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The Epidemiological Transition of Falls in China a Comparative Policy Framed Analysis and Projection Using GBD 2023 Data

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Abstract

Background Driven by rapid population aging and epidemiological transition, falls in China have become a major public health challenge. Using the latest Global Burden of Disease (GBD) 2023 data, this study characterizes the long-term trends, drivers, and future trajectory of falls in China and proposes an actionable intervention roadmap through a novel health-system-response typology.

Methods We applied a multi-model integrated framework to GBD 2023 data (1990-2023). Joinpoint regression identified trends and turning points in age-standardized rates. Decomposition analysis quantified the contributions of population aging, growth, and epidemiological change, while age-period-cohort modeling disentangled period and cohort effects. Bayesian APC (BAPC) and Nordpred models projected disability-adjusted life years to 2050. International comparisons with Japan, the United States, and Brazil were framed by their health-system characteristics.

Results From 1990 to 2023, China's fall burden shifted from mortality-dominant to disability-dominant. Age-standardized rates for prevalence and incidence rose by 25.9% and 35.7%, while mortality fell by 18.5%. Decomposition identified aging as the primary driver (greater in females); age-period-cohort analysis revealed a favorable period window (2007-2016). Low bone mineral density became the leading risk factor (population attributable fraction 26.5%). International comparisons revealed four distinct trajectories. Both models projected continued increases in age-standardized DALY rates through 2050, whereas total DALY numbers remained broadly stable.

Conclusions China is at a critical window of accelerating fall burden. We propose a phased, gender-sensitive "Three-Step" intervention roadmap aligned with the "Healthy China 2035" and "Active Response to Population Aging" strategies, providing quantitative evidence and a replicable methodological approach for fall prevention.

Keywords: falls, epidemiology, Global Burden of Disease Study, gender disparities, China

List of abbreviations

ASR: age-standardized rate; DALY: disability-adjusted life year; DALYs: disability-adjusted life years; YLL: years of life lost; YLD: years lived with disability; PAF: population attributable fraction; APC: age-period-cohort; BAPC: Bayesian age-period-cohort; AAPC: average annual percent change; LTCI: long-term care insurance; UI: uncertainty interval; GBD: Global Burden of Disease.

1 Introduction

Falls are defined by the World Health Organization as incidents in which a person unintentionally comes to rest on the ground, floor, or a lower level, and they rank as the second leading cause of accidental death worldwide [1,2]. As one of the most common injury mechanisms, falls persistently threaten health and longevity across all age groups. Among younger, otherwise healthy individuals, falls can result in lifelong disabilities, including spinal cord injury or traumatic brain injury, often requiring sophisticated

surgical interventions [3]. In older adults, the adverse effects of falls are frequently amplified by concurrent conditions such as reduced bone density, osteoporosis, or the use of antiplatelet and anticoagulant therapies [4,5]. Globally, falls pose a substantial public health challenge, imposing heavy burdens on health systems and incurring substantial medical care costs [6]. An estimated 37.3 million severe falls occur worldwide each year, resulting in approximately 17 million disabling injuries and 684,000 deaths, with over 80% of these incidents occurring in low- and middle-income countries [2].

In China, falls represent a major threat to population health and well-being. In 2019, approximately 9.76 million severe falls were recorded among individuals aged 60 years and older, leading to a cumulative loss of more than 3.18 million DALYs [7]. This number is expected to rise as the population continues to age. National statistics indicate that around 40 million older adults in China experience at least one fall annually, with direct medical costs exceeding 5 billion yuan each year [8]. Despite this growing burden, research on falls in China remains relatively limited; existing studies have highlighted substantial health and economic impacts but lack systematic, timely, and internationally comparable analyses [9,2,7].

A critical examination of the existing literature reveals three important limitations. First, the available data are not sufficiently timely. Most studies are based on GBD 2019 or earlier data and fail to capture structural changes in fall patterns, healthcare access, and rehabilitation services that occurred during and after the COVID-19 pandemic. Second, international comparisons remain overly broad. Existing cross-country analyses are largely confined to global or G20-level comparisons, lacking in-depth comparisons with reference countries selected on the basis of developmental stage, aging models, and cultural backgrounds. Different countries exhibit considerable heterogeneity in fall burden trajectories, risk factor attribution, and injury patterns; the absence of typology-based comparative studies limits the contextual translation of international experience. Third, the policy narrative lacks systematization and foresight. Previous studies have not constructed a complete evidence chain from "burden identification—risk attribution—intervention strategy," nor have they aligned their findings with national long-term development strategies such as "Healthy China 2035" and "Active Response to Population Aging," or with WHO initiatives like the "Decade of Healthy Ageing (2021–2030)."

While several previous studies have described the burden of falls in China using earlier GBD data [7,9], the present study advances the field in three specific ways. First, it extends the analysis to 2023, capturing post-pandemic changes in healthcare access, rehabilitation service utilization, and fall patterns that may have altered the epidemiological landscape. Second, it introduces a health-system typology-based international comparison—grounded in long-term care insurance models, healthcare financing structures, and urbanization trajectories—that generates context-specific policy lessons rather than generic, one-size-fits-all recommendations. Third, and most importantly, it translates epidemiological findings into a phased, assessable intervention roadmap directly aligned with China's national development strategies, addressing the persistent gap between burden description and policy action identified in prior work. This policy-focused translational approach distinguishes the present study from earlier GBD-based descriptive analyses and responds directly to calls for burden of disease research to inform evidence-based legislation and precision public health.

To address these gaps, this study uses the latest GBD 2023 data with the following objectives. First, we aim to update long-term trends in the burden of falls in China from 1990 to 2023, capturing post-pandemic changes, and to project the burden to 2050 using Bayesian APC (BAPC) and Nordpred models. Second, we conduct in-depth comparative analyses with Japan, the United States, and Brazil—countries selected on the basis of their developmental stage, aging models, and cultural contexts—to examine differences in burden levels, risk factor attribution, injury patterns, and prevention experiences. Third,

we apply decomposition analysis and APC models to quantify the independent contributions of aging, population growth, and epidemiological changes, while identifying gender- and age-specific high-risk groups. Fourth, we construct a "burden-risk-intervention" narrative chain and propose a phased, assessable intervention roadmap grounded in international experience and China's national context, thereby providing evidence-based support for fall prevention strategies and aligning research with global aging and safety initiatives.

This study makes contributions at three levels. Methodologically, we employ a multi-model cross-validation framework (BAPC + Nordpred) to enhance the robustness of our projections, offering a replicable methodological approach for public health forecasting under data constraints. For the comparative framework, we establish an international comparison framework based on "health-system response typologies"—encompassing long-term care systems, healthcare financing models, and urbanization trajectories—to disentangle the heterogeneous drivers of fall burden changes across different socioeconomic pathways. For policy translation, we explicitly link epidemiological evidence with China's medium- and long-term national development strategies ("Healthy China 2035" and "Active Response to Population Aging") and propose an actionable, phased intervention roadmap, thereby bridging the gap between public health research and policy practice. Through these integrated analyses, this study aims to provide timely, internationally comparable, and methodologically innovative empirical support for fall prevention in China.

2 Methods

2.1 Data Source

This study utilized data from the Global Burden of Disease (GBD) 2023 study, which provides comprehensive health metrics updated annually through international collaboration and covers 88 risk factors, 371 diseases, and 288 causes of death and injuries across 204 countries and territories. For China, primary input data were derived from national censuses, Disease Surveillance Points systems, population surveys, the Chinese CDC's Cause of Death Reporting System, and systematic reviews assessing disease incidence and prevalence [10]. We extracted data on incidence, prevalence, mortality, years of life lost (YLLs), years lived with disability (YLDs), and DALYs for falls, along with their corresponding age-standardized rates (ASRs), from the Global Health Data Exchange (<https://vizhub.healthdata.org/gbd-results/>). All estimates were stratified by sex, age group, and year.

Risk factor data and population attributable fractions: Data on population attributable fractions (PAFs) for fall-related DALYs were extracted directly from the GBD 2023 Results Tool. In the GBD framework, PAFs are estimated for each risk-outcome pair using a comparative risk assessment approach that combines (1) the distribution of exposure to each risk factor by age, sex, location, and year; (2) the relative risk of the outcome given exposure; and (3) the counterfactual distribution of exposure (typically the theoretical minimum-risk exposure distribution). The PAF represents the proportion of DALYs that would be averted if exposure were reduced to the counterfactual level [11]. PAFs are estimated separately by age group, sex, location, and year. For this study, we extracted PAFs for all GBD risk factors attributable to falls for China, both sexes combined and sex-specific, from 1990 to 2023. Uncertainty intervals for PAFs were derived from the 95% uncertainty intervals provided in the GBD 2023 database, which propagate uncertainty from exposure estimates, relative risks, and counterfactual distributions using Monte Carlo simulation [12]. The reported PAFs represent the posterior mean estimates.

Treatment of uncertainty: All primary analyses (Joinpoint regression, decomposition, APC modeling, PAF extraction, and international comparison) were conducted using the posterior mean estimates from the GBD 2023 database. The 95% uncertainty intervals reported in the GBD database reflect the

uncertainty of the original burden estimates but were not formally propagated through the secondary analyses (e.g., decomposition, APC, or projection models). This is a recognized limitation of secondary analyses of GBD data and is discussed further in Section 4.8. Future studies could address this by repeating the analyses across GBD draws or by implementing probabilistic sensitivity analyses.

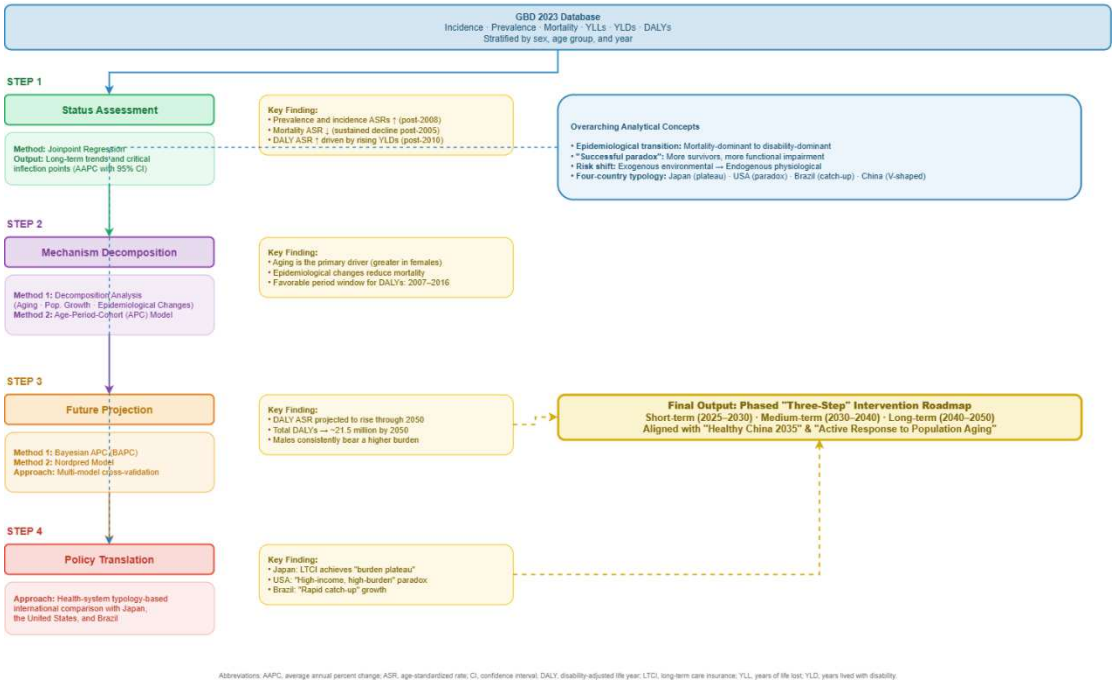
All statistical analyses were conducted using R software (version 4.4.2; R Foundation for Statistical Computing, Vienna, Austria) and Joinpoint regression software (version 5.4.0; National Cancer Institute, Bethesda, MD, USA). The BAPC analysis was performed using the BAPC package (version 0.0.36), and the Nordpred analysis was implemented through the nordpred package (version 1.1). Figures were generated using the ggplot2 package (version 3.5.1) in R. The analytical code and processed data used in this study are available from the corresponding author upon reasonable request. This study followed the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER) recommendations for reporting disease burden estimates [13].

2.2 Analytical Framework

To move beyond purely descriptive reporting and address the need for methodological innovation, we executed a four-step, integrated analytical pipeline (Supplementary Figure S1). Step 1 (Status Assessment) employed Joinpoint regression to identify long-term temporal trends and critical inflection points in ASRs. Step 2 (Mechanism Decomposition) applied decomposition analysis and APC modeling to disentangle the independent contributions of population aging, demographic growth, and epidemiological shifts, while simultaneously capturing period and cohort heterogeneity. Step 3 (Future Projection) utilized BAPC and Nordpred models in a cross-validation framework to project DALY burden to 2050, thereby enhancing the robustness of our forecasts. Step 4 (Policy Translation) incorporated a health-system typology-based international comparison to translate the empirical findings into a phased, actionable intervention roadmap aligned with national development strategies.

Supplementary Figure S1. Analytical framework for the epidemiological transition of falls in China.

Legend: The framework comprises four sequential steps: (1) Status Assessment using Joinpoint regression to identify long-term trends and inflection points in age-standardized rates; (2) Mechanism Decomposition using decomposition analysis and age-period-cohort modeling to disentangle the independent contributions of aging, population growth, and epidemiological changes; (3) Future Projection using BAPC and Nordpred models in a multi-model cross-validation framework to project DALY burden to 2050; and (4) Policy Translation using a health-system typology-based international comparison to inform a phased, assessable intervention roadmap aligned with China's national strategies. Key conceptual threads—epidemiological transition, the "successful paradox," the exogenous-to-endogenous risk shift, and the four-country typology—are summarized in the right panel. DALY, disability-adjusted life year; APC, age-period-cohort; BAPC, Bayesian age-period-cohort; LTCI, long-term care insurance.



2.3 Joinpoint Regression Analysis

We assessed long-term secular trends in fall burden by calculating the average annual percent change (AAPC) with 95% confidence intervals (CIs) using Joinpoint regression software (version 5.4.0; National Cancer Institute, USA) [14,15]. This approach partitions the time series into distinct segments, fitting a log-linear model to each segment and detecting statistically significant changes in trends via permutation tests [14,15]. The AAPC, derived as a weighted average of the segment-specific annual percent changes, was used to summarize the overall trend. A positive AAPC with a lower bound of the 95% CI above zero signified a significant increase in the ASR, whereas a negative AAPC with an upper bound below zero indicated a significant decrease.

2.4 Decomposition Analysis

We performed decomposition analysis to quantify the independent contributions of three key demographic drivers—population growth, population aging, and epidemiological changes—to the total change in fall-related prevalence and mortality from 1990 to 2023. This method estimates the contribution of each factor while holding the other two constant at their baseline values [16]. By partitioning the absolute change in total case numbers and deaths, this approach allowed us to isolate the specific impact of the demographic transition (particularly the aging population) from broader epidemiological improvements or deteriorations.

2.5 Age-Period-Cohort Modeling

To investigate the independent, non-linear effects of age, time period, and birth cohort on fall-related mortality and DALY rates, we employed an age-period-cohort (APC) model [17,18]. The following methodological details are specified:

Age range and grouping: Data were organized into consecutive five-year age groups from 0–4 years to 95+ years (21 groups). Period groups were defined in five-year intervals from 1990–1994 through 2020–2023 (the final period 2020–2023 was a four-year interval owing to the study endpoint). Birth cohorts were constructed by subtracting the age group midpoint from the period midpoint, yielding cohorts from approximately 1895 to 2015.

Reference categories: The median age group (45–49 years), the median period group (2005–2009),

and the median birth cohort (1955–1959) were designated as reference categories. When the number of categories was even, the lower median was selected as the referent [19].

Model specification and constraints: The APC model employed a log-linear framework incorporating additive effects of age, period, and cohort. Because the three temporal variables are linearly dependent (age + period − cohort = constant), the model is not identifiable without constraints. We adopted the standard approach of constraining the linear component of the cohort effect to zero, thereby attributing the linear trend to age and period effects, while cohort effects are estimated as non-linear deviations from this trend [18]. Estimable functions (age, period, and cohort effects) were derived using the R package provided by the Biostatistics Branch of the National Institutes of Health, USA [19].

Treatment of the incomplete 2020–2023 period: The final period (2020–2023) was a four-year interval rather than a standard five-year interval. To account for this, the person-year denominators for this period were adjusted accordingly, and the period effect for 2020–2023 was estimated relative to the preceding full five-year period (2015–2019). In sensitivity analyses, we excluded the 2020–2023 period and found that the overall trends were unchanged (results not shown).

Interpretation of the favorable period window (2007–2016): The period effects estimated from the APC model represent the log-linear deviation of each five-year period from the reference period (2005–2009), after adjusting for age and cohort effects. The favorable window we identified corresponds to the period groups 2005–2009 and 2010–2014 (and extending into 2015–2019), which collectively span approximately 2007–2016. We have clarified this in the Results section.

2.6 Projection Modeling

We adopted a multi-model strategy to project the future burden of falls, cross-validating results from two distinct methodological approaches to enhance forecast reliability. First, we implemented the BAPC model, an extension of conventional generalized linear models that integrates Bayesian principles to dynamically account for age, period, and cohort variations [20]. The BAPC model was executed using the BAPC package (version 0.0.36) in R software (version 4.4.2, <http://www.r-project.org/>). This approach is particularly adept at handling sparse data and providing credible intervals for future predictions. Second, as a sensitivity analysis, we used the Nordpred model, which projects future disease burden by analyzing trends and demographic shifts, explicitly accounting for generational impacts and structural population changes [21]. The Nordpred APC model was implemented through the nordpred package (version 1.1). Consistency between the BAPC and Nordpred projections was interpreted as providing preliminary support for the direction of the projected trends.

2.7 International Comparative Strategy

To contextualize China's fall burden trajectory within diverse developmental and health-system contexts, we conducted a comparative analysis with Japan, the United States, and Brazil. These countries were purposively selected to represent distinct archetypes: Japan (a super-aged society with a mature long-term care insurance system), the United States (a high-income country with a fragmented healthcare system and high chronic disease burden), and Brazil (a BRICS nation undergoing rapid urbanization and demographic transition, sharing similar developmental status with China). We compared age-standardized DALY rates across these countries from 1990 to 2023, anchoring our discussion in the specific health-system responses (e.g., community-based integrated care, preventive service coverage, and post-fall acute care efficiency) characteristic of each setting.

3 Results

3.1 Secular Trends and the Epidemiological Transition

From 1990 to 2023, China experienced a substantial increase in the absolute burden of falls. Total prevalent cases reached 455.7 million in 2023 (a 105.8% increase from 1990), incident cases totaled 144.1 million (+40.8%), and fall-related deaths numbered 139,484 (+97.4%). The all-age DALYs reached 21.7 million person-years, representing a 68.8% increase over the study period. Males consistently accounted for a higher proportion of the burden across all indicators compared with females (Table 1).

However, the ASRs revealed a profound and divergent trajectory that defines the epidemiological transition of falls in China (Figure 1). Between 1990 and 2023, ASRs for prevalence and incidence increased by 25.9% and 35.7%, respectively, while the ASR for mortality declined by 18.5%. Similarly, the ASR for YLLs decreased substantially (−37.6%), whereas the ASR for YLDs increased by 15.0%. The DALYs ASR showed a modest net increase of 1.9%, masking the underlying compositional shift. This contrasting pattern—rising non-fatal burden alongside declining fatal burden—signals a fundamental transition from a mortality-dominant to a disability-dominant fall burden profile.

Joinpoint regression analyses further delineated the temporal dynamics of this transition (Figures 2 and 3). Prevalence and incidence ASRs exhibited highly synchronized movements: slow increases from 1990 to 2003, a brief decline during 2003–2008, and then sustained, accelerated increases from 2008 onward. This suggests that non-fatal fall-related health issues have become increasingly prominent since the late 2000s. In contrast, mortality ASR declined during 1990–1994, rose significantly during 1999–2005, and then entered a sustained, uninterrupted decline from 2005 through 2023, reflecting improvements in acute care and trauma management. The overall DALYs ASR decreased until 1999, stabilized until 2005, slightly declined until 2010, and then increased continuously after 2010. The post-2010 increase in DALYs was driven almost entirely by rising YLDs, confirming that the growing burden of long-term disability from falls has outpaced reductions in premature mortality.

Table 1 Descriptive analysis of fall burden in China, 1990 vs 2023

Legend: Summary of all-age numbers (in thousands), all-age rates per 100,000, and age-standardized rates per 100,000 for fall-related incidence, prevalence, deaths, YLLs, YLDs, and DALYs in China in 2023, with percentage changes from 1990 to 2023. Data are presented for males, females, and both sexes combined, with 95% uncertainty intervals (UI) in parentheses. Age-standardized rates increased for prevalence (+25.86%), incidence (+35.74%), and YLDs (+15.04%), while mortality (−18.51%) and YLLs (−37.61%) decreased; DALYs ASR showed a slight increase (+1.90%). Males consistently had higher burden than females across all indicators.

Measure	Sex	All-ages number in thousands,2023,n (95%,UI)	All-ages number changes 1990-2023,(%)	All-ages rates per 100,000 people,2023(95%,UI)	All-ages rates changes, 1990-2023,(%)	Age-standardized rates per 100,000 people,2023(95%,UI)	Age-standardized rates changes,1990-2023,(%)
Incidence	Male	90512777.62(79197841.25,102253982.10)	41.49	12360.09 (10814.97, 13963.43)	17.41	13784.77 (11925.23, 15864.80)	38.68
	Female	53571982.11(46289099.74, 61791381.95)	39.60	7671.26 (6628.38, 8848.24)	14.24	8592.67 (7257.60, 10186.95)	29.80
	Both	144084759.70(125832457.50,163806612.90)	40.78	10071.31 (8795.50, 11449.84)	16.03	11340.04 (9763.44, 13209.50)	35.74
Prevalence	Male	279278849.10(246642543.40,320144586.00)	106.29	38137.30 (33680.61, 43717.78)	71.18	30607.89 (26864.70, 35177.08)	28.86
	Female	176445754.40(155997889.60,203874540.10)	105.00	25266.21 (22338.17, 29193.89)	67.76	19500.96 (17072.46, 22800.92)	21.63
	Both	455724603.50(403026692.60,523797029.70)	105.79	31854.48 (28170.98, 36612.65)	69.61	25171.11 (22161.57, 29145.80)	25.86
Deaths	Male	82648.65(46990.33,108633.26)	78.32	11.29 (6.42, 14.83)	47.97	9.02 (5.20, 11.97)	-15.18
	Female	56835.45(29835.93,90221.84)	133.85	8.14 (4.27, 12.92)	91.36	5.12 (2.73, 8.05)	-21.66
	Both	139484.10 (79135.66, 189289.82)	97.42	9.75 (5.53, 13.23)	62.72	7.10 (4.10, 9.60)	-18.51

YLLs	Male	2227567.64(1331860.81, 2867785.03)	0.78	304.19 (181.87, 391.61)	-16.37	260.14 (162.29, 329.66)	-33.82
	Female	927257.70(526793.49, 1397333.67)	2.81	132.78 (75.43, 200.09)	-15.87	101.09 (60.49, 146.72)	-45.04
	Both	3154825.34(1944768.74, 4030135.81)	1.37	220.52 (135.94, 281.70)	-16.45	182.64 (116.65, 229.87)	-37.61
YLDs	Male	11172029.35(8016473.14, 15319365.00)	90.70	1525.61 (1094.70, 2091.96)	58.24	1216.81 (879.13, 1659.10)	19.00
	Female	7332055.16(5173219.83, 10034482.25)	90.10	1049.92 (740.78, 1436.89)	55.56	796.56 (559.89, 1100.41)	10.06
	Both	18504084.51(1319219 6.99, 25341185.78)	90.46	1293.41 (922.12, 1771.31)	56.98	1012.26 (724.55, 1387.03)	15.04
DALYs	Male	13399596.99(1005631 2.61, 17668618.30)	66.07	1829.80 (1373.25, 2412.76)	37.80	1476.95 (1122.39, 1946.76)	4.33
	Female	8259312.87(6143805.88, 11016988.46)	73.56	1182.70 (879.76, 1577.58)	42.03	897.65 (666.31, 1204.06)	-1.10
	Both	21658909.86(1640424 0.62, 28777316.74)	68.84	1513.93 (1146.63, 2011.49)	39.16	1194.90 (903.29, 1580.05)	1.90

Figure 1 presents sex-specific, all-age numbers and age-standardized rates for falls in terms of prevalence, incidence, and mortality from 1990 to 2023. All-age prevalent cases, incident cases, deaths, YLLs, YLDs, and DALYs all showed sustained increases. However, ASR trajectories diverged: prevalence and incidence rates generally increased, while mortality rates declined. YLLs ASR decreased significantly, YLDs ASR increased, and DALYs ASR showed a modest increase. Detailed sex- and year-specific trends for YLDs, YLLs, and DALYs are provided in Supplementary Figures 1A–C.

Figure 1 Trends in fall prevalence, incidence, and mortality in China, 1990–2023

Legend: Sex-specific trends in all-age numbers (left axis) and age-standardized rates (right axis) for falls-related prevalence (A), incidence (B), and mortality (C) in China from 1990 to 2023. All-age cases increased steadily for all three outcomes. Age-standardized prevalence and incidence rates rose gradually, whereas age-standardized mortality rates declined after the mid-2000s. Shaded areas represent 95% uncertainty intervals. Data source: GBD 2023.

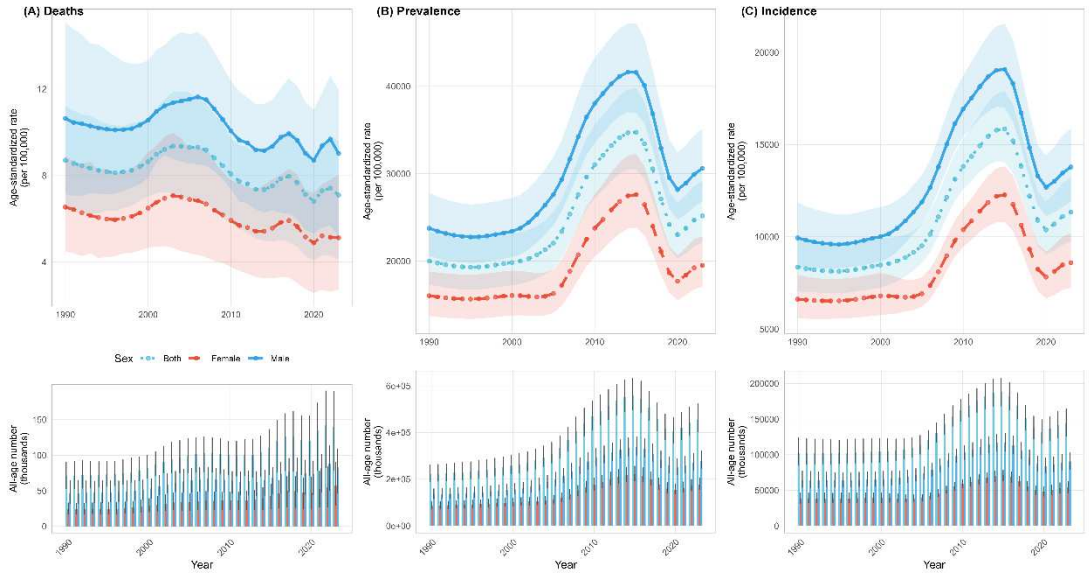


Figure 3 illustrates the evolution of overall disease burden. DALYs ASR steadily declined from 1990 to 1999, stabilized from 1999 to 2005, slightly decreased from 2005 to 2010, and then increased continuously from 2010 to 2023. YLDs ASR remained stable from 1990 to 1999, significantly declined from 1999 to 2005, slightly decreased from 2005 to 2010, and then rose continuously after 2010. YLLs ASR declined from 1990 to 1999, increased from 1999 to 2005, and then continuously declined from 2005 to 2023. The increase in DALYs was primarily driven by YLDs, reflecting the growing burden of long-term disability from falls since 2010. Sex-stratified analyses showed consistent trends across indicators (Supplementary Figures 2, 3).

Figure 2 Joinpoint regression trends of prevalence, incidence, and mortality ASRs

Legend: Joinpoint regression analysis of age-standardized rates (ASRs) for fall-related prevalence (A), incidence (B), and mortality (C) in China from 1990 to 2023. Prevalence and incidence showed slow increases from 1990–2003, brief declines during 2003–2008, then sustained increases after 2008. Mortality ASR declined during 1990–1994, slightly increased in 1994–1999, rose significantly in 1999–2005, then steadily declined from 2005 onward. Solid lines indicate observed ASRs; dashed lines represent fitted trends.

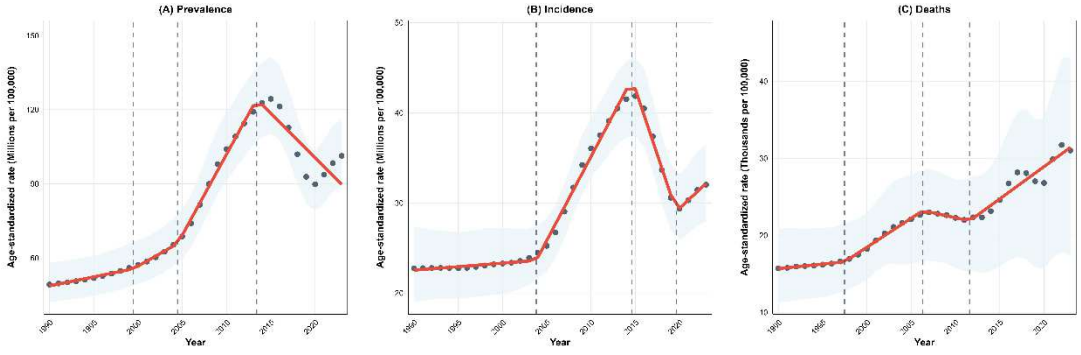
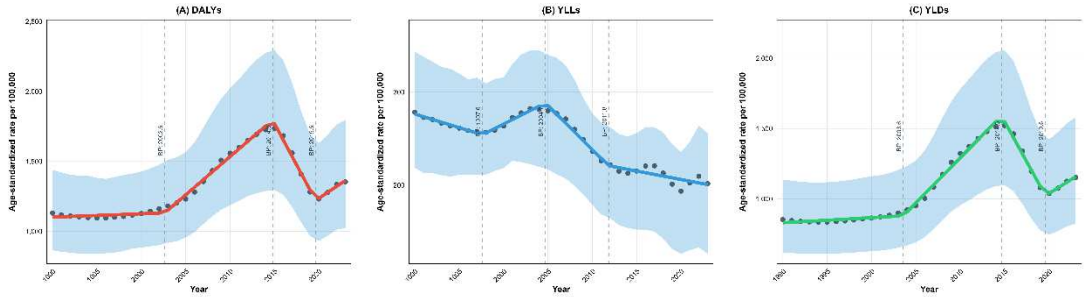


Figure 3 Joinpoint regression trends of YLLs, YLDs, and DALYs ASRs

Legend: Joinpoint regression analysis of age-standardized rates for fall-related years of life lost (YLLs), years lived with disability (YLDs), and disability-adjusted life years (DALYs) in China, 1990–2023. YLLs ASR declined from 1990–1999, increased in 1999–2005, then continuously declined after 2005. YLDs ASR was stable until 1999, declined sharply from 1999–2005, then rose continuously after 2010. DALYs ASR decreased until 1999, stabilized until 2005, slightly decreased until 2010, then increased after 2010, driven mainly by rising YLDs.



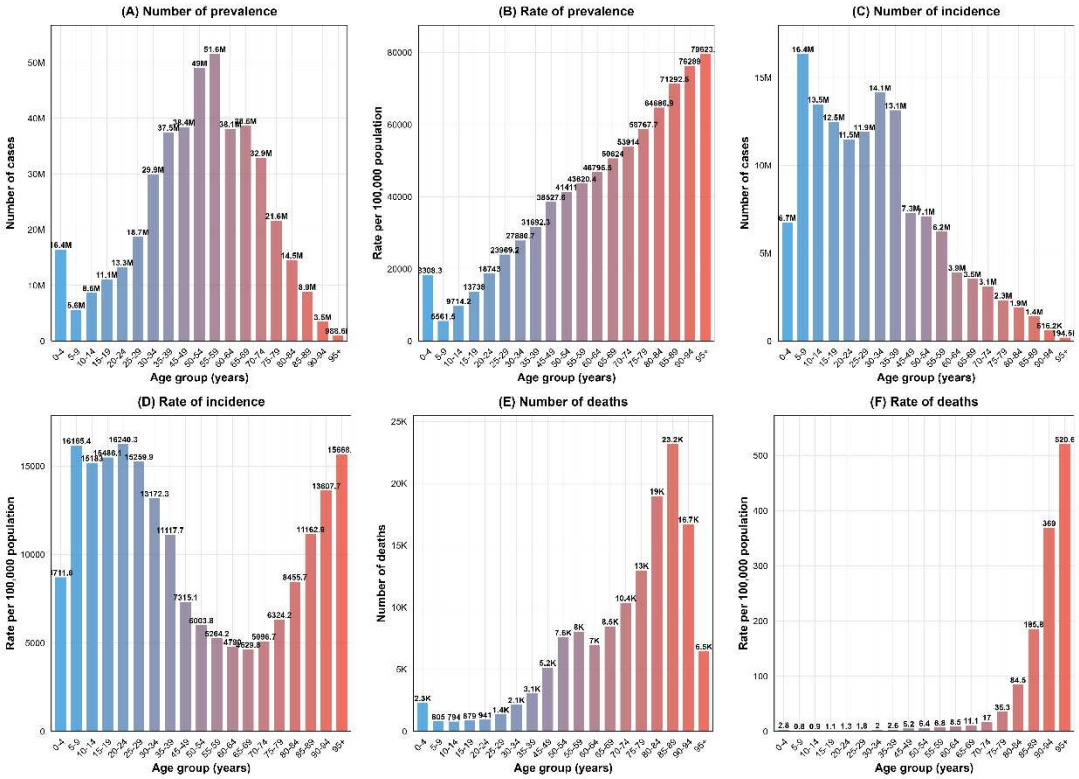
3.2 Age and Sex-Specific Patterns

The age distribution of fall burden revealed distinct patterns that underscore the differential vulnerabilities across the life course (Figure 4). In 2023, prevalent cases peaked in the 50–74 age group, whereas incident cases remained relatively stable across age groups but showed a male peak in the 25–39 age group, suggesting occupational and behavioral exposures among younger adults. Mortality rates increased sharply after age 75, with the highest rates observed in the 80–89 age group.

Strikingly, rates of prevalence, incidence, mortality, DALYs, YLDs, and YLLs all exhibited sharp increases after age 75, with particularly pronounced escalations in females. Total DALYs peaked in the 65–89 age group among females, whereas among males, DALYs peaked earlier in the 45–59 age group, driven largely by YLLs. YLLs displayed a U-shaped distribution, with a minor peak in children under 9 years and the highest numbers in females aged 75–94 years and males aged 30–59 years. YLDs, in contrast, peaked in the 50–74 age group for both sexes. These age- and sex-specific patterns underscore the need for tailored, age-appropriate prevention strategies that address both occupational risks in younger males and fall-related fragility in older adults, particularly older women.

Figure 4 Age and sex-specific fall burden in China, 2023Legend: Numbers (A, C, E) and rates per 100,000 population (B, D, F) of fall-related prevalence (A, B), incidence (C, D), and mortality (E, F) by age group and sex in China, 2023. Prevalence peaked in the 50 – 74 age group; incidence remained relatively stable across ages, with a male peak at 25 – 39 years; mortality increased sharply after age 75.

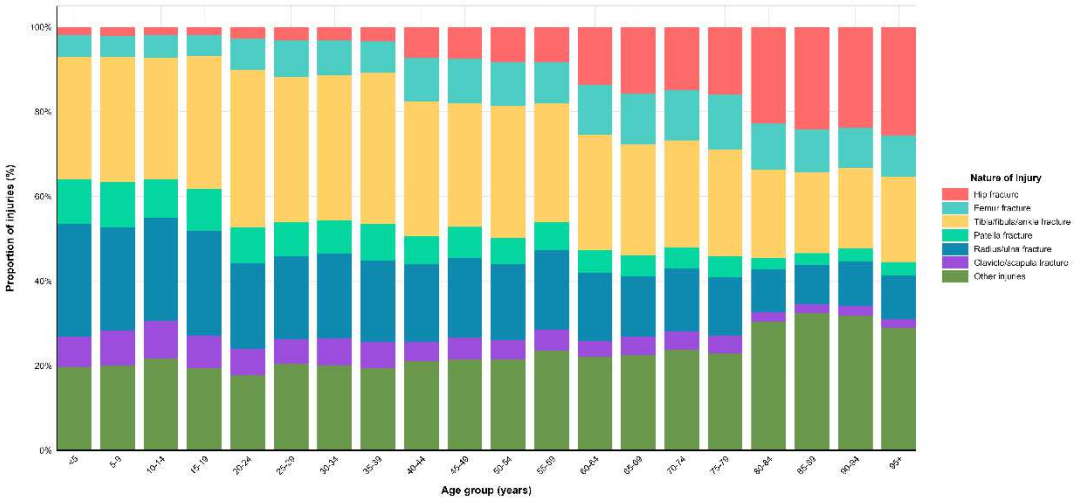
Males consistently had higher rates than females. Data source: GBD 2023.



3.3 Injury Patterns by Type

Analysis of injury types contributing to fall-related disability revealed important age-dependent variations (Figure 5). Averaged across 1990–2023, fractures of the lower extremity (patella, tibia, fibula, and ankle) were the predominant cause of disability across all age groups. However, the composition shifted markedly with age. Among children and adolescents (0–19 years), upper extremity fractures (radius/ulna) and clavicle/scapula fractures accounted for a notable proportion. In adulthood (20–59 years), tibia, fibula, and ankle fractures gradually became the dominant injury type. Critically, among older adults (60 years and above), hip fractures increased substantially, emerging as a major contributor to fall-related disability, while distal lower extremity fractures remained elevated, suggesting a higher risk of combined injuries in the older population. The rising prominence of hip fractures in older adults signals an urgent need for targeted bone health interventions.

Figure 5 Age-specific distribution of fall-related injury types, 1990–2023Legend: Proportion of fall-related disability (YLDs) attributable to different injury types by age group in China, averaged over 1990–2023. Lower extremity fractures (patella, tibia, fibula, ankle) dominated across all ages. Among children (0–19 years), upper extremity and clavicle/scapula fractures were notable. In adults (20–59 years), tibia/fibula/ankle fractures became dominant. In older adults (≥60 years), hip fractures increased markedly, becoming a major contributor to disability. Data source: GBD 2023.



3.4 Drivers of the Rising Burden: Decomposition and Age-Period-Cohort Effects

Decomposition analysis quantified the independent contributions of population growth, aging, and epidemiological changes to the increased burden (Figure 6). Aging emerged as the primary driver of both increased prevalent cases and deaths from 1990 to 2023, with a consistently greater contribution in females than in males. Epidemiological changes—reflecting shifts in age-specific incidence and survival—were the second-largest contributor to increased prevalence, with a slightly higher contribution in males. Population growth contributed positively but to a lesser extent. For mortality, while aging also drove increases in death counts, epidemiological changes showed a negative contribution (i.e., reducing deaths), and this effect was slightly stronger in males than in females. This finding suggests that improvements in healthcare and trauma management have partially offset the demographic pressures of aging, particularly for fatal outcomes.

APC modeling further elucidated the independent effects of age, period, and cohort on mortality and DALY rates (Figure 7). Age effects increased linearly with age, peaking in the oldest age groups for both outcomes, reinforcing the dominant role of biological aging. For period effects, mortality showed overall favorable (declining) trends from 1990 to 2023. For DALYs, period effects were generally unfavorable over the entire study period, except for a favorable window observed for both sexes during the period groups 2005–2009 and 2010–2014 (approximately 2007–2016). This window may correspond to a period of accelerated healthcare reform and improved trauma care capacity in China. Cohort effects showed overall fluctuating downward trends for both mortality and DALY rates from 1990 to 2023, suggesting that successive generations may have experienced lower cumulative risk exposure or better health status over time.

Figure 6 Decomposition analysis of changes in prevalence and mortality, 1990–2023

Legend: Decomposition of total change in fall-related prevalent cases (A) and deaths (B) in China from 1990 to 2023, partitioned into contributions from population growth, aging, and epidemiological changes. Aging was the primary driver for both outcomes, with a greater contribution in females than males. Epidemiological changes contributed positively to prevalence (slightly higher in males) but negatively to mortality (reducing deaths, slightly stronger in males). Population growth had a positive but smaller effect.

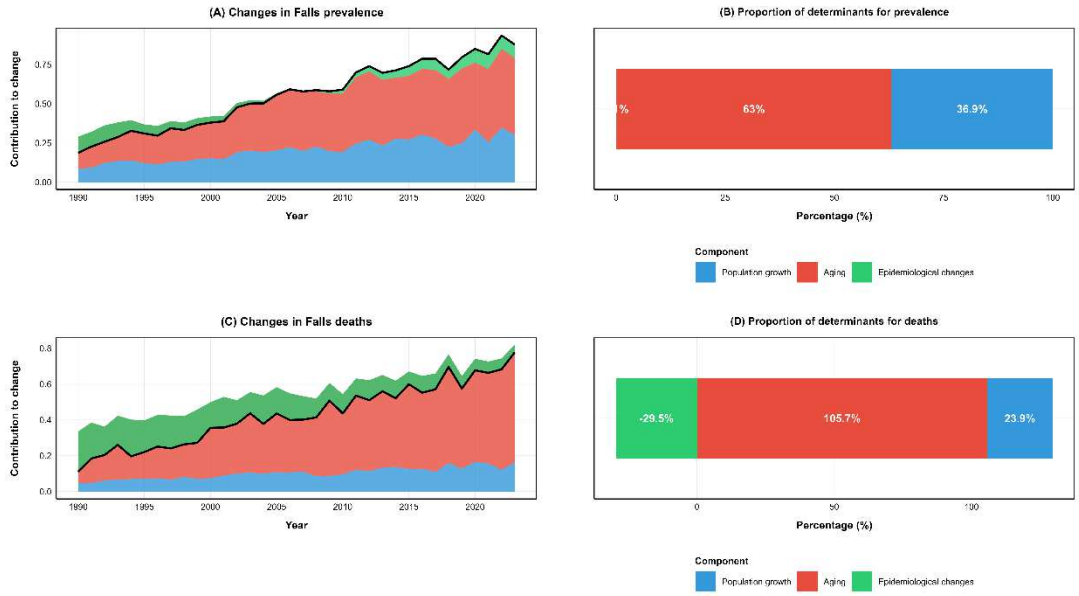
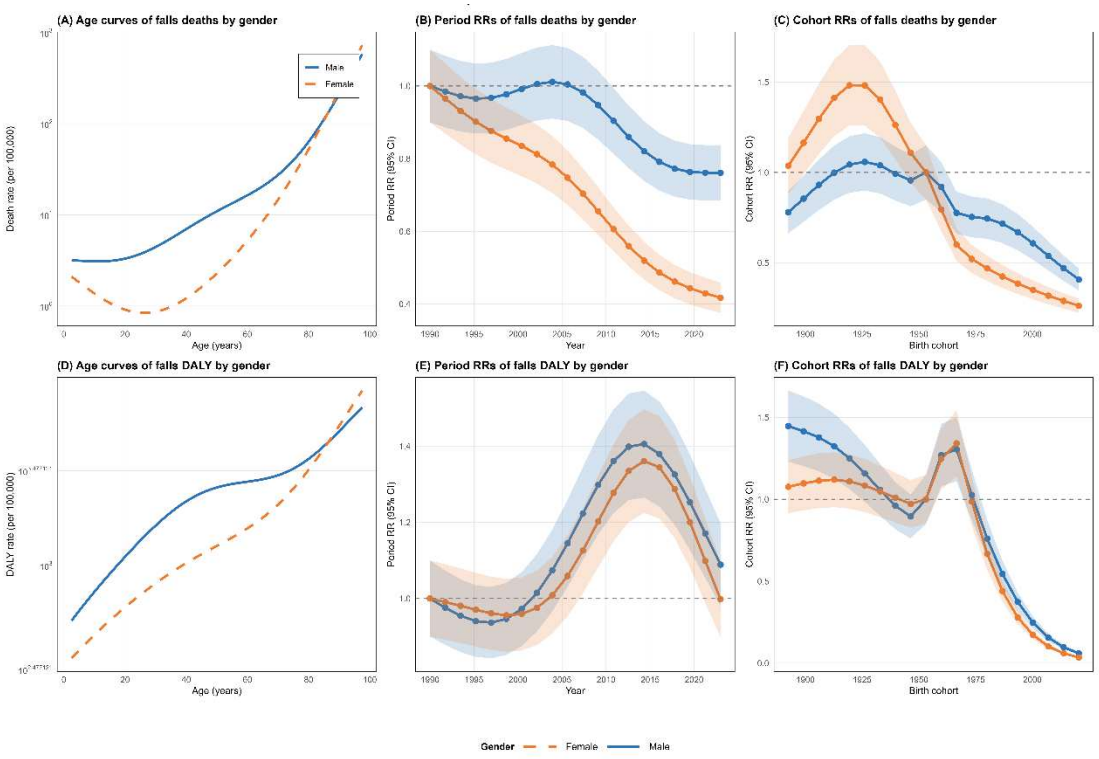


Figure 7 Age-period-cohort effects on fall mortality and DALY ratesLegend: Age-period-cohort (APC) model estimates for fall-related mortality (left) and DALY rates (right) in China, 1990–2023. Age effects increased linearly with age, peaking in the oldest groups. Period effects for mortality showed overall favorable (decreasing) trends, whereas period effects for DALYs were generally unfavorable, except for a favorable window during 2007–2016. Cohort effects showed fluctuating downward trends for both outcomes.



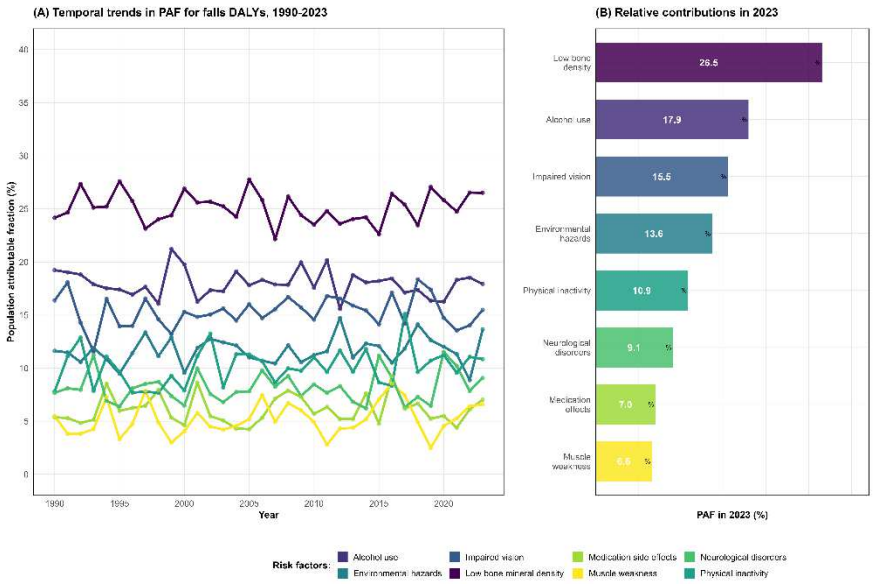
3.5 Evolution of Risk Factors

The population attributable fraction (PAF) for fall-related DALYs underwent marked changes from 1990 to 2023 (Figure 8). The most striking shift was the sustained increase in low bone mineral density (LBMD), which rose from approximately 18.4% in 1990 to 26.5% in 2023, making it the risk factor with

the highest PAF for fall-related burden. This increase reflects the growing impact of osteoporosis and age-related bone loss, particularly in the aging female population. In contrast, the PAF for occupational injuries declined continuously from approximately 34.2% in 1990 to 15.3% in 2023, indicating that workplace safety improvements have substantially reduced this traditional risk factor. Smoking remained a relatively stable contributor, accounting for less than 5% of the PAF throughout the study period, whereas alcohol use showed a gradual increase in PAF over time. In 2023, the top five risk factors by PAF were LBMD (26.5%, 95% UI: 22.1–30.8%), alcohol use (17.9%, 95% UI: 14.2–22.1%), vision impairment (15.5%, 95% UI: 12.8–18.3%), environmental hazards (13.6%, 95% UI: 10.9–16.4%), and physical inactivity (10.9%, 95% UI: 8.7–13.2%). The 95% uncertainty intervals for LBMD and occupational injuries did not overlap in 2023 (LBMD: 22.1–30.8%; occupational injuries: 12.1–18.6%), suggesting that the ranking difference is statistically distinguishable. However, because PAFs are not additive and reflect independent attributable fractions, these estimates should be interpreted as the proportion of DALYs attributable to each risk factor independently, rather than as mutually exclusive contributions. The change in the relative importance of LBMD compared with occupational injuries suggests a shift in the epidemiological profile of falls in China, with endogenous physiological vulnerabilities accounting for a larger attributable fraction of fall-related DALYs than exogenous environmental risks.

Figure 8 Trends in population attributable fractions (PAF) of major risk factors for falls

Legend: Population attributable fraction (PAF) of falls-related DALYs attributable to selected risk factors in China, 1990–2023. Low bone mineral density (LBMD) increased from ~18.4% in 1990 to 26.5% in 2023, becoming the leading risk factor. Occupational injuries declined from ~34.2% to 15.3% over the same period. Alcohol use, vision impairment, environmental hazards, and physical inactivity showed smaller or stable contributions. In 2023, the top five risk factors were LBMD (26.5%), alcohol use (17.9%), vision impairment (15.5%), environmental hazards (13.6%), and physical inactivity (10.9%).



3.6 International Comparison: Divergent Trajectories Across Health-System Archetypes

Comparative analysis of age-standardized DALY rates across China, Japan, the United States, and Brazil revealed four distinct trajectories that reflect different developmental stages and health-system responses (Figure 9).

China exhibited a "V-shaped" pattern: the ASR decreased from approximately 1,373/100,000 in 1990 to a low point around 2005–2010 (approximately 727/100,000), then rebounded sharply to approximately 1,195/100,000 by 2023. This unique U-shaped recovery signals the unintended consequences of population aging outpacing improvements in prevention and long-term care.

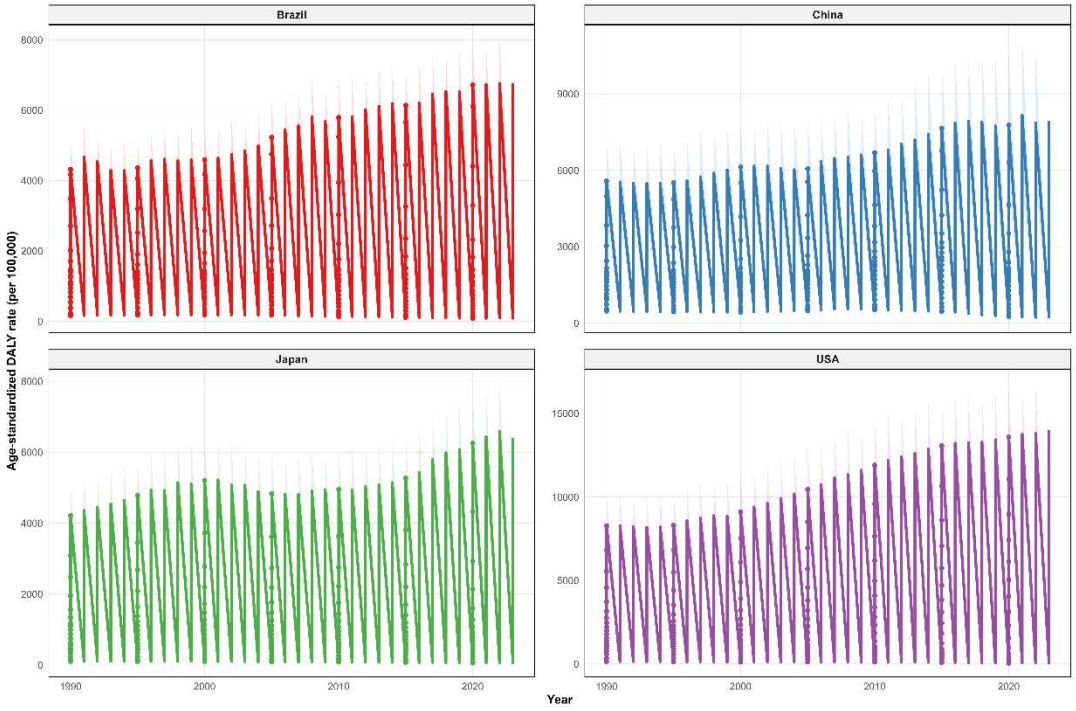
Japan showed an early increase followed by a plateau after 2000, stabilizing at approximately 367/100,000 by 2023. The stabilization coincides with the implementation of the LTCI system in 2000, which likely contributed to containing the aging-driven burden through community-based integrated care and environmental modifications.

The United States displayed a sustained, monotonic increase from approximately 500/100,000 in 1990 to approximately 570/100,000 in 2023—a "high-income, high-burden" paradox that suggests a fragmented healthcare system and high prevalence of chronic conditions may offset advances in acute care.

Brazil, starting from the lowest baseline (approximately 141/100,000 in 1990), exhibited the most rapid growth, reaching approximately 298/100,000 by 2023. This rapid catch-up pattern likely reflects infrastructure lags in urbanization and insufficient public health prevention systems during demographic transition.

Although formal statistical testing was not performed, the 95% uncertainty intervals for the four countries showed distinct patterns over the study period, with minimal overlap in the most recent decade. These divergent patterns provide critical policy lessons: Japan's experience demonstrates that systematic long-term care systems can curb aging-driven increases, while the US and Brazil trajectories caution that economic growth and medical advances alone are insufficient to automatically reduce fall burden without proactive, population-based prevention strategies.

Figure 9 International comparison of age-standardized fall DALY rates, 1990–2023Legend: Age-standardized DALY rates per 100,000 for falls in China, Japan, the United States, and Brazil from 1990 to 2023. China exhibited a "V-shaped" pattern: decreasing from ~1,373 in 1990 to a low around 2005–2010 (~727), then increasing to ~1,195 by 2023. Japan showed an early increase followed by a plateau after 2000 (~367 by 2023). The United States had a sustained monotonic increase from ~500 to ~570. Brazil, starting from the lowest baseline (~141 in 1990), showed the most rapid growth, reaching ~298 by 2023. Shaded areas: 95% uncertainty intervals.



3.7 Future Projections: Continued Growth Through 2050

Both the BAPC and Nordpred models consistently projected that China's fall-related DALYs ASR will continue to increase, whereas total numbers are projected to remain broadly stable through 2050 (Figures 10 and 11). Under the BAPC model, the age-standardized DALY rate, having reached its lowest point around 2012, is projected to rise continuously through the coming decades. Under the BAPC model, total DALYs for both sexes combined are projected to change from approximately 21.7 million in 2023 to approximately 21.5 million by 2050, with males (approximately 11.5 million) consistently bearing a higher burden than females (approximately 10.0 million). We note that the projected 2050 total (21.5 million) is slightly lower than the 2023 observed total (21.7 million) because the BAPC model projects a continued increase in age-standardized DALY rates but a decline in total DALYs owing to population aging and the resulting changes in age composition. This pattern is consistent with the Nordpred projections (Figure 11). The Nordpred projections, serving as a sensitivity analysis, showed highly consistent trends, providing preliminary support for the projected rise.

These projections extend the forecasting horizon from 2030 to 2050, aligning with China's medium- and long-term development strategies. The sustained growth in age-standardized rates signals an urgent need for proactive, systematic, and well-resourced fall prevention strategies to avert an impending public health crisis.

Figure 10 BAPC projections of fallrelated DALYs to 2050

Legend: Bayesian age-period-cohort (BAPC) projections of age-standardized DALY rates (A) and total DALY numbers (B) for falls in China from 2024 to 2050, by sex. The age-standardized DALY rate, after reaching a low around 2012, is projected to increase continuously through 2050. Total DALYs for both sexes combined are projected to remain stable at approximately 21.5 million by 2050, with males consistently bearing a higher burden than females. Note: The projected total for 2050 (21.5 million) is slightly lower than the observed total for 2023 (21.7 million) because the BAPC model projects a continued increase in age-standardized rates but a decline in total DALYs owing to changes in population age composition. Shaded areas represent 95% credible intervals.

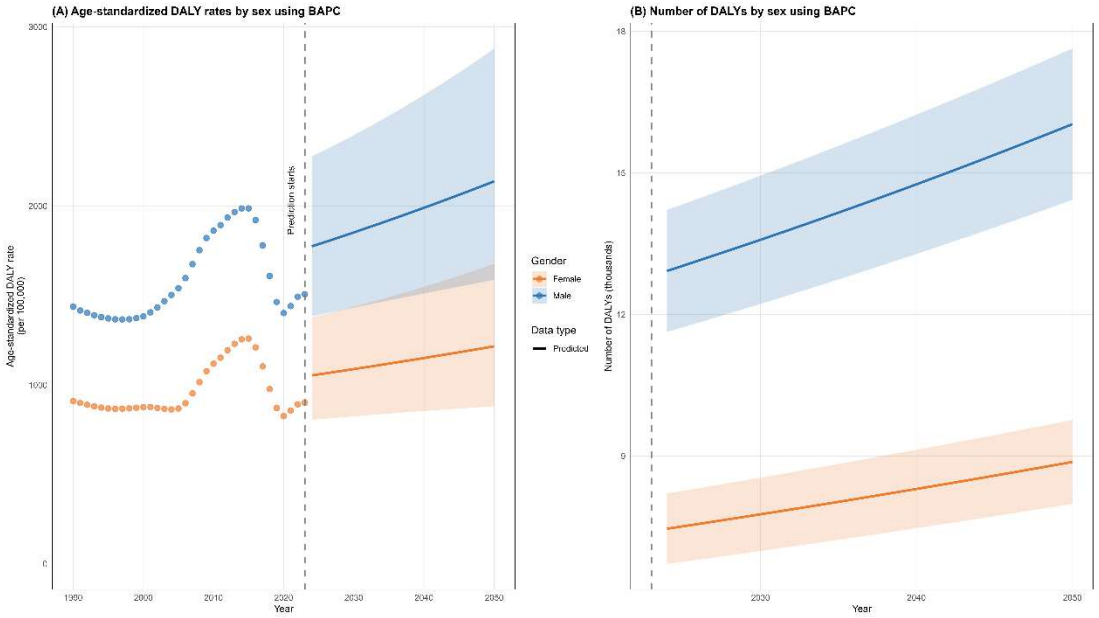
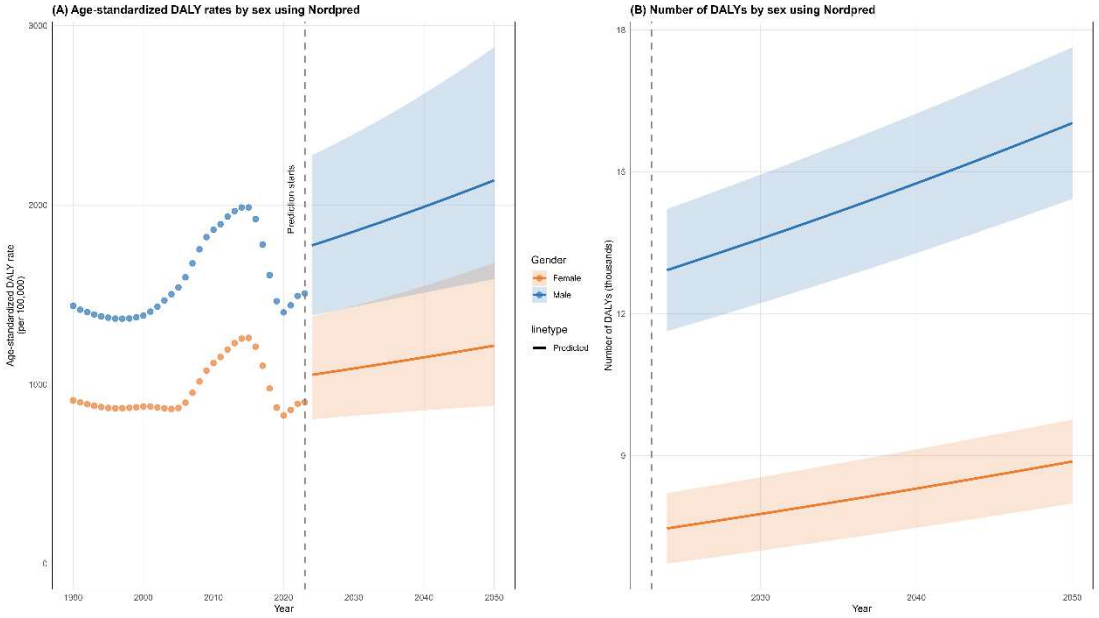


Figure 11 Nordpred projections of fallrelated DALYs to 2050 (sensitivity analysis)

Legend: Nordpred model projections of age-standardized DALY rates (A) and total DALY numbers (B) for falls in China from 2024 to 2050, by sex. The trends are consistent with BAPC projections (Figure 10), showing continued increases in age-standardized DALY rates through 2050 and a stable total DALY burden of approximately 21.5 million by 2050. These results provide preliminary support for the projected rise in fall-related disease burden in China over the coming decades.



4 Discussion

This study, based on the latest GBD 2023 data, systematically evaluated long-term trends, age-period-cohort characteristics, risk factor attribution, and injury pattern changes of falls burden in China from 1990 to 2023. Through in-depth comparative analyses with Japan, the United States, and Brazil—countries representing distinct health-system archetypes—and projections to 2050 using a multi-model cross-validation framework, we present three main contributions: (1) documenting the epidemiological transition from mortality-dominant to disability-dominant fall burden and identifying the inflection points and drivers; (2) demonstrating through international comparison that health-system responses,

rather than economic development alone, determine burden trajectories; and (3) translating these empirical findings into a phased, assessable intervention roadmap aligned with China's national strategies. These findings are systematically interpreted below, with their public health and policy implications discussed.

4.1 The Epidemiological Transition of Falls in China: A "Successful Paradox"

Our findings reveal a profound structural transition in China's falls burden over the past three decades. On one hand, ASRs of prevalence and incidence continuously increased, particularly entering an accelerated growth phase after 2010. On the other hand, ASRs of mortality and YLLs showed significant declining trends, especially after 2005. This contrasting pattern—"rising non-fatal burden and declining fatal burden"—marks a transition from "mortality-dominant" to "disability-dominant" fall burden [22,23,7].

We term this the "successful paradox" of fall burden transition. The decline in mortality likely reflects China's substantial progress since the 2000s in emergency medical service system development, trauma care capacity enhancement, and improved healthcare accessibility [24,25]. Enhanced management of severe fall-related complications—intracranial hemorrhage, pulmonary infections following hip fracture-related immobilization—has effectively reduced short-term mortality risks. However, the continuous increase in prevalence and YLDs rates, especially the acceleration after 2010, reflects the unintended consequence of this success: more people survive falls but live with permanent functional impairment.

The 2010 turning point identified in Joinpoint analysis coincides with accelerated population aging and the rising prevalence of chronic diseases (e.g., osteoporosis, sarcopenia, neurological disorders) in China [26]. Even when falls are not fatal, older adults often suffer long-term functional impairment and disability from fractures or traumatic brain injuries, which is the fundamental driver of YLD accumulation [22,27,23,28]. This transition fundamentally changes the nature of the public health challenge: the goal is no longer merely saving lives, but preserving function and quality of life in an aging population.

4.2 Aging as the Core Driver, with GenderSpecific Pathways

Through decomposition analysis and APC modeling, this study quantified the dominant role of aging in China's falls burden. Decomposition analysis showed that aging was the primary driver of both increased prevalence and mortality over the past three decades, with a significantly greater contribution in females than males. APC modeling confirmed that age effects increased linearly with age, rising sharply after age 75. These findings reinforce the conclusion that addressing aging is central to fall prevention.

Gender disparities were particularly prominent and nuanced in this study. Males consistently had higher burden than females across all indicators, yet females bore a greater burden from the aging effect [29,30]. This seemingly paradoxical phenomenon reflects the interplay of risk exposure and physiological vulnerability across different life stages. The peak incidence in young adult males (25–39 years) is associated with outdoor activities and occupational exposures—working at heights, manual labor, and transportation-related falls [31,32]. In contrast, the high YLL and DALY burden in older females is closely related to postmenopausal estrogen decline leading to rapid bone density loss, osteoporosis, and sarcopenia [33,34].

The PAF for low bone mineral density reaching 26.5% in 2023—with a particularly strong impact on females—directly confirms this physiological vulnerability. This finding has critical implications: fall prevention strategies must be gender-sensitive and age-appropriate. For younger males, the priority is occupational safety and environmental modification. For older females, the priority shifts to bone health screening, osteoporosis management, and fall-related fracture prevention.

4.3 International Comparisons: HealthSystem Archetypes and Policy Lessons

This study places China's falls burden within a comparative framework with Japan, the United States, and Brazil based on health-system response typologies, revealing heterogeneous trajectories that offer actionable policy lessons. This international comparison represents a novel contribution of our study.

Japan-The LTCI "Plateau" Model: As a super-aged society, Japan's falls ASR showed an early increase followed by a plateau after 2000. This pattern is closely linked to the implementation of its LTCI system in 2000. Through mandatory coverage of community-integrated care, home environment modification, and preventive rehabilitation services, the LTCI effectively delayed functional decline in older adults [35]. Empirical studies have shown that after LTCI implementation, institutional care utilization rates declined while home-based rehabilitation service coverage increased substantially, curbing the unbounded rise in falls burden . The key lesson for China: a comprehensive, legislatively mandated long-term care system can counteract the negative impacts of aging on fall burden, provided it includes strong preventive components.

The United States-The "High-Income, High-Burden" Paradox: Despite being a high-income country, the United States showed a sustained, monotonic increase in falls ASR. This paradox may be associated with high obesity and chronic disease rates leading to balance impairments, adverse effects from over-reliance on medications (e.g., anticoagulants, psychotropic drugs), and insufficient investment in preventive services within its fragmented healthcare system [36,37]. Notably, YLL rates in the United States also increased during this period, contrary to global and Chinese trends, suggesting potential room for improvement in post-fall medical care effectiveness. The key lesson for China: economic growth and advanced medical technology alone cannot curb the rising fall burden without systematic, community-based prevention infrastructure.

Brazil-The "Rapid Catch-Up" Model: As a BRICS country with similar developmental status to China, Brazil started with the lowest baseline burden but showed the most rapid growth trajectory. This "catch-up" growth pattern reflects infrastructure lags in sidewalk and public space safety, insufficient public health prevention systems during rapid urbanization and aging, and limited primary care integration for fall prevention [38]. The key lesson for China: economic development does not automatically lead to declining fall burden; proactive prevention strategies must be integrated into urbanization and primary care planning from the outset.

China-The "V-Shaped" Trajectory: China's unique pattern—a decline followed by a rebound—signals that initial gains from healthcare improvements are being eroded by demographic pressures. China is currently in a window period similar to that before Japan's LTCI system establishment. Drawing on international experience to build a "prevention-emergency-rehabilitation-care" integrated fall prevention system is crucial to avoiding both the US's "high-burden trap" and Brazil's "rapid catch-up" scenario.

These divergent patterns are consistent with recent evidence demonstrating that disease patterns among older populations vary geographically and are shaped by socioeconomic and environmental factors, with potential sex-specific differences [39]. Our findings extend this literature by showing that health-system responses—particularly the presence and design of long-term care systems—may be a key determinant of whether aging populations experience a plateau or continued increase in fall-related burden.

4.4 The Changing Profile of Risk Factors: From Exogenous to Endogenous

Analysis of fall injury patterns and risk factor trends reveals another notable shift. The significant increase in hip fractures among older adults—now a core contributor to disability—represents a catastrophic event in geriatric public health. Hip fractures carry high disability rates, high mortality (one-year mortality reaches 20%–30% in older adults), and substantial care costs; approximately 50% of

survivors experience permanent functional impairment, and over 30% require long-term institutional care [40].

This finding directly echoes the sustained increase in PAF for low bone mineral density. From 1990 to 2023, the PAF for LBMD increased from 18.4% in 1990 to 26.5% in 2023, becoming the risk factor with the highest PAF, far exceeding traditional factors such as alcohol use and environmental hazards. This change suggests a shift in the relative importance of risk factors, with endogenous physiological vulnerabilities (e.g., LBMD) accounting for a larger attributable fraction of fall-related DALYs than exogenous environmental risks (e.g., occupational injuries). However, given the overlapping nature of PAFs, this interpretation should be considered suggestive rather than definitive.

Correspondingly, the PAF for occupational injuries declined from approximately 34% in 1990 to approximately 15% in 2023, indicating that with industrial structure upgrading and improved occupational safety standards, workplace falls are no longer the dominant factor. However, alcohol use (17.9%) and vision impairment (15.5%), as modifiable risk factors with high PAF, remain significant. Vision impairment, particularly in older adults, closely overlaps with age-related eye diseases such as cataracts and glaucoma, suggesting that fall prevention requires multidisciplinary collaboration across ophthalmology, geriatrics, and rehabilitation medicine [41].

The implications of this shift are clear: prevention strategies must evolve. While workplace safety remains important, the new frontier is bone health management, vision screening, and environmental modification in homes and communities where older adults spend most of their time.

4.5 Future Projections and the Path Forward

Both BAPC and Nordpred models project that China's falls DALYs ASR will continue to increase, whereas total numbers are projected to remain broadly stable through 2050. This projection extends the forecasting horizon from 2030 in previous studies to 2050 [7], aligning with national medium- and long-term development strategies such as "Healthy China 2035" and "Active Response to Population Aging." The projections from two models provide quantitative evidence to inform policy discussion.

The "Three-Step" Intervention Roadmap. Based on our integrated findings—the epidemiological transition, the aging-driven burden, the gender-specific pathways, the shift in risk factors, and the international lessons—we propose a phased, assessable intervention roadmap tailored to China's national context:

Short-Term Priority (2025–2030): Foundation Building

- **Community-based screening:** Integrate osteoporosis and sarcopenia screening into the basic public health service package for adults aged 60 years and above, with particular emphasis on postmenopausal women.
- **Home environmental modification:** Develop and disseminate evidence-based home safety checklists; provide subsidies for low-income older adults to install grab bars, improve lighting, and remove tripping hazards.
- **Vision screening:** Include annual vision assessment in geriatric health checkups, with referral pathways for cataract surgery and prescription adjustments.
- **Public awareness campaigns:** Launch nationwide fall prevention education campaigns targeting both older adults and their caregivers, emphasizing the importance of strength and balance exercises (e.g., Tai Chi).

Medium-Term Priority (2030–2040): System Integration

- **Multidisciplinary fall clinics:** Establish integrated fall clinics within secondary and tertiary hospitals, bringing together geriatricians, orthopedists, rehabilitation specialists,

ophthalmologists, and pharmacists to provide comprehensive fall risk assessment and management.

- **Community-based prevention networks:** Expand community health service centers' capacity for fall prevention through workforce training, standardized care pathways, and referral mechanisms to specialty care.
- **Integration with chronic disease management:** Embed fall risk assessment and prevention into the routine management of hypertension, diabetes, and other chronic conditions.
- **Digital health innovations:** Pilot digital fall prevention programs (e.g., remote exercise coaching, home monitoring technologies, fall detection devices) in demonstration communities.

Long-Term Priority (2040–2050): National Strategy Consolidation

- **Legislative framework:** Enact fall prevention legislation that mandates fall risk assessment for all adults aged 65 years and above, similar to Japan's LTCI framework, and establishes quality standards for community-based fall prevention services.
- **National surveillance system:** Establish a comprehensive, real-time national fall surveillance system that captures falls occurring in both community and institutional settings, enabling timely policy adjustments.
- **Workforce development:** Build a fall prevention workforce across sectors—healthcare, social care, urban planning, and housing—with standardized training and certification.
- **International collaboration:** Actively participate in WHO's "Decade of Healthy Ageing (2021–2030)" and contribute to global fall prevention evidence and best practices.

4.6 Policy implications and alignment with national health strategies

The proposed "Three-Step" roadmap is not merely a theoretical construct but is explicitly designed to align with China's ongoing health system reforms and national development frameworks. The short-term priorities—community-based osteoporosis and sarcopenia screening, home environmental modification, and vision assessment—directly support the current 14th Five-Year Plan's (2021–2025) emphasis on strengthening primary care and promoting healthy aging [43]. The medium-term integration of multidisciplinary fall clinics into chronic disease management corresponds to the "Healthy China 2035" strategy's goal of establishing integrated, life-course health services that bridge preventive and curative care. The long-term legislative framework, akin to Japan's Long-Term Care Insurance system, would represent a substantial shift in how fall prevention is financed and delivered in China—moving from a fragmented, reactive model to a systematic, proactive population health approach.

Crucially, this roadmap provides a measurable framework for policy evaluation. Process indicators—such as screening coverage rates among adults aged 60 years and above, home modification completion rates, and the proportion of primary care facilities offering fall risk assessments—can be tracked through China's existing health information systems. Outcome indicators—including fall-related hospitalization rates, hip fracture incidence, and fall-related disability-adjusted life years—can be monitored through the national Disease Surveillance Points system and the Chinese CDC's Cause of Death Reporting System. This evaluability is essential for translating research evidence into sustained policy action, as it enables iterative feedback and course correction.

Beyond China's borders, the analytical framework and policy roadmap developed in this study offer a replicable model for other rapidly aging middle-income countries facing similar epidemiological transitions. The health-system typology-based international comparison—contrasting China's V-shaped trajectory with Japan's LTCI-associated plateau, the United States' high-income–high-burden paradox, and Brazil's rapid catch-up growth—provides contextualized lessons that transcend generic

recommendations. For countries at earlier stages of demographic transition, our findings underscore that proactive investment in community-based prevention and long-term care infrastructure, rather than reactive acute care expansion alone, is the more sustainable pathway for curbing the rising burden of fall-related disability.

4.7 Methodological Contributions and Future Directions

As a methodological contribution, this study employed a multi-model cross-validation strategy (BAPC + Nordpred) that enhances the robustness of our projections. This approach is particularly valuable in data-constrained settings where model uncertainty is a key concern. The consistency between the two projection models provides preliminary support for the projected trends.

Future research could extend this work by incorporating machine learning time-series models and counterfactual policy simulations to provide more persuasive causal evidence for policy selection. For example, quantifying "how much lower the 2023 DALY burden would have been if China had implemented a community-integrated care policy similar to Japan's in 2010".

4.8 Limitations and Future Research

This study has several limitations. First, GBD data are based on modeled estimates, and their accuracy depends on the quality and completeness of primary input data. Disease surveillance data from some regions of China, especially remote rural areas, may have incomplete coverage, introducing uncertainty into the estimates. Second, although we conducted cross-country comparisons, inherent differences in data collection methods, disease coding practices, and health system statistical standards across countries may introduce comparative bias. Third, our analysis of risk factors was limited to the set provided by GBD and could not include micro-level factors such as fear of falling, home environment details (e.g., lighting, flooring materials), and social support levels, which also play critical roles in fall occurrence [42]. Fourth, although we proposed the potential application of machine learning models, this analysis still relied primarily on traditional statistical models; future research is needed to further validate the stability and interpretability of machine learning models in large-scale public health forecasting. Fifth, our projections assumed relatively stable secular trends in risk factors; unexpected shifts (e.g., new fall prevention technologies, policy changes, or emerging health threats) could alter these trajectories. Sixth, our secondary analyses (decomposition, APC modeling, and projections) were conducted using point estimates from GBD 2023, and uncertainty from the original GBD estimates was not formally propagated through these analyses. Consequently, the confidence intervals reported for derived quantities (e.g., decomposition contributions, APC effects) do not capture the full uncertainty of the underlying input data. While the consistency between BAPC and Nordpred projections provides some reassurance regarding the direction of future trends, the magnitude of projected changes should be interpreted with caution. Future research could employ probabilistic sensitivity analysis or Monte Carlo simulation across GBD draws to quantify the uncertainty of derived estimates more rigorously.

5 Conclusion

Between 1990 and 2023, China's falls burden underwent a profound epidemiological transition from mortality-dominant to disability-dominant, characterized by rising prevalence and YLDs burden alongside declining mortality and YLLs. Aging is the core driver of increasing burden, with a particularly pronounced impact on females. While males consistently have higher burden across all age groups, the driving mechanisms differ significantly by age: occupational exposure predominates in young adult males, while declining bone density predominates in older females. International comparisons reveal divergent patterns across health-system archetypes: Japan effectively curbed the aging-driven burden increase through comprehensive long-term care systems; the sustained increase in the United States

warns of the limitations of relying solely on medical technology; Brazil's rapid catch-up reflects prevention lags in emerging economies during urbanization. China is currently at a critical window period of accelerating burden growth and urgently needs to draw on international experience.

By 2050, China's age-standardized fall DALY burden is projected to continue increasing, presenting a severe prevention challenge. Addressing China's fall challenge requires an evidence-based, life-course, gender-sensitive prevention strategy. We propose a "Three-Step" intervention roadmap: short-term focus on environmental modification and high-risk population screening; medium-term promotion of integrated community-based fall prevention service systems; long-term cultivation of active aging perspectives and safety culture, integrating fall prevention into the core frameworks of "Healthy China" and "Active Response to Population Aging" national strategies. This study provides quantitative evidence and a methodological paradigm for developing such a phased, assessable intervention roadmap.

Declarations

Ethical approval

This study utilized de-identified, publicly available data from the GBD 2023 study and was therefore exempt from ethics committee approval.

Consent to participate

Not applicable. This study used only de-identified, publicly available GBD 2023 data and did not involve the collection or reporting of individual patient data or identifiable personal information; therefore, consent to participate is not applicable.

Consent to Publish

Not applicable. This study used only de-identified, publicly available GBD 2023 data and did not involve the collection or reporting of individual patient data or identifiable personal information; therefore, consent to publish is not applicable.

Clinical trial number: not applicable.

Data Availability Statement

The datasets generated during and/or analysed during the current study are available in the Global Health Data Exchange (GHDx) repository, https://ghdx.healthdata.org/gbd-2023.

Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Authors' contributions

WJ: Conceptualization, Methodology, Visualization, Writing - original draft, Writing - review & editing. JL: Methodology, Visualization, Writing - review & editing. LL: Investigation, Writing - review & editing. LW: Data curation, Writing - review & editing. HZ: Formal analysis, Writing - review & editing. LM: Conceptualization, Project administration, Supervision, Writing - review & editing. YL: Conceptualization, Project administration, Supervision, Writing - review & editing.

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Supplementary material

The supplementary material for this article contains Supplementary Figures 1A–C, 2, and 3, which provide additional sex- and year-specific trends for YLDs, YLLs, and DALYs, age- and sex-stratified data, and sex-stratified Joinpoint regression analyses.

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