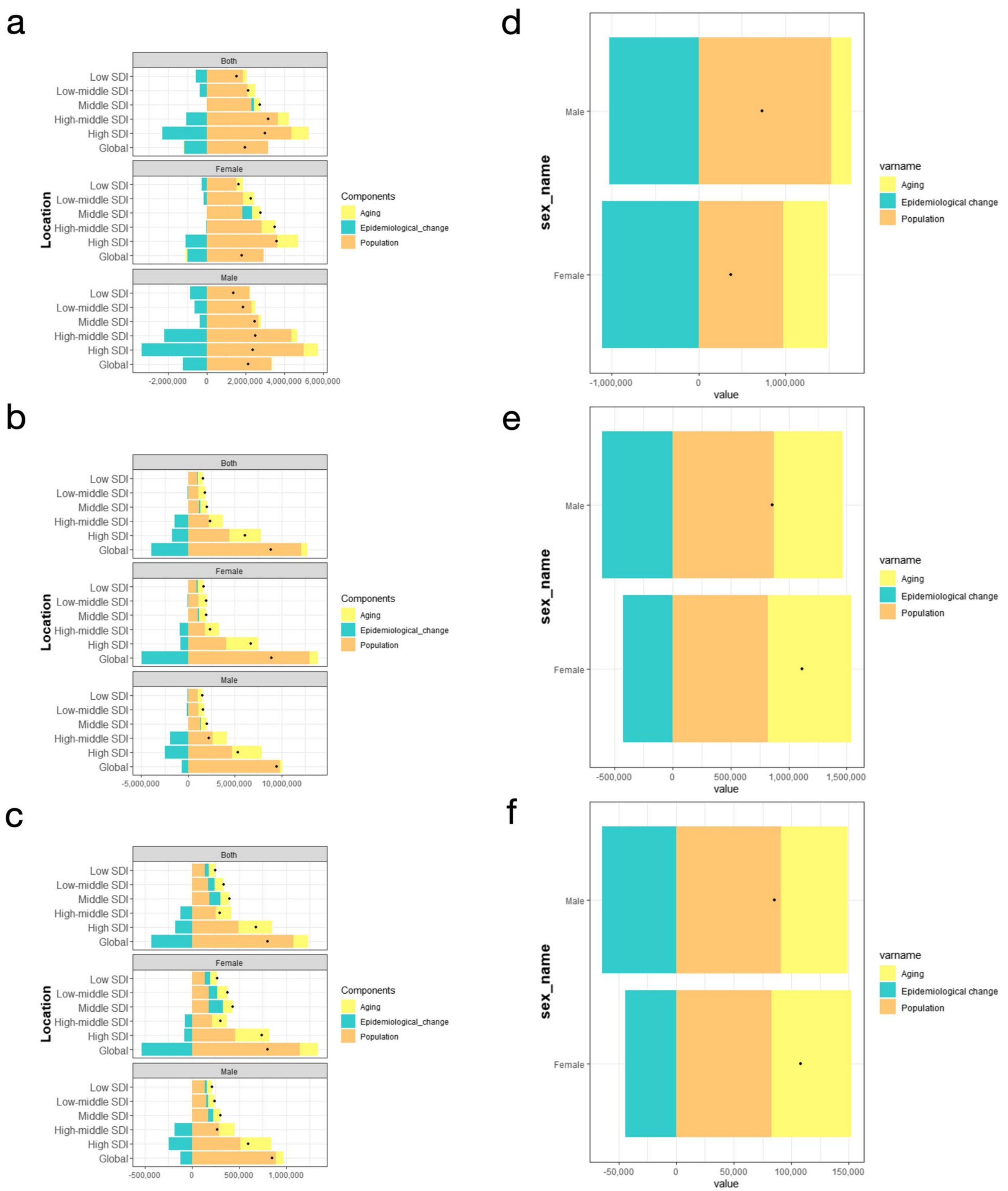

Fig. 6. Decomposition analysis of the global disease burden. **a** Incidence across different SDI regions; (**b**) Prevalence across different SDI regions; (**c**) YLDs across different SDI regions. (**d**) Incidence by sex; (**e**) Prevalence by sex; (**f**) YLDs by sex. YLD, years lived with disability.

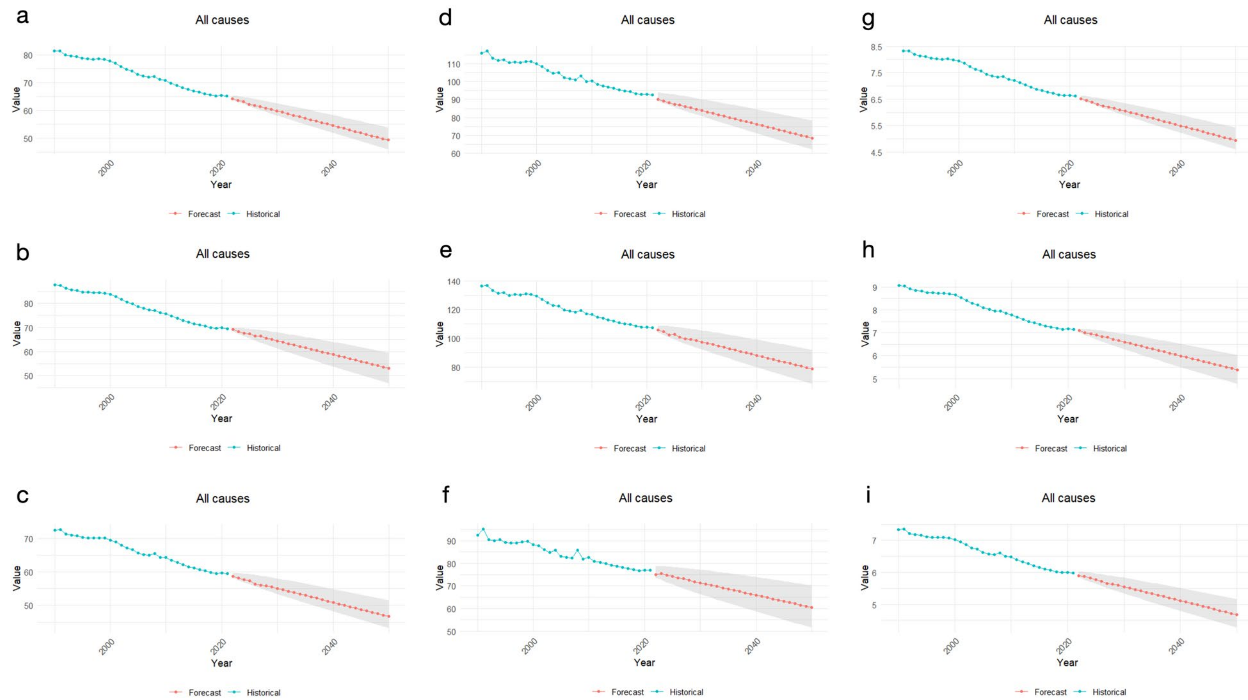

Fig. 7. Predicted trends for vertebral fractures incidence, prevalence and YLDs. **a** Global age standardized prevalence rate; (**b**) Age standardized prevalence rate in meles; (**c**) Age standardized prevalence rate in femeles; (**d**) Global age standardized incidence rate; (**e**) Age standardized incidence rate in meles; (**f**) Age standardized incidence rate in femeles; (**g**) Global age standardized YLD rate; (**h**) Age standardized YLD rate in meles; (**i**) Age standardized YLD rate in femeles. YLD, years lived with disability.

fracture susceptibility [19]. In China, women over the age of 40 are four to five times more likely to develop osteoporosis than their male counterparts, with postmenopausal women constituting the primary demographic affected by osteoporotic fractures [20–22]. Furthermore, the risk of sports-related injuries during recreational activities rises with age among women, with vertebral fractures frequently associated with such injuries. A study on recreational fractures in the U.S. (2003-2022) found that horseback riding accounted for 44.4% of cervical and 74.7% of thoracic vertebral fractures in females [1]. The axial loading and compression forces inherent in these activities likely exacerbated fracture risk [23–25]. Overall, amid aging and sports-related injuries, robust preventive strategies were essential to reduce vertebral fractures and their disabling consequences in postmenopausal women. Moreover, GBD studies reported a notable incidence of vertebral fractures among children and adolescents, particularly in high-SDI countries (e.g., North America, Australia, Central and Eastern Europe) [3]. This might stem from higher participation in physically demanding activities and risk-prone behaviors, elevating fracture susceptibility in younger populations.

Vertebral fractures arise from various causes, including traumatic, pathological, and iatrogenic factors [26–28]. In younger individuals, high-energy injuries are the primary cause, while in the elderly, low-energy trauma, particularly falls, predominates [29–31]. Our study confirmed falls as the leading cause, aligning with prior GBD findings [28]. The risk of falling is significantly increased in the elderly due to physiological decline and the influence of drugs [32, 33]. Therefore, preventive measures should be strengthened, including calcium and vitamin D supplementation, physical exercise, and nursing support for patients with severe injuries [34, 35]. Additionally, improved osteoporosis management is crucial to lowering fracture-related disability and mortality [36].

In high-SDI regions such as Australia, Western Europe, and high-income North America, ASPR significantly exceeds that of low-SDI regions like Sub-Saharan Africa. From 1990 to 2021, ASRs generally declined with fluctuations. By 2021, a clear inverse relationship between ASPR and SDI emerged: High SDI regions had the highest ASPR of 131.7 (95% UI: 114.8–149.2) per 100,000, while Low SDI regions had the lowest at 33.5 (95% UI: 27.7–41.4) per 100,000. ASIR and ASYP trends mirrored those of ASPR, supporting the 2019 GBD report, which highlighted the positive correlation between SDI and both ASIR and ASYP. This phenomenon may be explained, in part, by the widespread promotion of sports culture in high-Socio-Demographic Index (SDI) regions, which has led to a surge in participation in energy-intensive activities, thereby elevating the risk of sports-related fractures [37]. Additionally, high-SDI regions may experience a latent structural imbalance in healthcare resource allocation, characterized by disproportionate investment in treatment relative to prevention. Although this mismatch may be temporarily obscured by economic growth, it poses a potential long-term public health threat by exacerbating the burden of chronic diseases. It is recommended that sports-related safety education be strengthened in high-Socio-Demographic Index (SDI) regions, alongside enhanced fall prevention and management programs in hospitals and long-term care facilities.

This study has several limitations. First, restricted access to original data is a key constraint. In some countries, incomplete disease records necessitate the use of predictive models, which may introduce bias due to data quality issues. Additionally, regional variations in diagnostic practices and screening accuracy could further bias the final dataset. Nonetheless, GBD 2021 adopts more advanced methodologies and a larger data pool compared to previous iterations, enhancing the precision and relevance of disease burden assessments.

Conclusions

As global populations expand and age, vertebral fractures—particularly among the elderly—have emerged as a growing health burden, with falls identified as the primary risk factor. Over the past three decades, the incidence, prevalence, and YLDs associated with vertebral fractures have risen, even as ASRs declined between 1990 and 2021. This paradox of"falling rates yet rising counts"highlights the need for a comprehensive response: (1) Prevention: Expand community-based fall-prevention initiatives, such as age-friendly home modifications, prioritizing high-risk regions with limited healthcare access; (2) Clinical management: Establish multidisciplinary collaborations among orthopaedics, geriatrics, and rehabilitation services to standardize osteoporosis screening and treatment pathways; (3) Policy support: Develop tiered healthcare financing mechanisms to alleviate the burden on low-income populations, and enhance bone health surveillance systems to monitor regional disparities. Only through an integrated approach can the escalating burden driven by demographic shifts be effectively mitigated.

Abbreviations

ASR	age-standardized rate
ASIR	age-standardized incidence rate
ASPR	age-standardized prevalence rate
YLD	years lived with disability
GBD	Global Burden of Disease
EAPC	Estimated annual percentage change
UI	uncertainty interval
CI	confidence interval
ASYR	age standardized YLD rate
SDI	socio-demographic index
ARIMA	Autoregressive Integrated Moving Average
XG-Boost	Extreme Gradient Boosting
LSTM	Long Short-Term Memory
ICD	International Classification of Diseases
AR	Autoregressive
I	Integrated
MA	Moving Average

Acknowledgements
We thank all epidemiologists, statisticians or other scientists who contributed their time, and work to the management of the GBD study rounds.

Authors' contributions
Conceptualization and design of the study, as well as data acquisition: HL, ZH; Acquisition of data: ZH, HL, SS, HC; Data analysis and interpretation: HL, ZH, TL, MC; Drafting the manuscript: HL; Revising the manuscript critically for important intellectual content: ZH, YY, FW.

Funding
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors, and no material support of any kind was received.

Data availability
Data used for the analyses are publicly available from http://ghdx.healthdata.org/gbd-results-tool. This public link to the database of GBD study is open, and the use of data does not require additional consent from IHME.

Declarations

Ethics approval and consent to participate
Not required.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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Received: 3 April 2025 Accepted: 11 May 2025
Published online: 17 May 2025

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