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Trends in Mortality and Disease Burden of Falls Attributable to Low Bone Mineral Density: A Global, Socio-demographic Index, and National Analysis for Türkiye

Düşük Kemik Mineral Yoğunluğuna Atfedilen Düşme Kaynaklı Ölüm ve Hastalık Yükünün Eğilimleri: Küresel, Sosyo-demografik İndeks ve Türkiye Analizi

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Abstract

Objective: This study aims to evaluate the trends over time in age-standardized and sex-specific mortality and disability-adjusted life years (DALY) rates from falls attributable to low bone mineral density globally, across socio-demographic index (SDI) groups, and specifically in Türkiye during the period 1990-2023.

Materials and Methods: The data for this study, designed as an ecological time-series analysis, were obtained from the global burden of disease study 2023. Age-standardized and sex-specific mortality and DALY rates (per 100,000 population) were analyzed over a 34-year period. Descriptive analyses were performed using JASP (version 0.96.0.0), and trend analyses were conducted using a Joinpoint regression model ($p<0.05$).

Results: Between 1990 and 2023, the global average age-standardized mortality rate was higher in males, while the DALY rate was higher in females. Over the 34-year period, global mortality rates increased in males but remained stable in females. DALY rates showed a significant and equal increasing trend in both sexes. While mortality rates decreased in low, low-middle, and high-middle SDI groups, the middle group remained stable, and an increase was observed in the high SDI group. Contrary to the increase in the global mortality rate in males, Türkiye's data diverged from this trend, showing a decrease in both sexes. Despite Türkiye's overall DALY rate remaining stable, an increase in males and a decrease in females were observed in recent years.

Conclusion: This study shows that notwithstanding the increasing mortality rate in the high SDI group, Türkiye has diverged positively from the trend by decreasing mortality. However, despite the decreasing mortality rates in Türkiye, the recent increase in disease burden (DALY rate) in males reveals that survival success is not fully reflected in healthy life expectancy.

Keywords: Osteoporosis, low bone mineral density, falls, mortality, disability-adjusted life years, global burden of disease

Öz

Amaç: Bu çalışmada; 1990-2023 döneminde düşük kemik mineral yoğunluğuna atfedilen düşme kaynaklı yaşa standardize ve cinsiyete özel ölüm ve engelliliğe ayarlanmış yaşam yılı (DALY) hızlarının küresel ölçekte, sosyo-demografik indeks (SDI) gruplarında ve Türkiye özelinde zaman içindeki eğilimlerinin incelenmesi amaçlanmıştır.

Gereç ve Yöntem: Ekolojik zaman serisi desenindeki bu çalışmanın verileri global burden of disease study 2023'ten elde edildi. Otuz dört yıllık süreçteki yaşa standardize ve cinsiyete özel mortalite ve DALY hızları (yüz bin kişide) analiz edildi. Tanımlayıcı analizler JASP (versiyon 0.96.0.0) ile gerçekleştirildi ve trend Joinpoint regresyon modeli ile incelendi ($p<0,05$).

Bulgular: 1990-2023 arasında küresel yaşa standardize ortalama mortalite hızı erkeklerde, DALY hızı ise kadınlarda daha yüksek bulundu. Otuz dört yıllık süreçte küresel mortalite hızları erkeklerde artış gösterirken, kadınlarda sabit kaldı. Düşük, düşük-orta ve yüksek-orta SDI gruplarında mortalite hızları azalırken, orta grupta sabit kaldı ve yüksek SDI grubunda artış gözlendi. Küresel mortalite hızı erkeklerde artarken, Türkiye verileri küresel trendden ayrılarak her iki cinsiyette de azalma sergiledi. Türkiye'de genel DALY hızı trendi sabit iken, son yıllarda erkeklerde artış, kadınlarda azalma gözlendi.

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Sonuç: Bu çalışma, yüksek SDI grubunda artan mortalite hızına karşın, Türkiye'nin mortaliteyi azaltarak trendden pozitif yönde ayrıştığını göstermiştir. Ancak Türkiye'de azalan mortalite hızlarına rağmen, son dönemde erkeklerde artan hastalık yükü (DALY hızı), sağkalım başarısının sağlıklı yaşam süresine tam yansımadığını ortaya koymaktadır.

Anahtar kelimeler: Osteoporoz, düşük kemik mineral yoğunluğu, düşmeler, ölüm, engelliliğe ayarlanmış yaşam yılları, küresel hastalık yükü

Introduction

Musculoskeletal diseases have become a leading cause of morbidity worldwide, driven by increasing life expectancy and an ageing population (1,2). Among these disorders, low bone mineral density (LBMD), defined as a decrease in bone mass and deterioration of bone microarchitecture, is a global public health concern. Often progressing silently, LBMD increases bone fragility, leaving individuals vulnerable to trauma (3). LBMD currently affects millions of people worldwide and is a chronic condition with a rising prevalence, particularly among those aged 50 and over. Two meta-analyses reported a global osteoporosis prevalence of 19.7%, reaching 21.7% in older adults, revealing that one in five individuals is at risk (4,5).

The most devastating clinical consequences of LBMD are fractures resulting from falls. While healthy individuals may survive low-energy falls with simple soft-tissue trauma, those with reduced bone density can sustain major fractures in the hip, vertebrae and distal forearm. These fractures not only necessitate an acute treatment process but also lead to severe morbidity, such as chronic pain, mobility limitations, loss of independence, and long-term care dependency. Furthermore, complications such as embolisms and infections, which develop particularly after hip fractures, can lead to fall-related mortality and significantly shorten life expectancy (6,7).

It has been demonstrated that LBMD carries serious health consequences and imposes a heavy economic burden on national healthcare systems (8). Complications associated with LBMD are largely preventable. This burden can be reduced through early diagnosis using dual-energy X-ray absorptiometry (DXA) scans, ensuring adequate calcium and vitamin D intake, increasing physical activity and implementing fall prevention strategies (9,10). Despite advancements in preventive healthcare services, the pace of demographic transition and shifts in risk factors have made the future trajectory of this global burden uncertain. To evaluate the effectiveness of current policies and develop forward-looking strategies, it is crucial to monitor long-term trends in mortality and in the disease burden of falls attributable to LBMD using up-to-date data.

This study aims to evaluate the temporal trends in age-standardized, sex-specific mortality and disability-adjusted life-year (DALY) rates from falls attributable to LBMD between 1990 and 2023, at the global level and across socio-demographic index (SDI) groups. The study also focuses on trends in Türkiye.

Materials and Methods

Research Type and Permissions

This study was designed as an ecological time-series analysis. As the study data were publicly accessible and there was no direct contact with human subjects, no ethical or formal permissions were required. Due to the study methodology, obtaining verbal or written informed consent from participants was not applicable.

Data Sources and Variables

The research was conducted between June 1, 2025, and February 28, 2026. Data for the study were obtained from the global burden of disease (GBD) study 2023 (11). The GBD study 2023 provides comprehensive, up-to-date epidemiological data, including the metrics used in this research. It is coordinated by the Institute for Health Metrics and Evaluation at the University of Washington. The strength of this dataset derives from its integration of numerous primary data sources. The GBD Study 2023 estimates the burden attributable to LBMD using a comparative risk assessment (CRA) framework, in which population attributable fractions are calculated by comparing the exposure distribution of LBMD in a given population with the theoretical minimum risk exposure level using age- and sex-specific bone mineral density data. Mortality and DALY estimates are subsequently derived by applying these fractions to the overall burden of falls. As the methodology is extensively detailed elsewhere, readers are referred to the published resources for comprehensive information (12,13).

The primary variables of the study were the age-standardized, sex-specific mortality and DALY rates from falls attributable to LBMD, recorded annually per 100,000 population. While mortality is a measure of deaths occurring within a specific population during a given period, DALY serves as a metric for the burden of disease (14). Rates were obtained for the 34-year period between 1990 and 2023 at the global level, across SDI groups, and for Türkiye. The five SDI groups provided by the GBD Study 2023—low, low-middle, middle, high-middle, and high—were utilized. These groups were established by calculating a composite indicator ranging from 0 to 1, incorporating variables such as the total fertility rate under the age of 25, mean education for those aged 15 and older, and lag-distributed income (15). Data were extracted from the GBD Study 2023 using the following parameters: GBD estimate: risk factor; measure: deaths and DALYs; metric: rate (per 100,000 population); risk: LBMD; cause: falls; location: global, five SDI quintiles (low, low-middle, middle, high-middle, high), and Türkiye; age: age-standardized; sex: male, female, and both; year: 1990-2023.

Statistical Analysis

JASP (version 0.96.0.0; JASP Team, 2024) was used for data preprocessing and descriptive analyses, while the Joinpoint Regression Program (version 5.4.0) was utilized to determine temporal trends. Standard error values for mortality and DALY rates were derived from the 95% uncertainty intervals provided

by the GBD Study 2023 using the formula SE = (upper limit-lower limit)/(2×1.96). The 34-year trends in mortality and DALY rates were evaluated using joinpoint regression analysis, which identified significant trend change points (joinpoints). The grid search method was applied. To ensure ease of understanding and interpretation, a maximum of two joinpoints was permitted. This deliberate choice was made to prevent overfitting and avoid rendering minor fluctuations statistically significant, which could obscure meaningful long-term trends. Major trend changes, particularly those relevant to public health policy, remain detectable under this constraint. Model selection was based on the Weighted Bayesian Information Criterion, and the final model was automatically selected by the program. Annual percentage change (APC) values were reported. A p-value of less than 0.05 was considered statistically significant.

Results

During the 34-year period from 1990 to 2023, the global age-standardized mortality rate per 100,000 population from falls attributable to LBMD was 3.93±0.08 in males and slightly lower in females at 3.71±0.09. The DALY rate, however, was 165.38±7.92 in males, while it was higher in females at 213.64±10.92. Among the SDI groups, the highest mortality rates in both males and females were observed in the low-middle and low groups. The lowest mortality rates for both sexes were found in the high SDI group. The highest DALY rates were recorded in the high and low-middle groups for males and in the low-middle and high groups for females. The lowest DALY rates for both sexes were observed in the middle SDI group. In Türkiye, during the 34-year period, the age-standardized mortality rate per 100,000 population from falls attributable to LBMD was 3.75±0.26 in males and 3.46±0.47 in females, while the DALY rate was 96.12±2.27 in males and 111.77±2.86 in females. Descriptive characteristics of the data used in the study are presented in Table 1.

Age-standardized, sex-specific mortality and DALY rates from falls attributable to LBMD were analyzed at the global level, across SDI groups, and for Türkiye: the APC values, joinpoints, and significance levels occurring over the 34-year period between 1990 and 2023 are presented in Table 2. Trends and joinpoints are provided in Supplementary Figures S1-S7.

While the global mortality rate increased significantly among males over the 34-year period, the rate remained stable among females. In males, a pattern of an initial increase followed by a decrease and a subsequent increase was observed; in females, an initial decrease was followed by an increase. For global DALYs, a significant and equal increase was observed in both sexes. In males, the upward trend was followed by a decrease and a subsequent increase. In females, the stable period was followed by a significant increase, and then a decrease.

When analyzed by SDI groups, the mortality rate decreased in the low, low-middle, and high-middle groups in both sexes combined, whereas an increase was observed in the high group. The middle group remained stable. For DALY rates, trends were downward in the low and low-middle groups but upward in the middle, high-middle, and high groups. In sex-specific mortality and DALY rates, the values for males were statistically significant and generally more pronounced compared to those for females. In Türkiye, mortality rates tended to decrease for both males and females. In males, the pattern consisted of an initial increase followed by a decrease and a subsequent increase, while in females, two different downward trends were followed by a stable period. Conversely, DALY rates in Türkiye remained stable for both sexes. In males, an initial increase was followed by a decrease and a subsequent increase; in females, the pattern was an initial increase followed by a decrease.

Discussion

During the 34-year period evaluated, global average mortality rates from falls attributable to LBMD were higher in males, whereas DALY rates were higher in females. A sex difference similar to the global trend was observed in Türkiye. This finding appears to be consistent with the morbidity-mortality paradox, as described in epidemiology textbooks. Studies in the literature have found similar results (16-18). This situation may stem from the differing impacts of biological and behavioral factors between the two sexes, as supported by existing evidence. Biological differences are constituted by hormonal changes that become prominent in the postmenopausal period in females, and the faster differentiation of female osteoclasts along with an increase in inflammatory pathways (19,20). Furthermore, the stages of bone modeling and remodeling based on sex steroid differences differ between females and males (21). Males undergo fewer screenings for LBMD compared to females (22,23). There are studies reporting that males fall more frequently than females, and that females often experience falls indoors while males experience them outdoors (24,25). Additionally, it is known that males engage in riskier behaviors due to gender norms (26,27). The trend analyses of the study also corroborate this sex difference. Notably, while mortality rates among females remained stable in the high SDI group, a statistically significant increase persisted among males. The fact that global female deaths, male deaths, and the disease burden have shown a significant upward trend in recent years indicates that gains in health are at risk. These findings, regardless of the underlying mechanism, point to the necessity of strengthening preventive services and improving risk awareness for both sexes. The trend analyses of the study reveal a complex picture of the global burden of falls attributable to LBMD between 1990 and 2023, paralleling the epidemiological data in the literature (28). The upward trend in global disease burden, along with mortality rates appearing stable but tending to increase in recent years, suggests that while improvements in healthcare, modern medicine, and care services can limit disability and fatal outcomes, they cannot be entirely prevented due to the vulnerability of the aging population (29-31). In terms of SDI, which is a composite of fertility rate, education level, and income, a decrease in mortality rates in the low, low-middle, and high-middle groups and an increase in mortality rates in the high group are noteworthy. The

Table 1. Characteristics of mortality and disease burden of falls attributable to LBMD over the 34-year period between 1990 and 2023

Rates[ǂ]	Mean	Standard deviation	Minimum	Maximum	Years	Period of data
Global mortality rate in males	3.93	0.08	3.81	4.13	1990-2023	Annually
Global mortality rate in females	3.71	0.09	3.57	3.90	1990-2023	Annually
Global mortality rate in both	3.79	0.08	3.67	3.97	1990-2023	Annually
Global DALY rate in males	165.38	7.92	154.33	178.39	1990-2023	Annually
Global DALY rate in females	213.64	10.92	198.29	234.34	1990-2023	Annually
Global DALY rate in both	192.23	9.07	179.42	208.80	1990-2023	Annually
Low SDI group mortality rate in males	6.14	0.32	5.45	6.49	1990-2023	Annually
Low SDI group mortality rate in females	6.94	0.21	6.53	7.30	1990-2023	Annually
Low SDI group mortality rate in both	6.54	0.20	6.20	6.81	1990-2023	Annually
Low SDI group DALY rate in males	137.34	6.61	122.71	143.94	1990-2023	Annually
Low SDI group DALY rate in females	192.31	5.61	181.18	201.23	1990-2023	Annually
Low SDI group DALY rate in both	165.20	4.60	155.49	172.08	1990-2023	Annually
Low-middle SDI group mortality rate in males	6.28	0.27	5.75	6.63	1990-2023	Annually
Low-middle SDI group mortality rate in females	7.40	0.31	6.85	7.99	1990-2023	Annually
Low-middle SDI group mortality rate in both	6.87	0.23	6.50	7.31	1990-2023	Annually
Low-middle SDI group DALY rate in males	170.16	8.73	150.45	182.39	1990-2023	Annually
Low-middle SDI group DALY rate in females	257.62	14.75	224.36	276.82	1990-2023	Annually
Low-middle SDI group DALY rate in both	215.91	11.03	191.44	230.16	1990-2023	Annually
Middle SDI group mortality rate in males	3.52	0.12	3.37	3.82	1990-2023	Annually
Middle SDI group mortality rate in females	4.07	0.09	3.90	4.22	1990-2023	Annually
Middle SDI group mortality rate in both	3.87	0.07	3.76	4.00	1990-2023	Annually
Middle SDI group DALY rate in males	128.46	10.89	115.45	147.97	1990-2023	Annually
Middle SDI group DALY rate in females	162.63	11.07	148.97	185.18	1990-2023	Annually
Middle SDI group DALY rate in both	148.15	10.94	134.83	169.23	1990-2023	Annually
High-middle SDI group mortality rate in males	3.53	0.17	3.20	3.78	1990-2023	Annually
High-middle SDI group mortality rate in females	3.84	0.24	3.40	4.23	1990-2023	Annually
High-middle SDI group mortality rate in both	3.71	0.20	3.31	4.04	1990-2023	Annually
High-middle SDI group DALY rate in males	160.41	7.65	152.59	177.48	1990-2023	Annually
High-middle SDI group DALY rate in females	199.99	10.10	187.39	224.11	1990-2023	Annually
High-middle SDI group DALY rate in both	181.72	8.69	171.74	202.31	1990-2023	Annually
High SDI group mortality rate in males	3.35	0.22	3.07	3.87	1990-2023	Annually
High SDI group mortality rate in females	2.76	0.13	2.60	3.07	1990-2023	Annually
High SDI group mortality rate in both	2.99	0.13	2.85	3.34	1990-2023	Annually
High SDI group DALY rate in males	178.92	12.72	160.38	196.99	1990-2023	Annually
High SDI group DALY rate in females	225.85	16.49	204.83	253.82	1990-2023	Annually
High SDI group DALY rate in both	205.52	13.73	187.33	227.90	1990-2023	Annually
Türkiye's mortality rate in males	3.75	0.26	3.26	4.23	1990-2023	Annually
Türkiye's mortality rate in females	3.46	0.47	2.82	4.17	1990-2023	Annually
Türkiye's mortality rate in both	3.55	0.39	2.97	4.11	1990-2023	Annually
Türkiye's DALY rate in males	96.12	2.27	91.72	101.56	1990-2023	Annually
Türkiye's DALY rate in females	111.77	2.86	107.96	118.83	1990-2023	Annually
Türkiye's DALY rate in both	105.23	2.13	102.64	111.18	1990-2023	Annually

[ǂ]: Rates are presented as age-standardized rates per 100,000 population, LBMD: Low bone mineral density, DALY: Disability-adjusted life years, SDI: Socio-demographic index

Table 2. Joinpoint analyses of mortality and DALY rates from falls attributable to LBMD

Rates	Trend 0			Trend 1			Trend 2			Trend 3			Trend change point(s)
	Years	APC	Lower-Upper CI	Years	APC	Lower-Upper CI	Years	APC	Lower-Upper CI	Years	APC	Lower-Upper CI	
Global mortality rate in males	1990-2023	0.10*	0.03-0.17	1990-2008	0.22*	0.12-0.44	2008-2014	-0.66*	-1.97-(-0.09)	2014-2023	0.77*	0.44-1.74	2008, 2014
Global mortality rate in females	1990-2023	0.02	-0.06-0.11	1990-1994	-1.56*	-4.05-(-0.07)	1994-2023	0.12*	0.02-0.40				1994
Global mortality rate in both	1990-2023	0.05	-0.04-0.13	1990-1993	-1.41	-3.07-0.04	1993-2019	0.04	-0.99-1.07	2019-2023	1.28*	0.05-3.55	1993, 2019
Global DALY rate in males	1990-2023	0.35*	0.21-0.49	1990-2016	0.64*	0.57-0.71	2016-2019	-3.12*	-3.77-(-1.63)	2019-2023	0.91*	0.12-2.73	2016, 2019
Global DALY rate in females	1990-2023	0.35*	0.20-0.50	1990-1995	-0.87	-3.29-0.18	1995-2014	0.86*	0.72-1.15	2014-2023	-1.12*	-1.62-(-0.72)	1995, 2014
Global DALY rate in both	1990-2023	0.32*	0.18-0.46	1990-1995	-0.73	-2.94-0.20	1995-2014	0.79*	0.66-1.06	2014-2023	-1.05*	-1.51-(-0.68)	1995, 2014
Low SDI group mortality rate in males	1990-2023	-0.44*	-0.58-(-0.29)	1990-2008	0.01	-0.11-0.16	2008-2018	-1.49*	-2.08-(-1.25)	2018-2023	1.53*	0.82-2.52	2008, 2018
Low SDI group mortality rate in females	1990-2023	0.01	-0.11-0.13	1990-2008	0.40*	0.20-0.70	2008-2013	-1.63*	-3.43-(-0.48)	2013-2023	0.57*	0.14-1.81	2008, 2013
Low SDI group mortality rate in both	1990-2023	-0.18*	-0.30-(-0.06)	1990-2008	0.23*	0.12-0.36	2008-2014	-1.59*	-2.86-(-1.06)	2014-2023	0.44*	0.16-0.83	2008, 2014
Low SDI group DALY rate in males	1990-2023	-0.42*	-0.55-(-0.30)	1990-2008	0.01	-0.07-0.11	2008-2019	-1.27*	-1.50-(-1.11)	2019-2023	1.54*	0.85-2.51	2008, 2019
Low SDI group DALY rate in females	1990-2023	0.05	-0.07-0.18	1990-2007	0.51*	0.37-0.69	2007-2021	-0.56*	-0.85-(-0.40)	2021-2023	4.05*	1.49-5.49	2007, 2021
Low SDI group DALY rate in both	1990-2023	-0.11*	-0.23-0.01	1990-2008	0.31*	0.21-0.42	2008-2020	-0.84*	-1.08-(-0.68)	2020-2023	2.36*	1.20-4.29	2008, 2020
Low-middle SDI group mortality rate in males	1990-2023	-0.38*	-0.47-(-0.29)	1990-2011	-0.09	-0.18-0.06	2011-2014	-2.59*	-3.24-(-1.03)	2014-2023	-0.01	-0.34-0.96	2011, 2014
Low-middle SDI group mortality rate in females	1990-2023	-0.07	-0.22-0.12	1990-2007	0.73*	0.52-0.99	2007-2012	-2.42*	-4.31-(-1.34)	2012-2023	0.41*	0.11-0.86	2007, 2012
Low-middle SDI group mortality rate in both	1990-2023	-0.17*	-0.28-(-0.05)	1990-2008	0.37*	0.24-0.52	2008-2013	-1.94*	-3.29-(-1.18)	2013-2023	0.24*	0.01-0.59	2008, 2013
Low-middle SDI group DALY rate in males	1990-2023	-0.43*	-0.56-(-0.30)	1990-2011	0.01	-0.12-0.16	2011-2019	-1.71*	-3.41-(-1.17)	2019-2023	0.51	-0.82-2.76	2011, 2019
Low-middle SDI group DALY rate in females	1990-2023	-0.40*	-0.59-(-0.19)	1990-1994	-1.91*	-5.17-(-0.10)	1994-2006	0.87*	0.48-2.18	2006-2023	-1.22*	-1.45-(-1.02)	1994, 2006
Low-middle SDI group DALY rate in both	1990-2023	-0.36*	-0.54-(-0.16)	1990-1994	-1.70*	-4.47-(-0.09)	1994-2007	0.64*	0.34-1.53	2007-2023	-1.14*	-1.35-(-0.95)	1994, 2007
Middle SDI group mortality rate in males	1990-2023	0.23*	0.13-0.33	1990-2008	0.33*	0.14-1.05	2008-2011	-1.37	-2.22-1.01	2011-2023	0.78*	0.19-2.16	2008, 2011
Middle SDI group mortality rate in females	1990-2023	-0.10*	-0.19-(-0.01)	1990-2007	0.16*	0.03-0.39	2007-2011	-1.34*	-2.28-(-0.35)	2011-2023	0.19	-0.02-0.82	2007, 2011
Middle SDI group mortality rate in both	1990-2023	0.03	-0.06-0.12	1990-2008	0.20*	0.07-0.53	2008-2011	-1.58*	-2.25-(-0.12)	2011-2023	0.42*	0.15-1.40	2008, 2011

Table 2. Continued

Rates	Trend 0			Trend 1			Trend 2			Trend 3			Trend change point(s)
	Years	APC	Lower-Upper CI	Years	APC	Lower-Upper CI	Years	APC	Lower-Upper CI	Years	APC	Lower-Upper CI	
Middle SDI group DALY rate in males	1990-2023	0.77*	0.61-0.92	1990-2000	0.07	-0.55-0.44	2000-2015	1.49*	1.27-1.87	2015-2023	-1.15*	-1.79-(-0.65)	2000, 2015
Middle SDI group DALY rate in females	1990-2023	0.56*	0.42-0.70	1990-2007	0.45*	0.04-0.65	2007-2014	1.93*	1.15-4.12	2014-2023	-1.18*	-1.77-(-0.71)	2007, 2014
Middle SDI group DALY rate in both	1990-2023	0.64*	0.50-0.77	1990-2005	0.41	-0.02-0.65	2005-2014	1.74*	1.22-3.63	2014-2023	-1.01*	-1.60-(-0.54)	2005, 2014
High-middle SDI group mortality rate in males	1990-2023	-0.38*	-0.51-(-0.26)	1990-2008	0.10	-0.06-0.31	2008-2013	-2.09*	-3.70-(-1.09)	2013-2023	0.04	-0.33-0.87	2008, 2013
High-middle SDI group mortality rate in females	1990-2023	-0.31*	-0.50-(-0.12)	1990-2007	0.71*	0.49-0.95	2007-2011	-3.20*	-4.87-(-1.48)	2011-2023	-0.48	-0.80-0.16	2007, 2011
High-middle SDI group mortality rate in both	1990-2023	-0.33*	-0.49-(-0.19)	1990-2008	0.41*	0.23-0.63	2008-2011	-3.75*	-4.59-(-1.34)	2011-2023	-0.33	-0.69-0.50	2008, 2011
High-middle SDI group DALY rate in males	1990-2023	0.32*	0.19-0.45	1990-2005	-0.09	-0.43-0.14	2005-2014	1.47*	0.97-3.22	2014-2023	-1.00*	-1.60-(-0.52)	2005, 2014
High-middle SDI group DALY rate in females	1990-2023	0.27*	0.12-0.41	1990-2016	0.58*	0.45-0.73	2016-2020	-3.43*	-5.77-(-1.39)	2020-2023	3.12*	0.37-7.32	2016, 2020
High-middle SDI group DALY rate in both	1990-2023	0.28*	0.14-0.41	1990-2007	0.14	-0.39-0.35	2007-2014	1.60*	0.75-3.92	2014-2023	-1.30*	-2.10-(-0.76)	2007, 2014
High SDI group mortality rate in males	1990-2023	0.61*	0.50-0.70	1990-2013	0.41*	0.24-0.52	2013-2023	1.33*	0.90-2.54				2013
High SDI group mortality rate in females	1990-2023	-0.11	-0.31-0.08	1990-1995	-2.21*	-3.64-(-1.54)	1995-2012	-0.30*	-0.47-(-0.12)	2012-2023	1.23*	0.94-1.66	1995, 2012
High SDI group mortality rate in both	1990-2023	0.18*	0.01-0.33	1990-1995	-1.51*	-2.78-(-0.88)	1995-2012	-0.01	-0.16-0.16	2012-2023	1.25*	0.99-1.66	1995, 2012
High SDI group DALY rate in males	1990-2023	0.59*	0.41-0.77	1990-1996	0.10	-1.25-0.67	1996-2012	1.26*	1.11-1.51	2012-2023	-0.79*	-1.05-(-0.55)	1996, 2012
High SDI group DALY rate in females	1990-2023	0.60*	0.43-0.77	1990-1998	-0.27	-0.89-0.15	1998-2014	1.33*	1.17-1.55	2014-2023	-1.17*	-1.60-(-0.81)	1998, 2014
High SDI group DALY rate in both	1990-2023	0.55*	0.38-0.71	1990-1997	-0.26	-1.03-0.20	1997-2013	1.23*	1.08-1.43	2013-2023	-0.93*	-1.25-(-0.65)	1997, 2013
Türkiye's mortality rate in males	1990-2023	-0.46*	-0.69-(-0.22)	1990-2007	0.34*	0.07-0.74	2007-2010	-6.71*	-7.90-(-3.40)	2010-2023	0.95*	0.50-1.59	2007, 2010
Türkiye's mortality rate in females	1990-2023	-1.23*	-1.44-(-0.99)	1990-2006	-0.99*	-1.36-(-0.06)	2006-2009	-5.50*	-6.88-(-2.12)	2009-2023	-0.08	-0.48-0.50	2006, 2009
Türkiye's mortality rate in both	1990-2023	-1.00*	-1.20-(-0.79)	1990-2006	-0.61*	-0.90-(-0.14)	2006-2009	-5.68*	-6.90-(-2.61)	2009-2023	0.18	-0.17-0.70	2006, 2009
Türkiye's DALY rate in males	1990-2023	0.03	-0.06-0.12	1990-2007	0.27*	0.11-0.65	2007-2010	-2.14*	-2.89-(-0.27)	2010-2023	0.54*	0.26-1.44	2007, 2010
Türkiye's DALY rate in females	1990-2023	0.08	-0.02-0.18	1990-2001	-0.10	-0.74-0.16	2001-2005	1.70*	0.64-2.77	2005-2023	-0.30*	-0.44-(-0.18)	2001, 2005
Türkiye's DALY rate in both	1990-2023	0.04	-0.05-0.12										

LBMD: Low bone mineral density, DALY: Disability-adjusted life years, SDI: Socio-demographic index, CI: Confidence interval, APC: Annual percent change *: Indicates statistical significance

low and low-middle SDI groups showed decreases in disease burden, whereas the middle, high-middle, and high SDI groups showed increases. These contrasting trends, observed across SDI groups, can be explained by the theory of epidemiological transition in osteoporosis. While the decrease in low SDI groups can be associated with high physical activity linked to agriculture and labor-based jobs and the protective effect of a relatively young population structure, the increase in high SDI groups may be related to the prevalence of a sedentary lifestyle and the accumulation of a frail elderly population due to prolonged life expectancy. This situation contains a warning that as countries develop, the burden of osteoporosis may become an increasing threat along with lifestyle and demographic changes, rather than decreasing (32-34). Furthermore, the relationship between osteoporosis risk and income and education levels has been frequently emphasized in the literature (35-39), and a study using GBD study 2019 data identified a correlation between SDI and LBMD-related death and DALY rates (40). Differences in healthcare access, osteoporosis screening coverage, and the availability of densitometry across SDI groups likely contribute to these diverging trends; particularly in low- and middle-income countries, DXA provision is often severely limited and reimbursement policies for osteoporosis treatment vary markedly, creating substantial barriers to early identification and management of LBMD (41). In Türkiye, while mortality rates tended to decrease, the disease burden remained stable. For Türkiye specifically, despite the absence of a large-scale national specific intervention program for osteoporosis and relatively low disease awareness in the community, the advanced access to treatment under general health insurance and improved post-fracture orthopedic care services may have been influential in the emergence of this picture (42,43).

Study Limitations

The strengths of this study lie in its examination of both mortality and DALY rates over a 34-year period using the up-to-date GBD study 2023 data, which, to our knowledge, represent the most recently available GBD dataset used in this context and extend the analytical period to 2023. Simultaneous analysis of mortality and DALY rates, disaggregated by sex, offers a more complete picture of disease burden. Beyond standard analyses, identifying change points in temporal trends using Joinpoint regression, revealing inequalities by classifying countries according to SDI groups, and focusing on Türkiye's data further enhance the study's novelty.

However, the study has several limitations. GBD estimates are derived from statistical modeling that integrates numerous primary data sources; however, these estimates are inherently subject to modeling assumptions, data sparsity, and potential misclassification biases, particularly in low-SDI regions where vital registration systems are incomplete and survey data are scarce, and these limitations may affect the precision of country- and region-specific estimates. The 95% uncertainty intervals accompanying GBD estimates reflected this variability and were incorporated into the SE calculations of the present study. Although the GBD CRA framework isolates LBMD as a risk factor by holding other risk factors constant, falls remain multifactorial, influenced by frailty, environmental hazards, and neurological status. Therefore, attributing falls exclusively to LBMD may not fully capture the complexity of causal pathways that should be considered when interpreting the findings. Furthermore, because this is an ecological study using aggregated data, findings are subject to the ecological fallacy; therefore, causal inferences at the individual level are not justified. The dataset also does not include the impact of diagnostic coding systems that change over time, nor specific clinical details of patients.

Conclusion

The findings of this study have revealed the global burden of falls attributable to LBMD between 1990 and 2023. Over the 34-year period, the global disease burden (DALY rates) increased in both sexes, whereas mortality rates remained stable among females but increased significantly among males; recently, mortality rates have begun to rise again for both sexes. Although the lowest average mortality rates were observed in the high SDI group, the trend in this group was toward a significant increase; in contrast, decreases were recorded in the low and low-middle groups. DALY rates show a downward trend in the low and low-middle groups but an upward trend in other groups. Although Türkiye has demonstrated success in decreasing mortality over the 34-year projection period, the recent increase in mortality and DALY rates among males indicates that the current improvement is fragile.

Based on the results of this study, it is recommended that regular DXA screening programs be expanded at the national level for both sexes, specifically targeting high-risk age groups; that environmental factors that increase the risk of falls be regulated; that nutritional habits and physical activity that support bone health be encouraged; and that a national action plan be implemented to increase osteoporosis awareness within the community in Türkiye.

Ethics

Ethics Committee Approval: Ethical approval was not required for this study because it used publicly available de-identified secondary data from the global burden of disease study 2023. The research was conducted in accordance with the principles of the Declaration of Helsinki.

Informed Consent: Not applicable. This study was designed as an ecological time-series analysis using aggregate data; therefore, it did not involve direct contact with human subjects, and no individual-level clinical data were used.

Footnotes

Authorship Contributions

Concept: E.N.Y.Ö., Design: E.N.Y.Ö., S.G., Data Collection or Processing: E.N.Y.Ö., S.G., Analysis or Interpretation: E.N.Y.Ö., S.G., Literature Search: E.N.Y.Ö., Writing: E.N.Y.Ö., S.G.

Conflict of Interest: No conflict of interest was declared by the authors.

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Supplementary Figures S1-S7: https://d2v96fxpocvxx.cloudfront.net/e1c28131-4444-460a-9703-9fa751c405df/content-images/9f4e5b58-a301-4f0e-b05e-00418a3b6989.pdf

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