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Global burden and epidemiological risk factors of musculoskeletal disorders from 1990 to 2023 using decomposition modeling and quadrant mapping

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Abstract

Background: Musculoskeletal disorders (MSK) are the leading cause of disability worldwide. With the increasing aging of the global population, the prevalence pattern of MSK is undergoing profound changes. This study aimed to systematically evaluate the spatiotemporal trends, population characteristics and underlying drivers of global burden of MSK from 1990 to 2023.

Method: Data on the prevalence, disability-adjusted life years (DALYs) and deaths of low back pain, osteoarthritis, neck pain, gout, rheumatoid arthritis and other MSK diseases were extracted from 21 regions in 204 countries and regions. Average annual percent change (AAPC) was used to estimate the growth rate. Four-quadrant analysis

was used to identify the priority of policy intervention. Attributable decomposition method was used to quantify the contribution of population growth, ageing and epidemiological risk changes to the growth of burden.

Result: There was significant geographical heterogeneity in the global burden of MSK in 2023, with North America having the highest standardized DALY rate and East Asia showing an explosive increase. The burden of rheumatoid arthritis (RA) was higher in women than in men except for gout (male to female ratio was 0.4). Osteoarthritis and gout are the subtypes with the fastest growing burden between 1990 and 2023, with Aapcs exceeding 2% in East Asia and North America in general. The four-quadrant analysis showed that gout and osteoarthritis (OA) in East Asia were in the "high burden-high growth" urgent intervention quadrant. Mortality pattern analysis showed that MSK-related mortality increased sharply after age 75 years old, which was highly coupled with the aging process. Attributable decomposition shows that the surge in global cases is mainly driven by population growth (about 60%) and ageing, but in high-income regions, the rise in epidemiological risks (such as the obesity epidemic) has become a real driver that cannot be ignored.

Conclusion: The global burden of musculoskeletal conditions continues to increase and is shifting from high-income countries to lower-middle-income countries. The growth in burden is driven by demographic transitions combined with rising lifestyle risks. Health policy makers should integrate MSK prevention and control into the whole life cycle health management according to the principle of "driver differentiation", especially adopt gender-sensitive early intervention measures in

high-growth regions to cope with the increasing challenge of aging.

Keywords: global burden of disease; Musculoskeletal disorders; Disability-adjusted

life years; Decomposition analysis; Mean annual percent change; Health policy

1. Introduction

Musculoskeletal Disorders (MSK) have gradually become one of the most serious challenges in the field of global public health. These diseases are anatomically characterized by pain and functional limitation, and are widely prevalent in all ages and social classes^[1]. Musculoskeletal diseases cover a range of complex disorders affecting bones, joints and muscles, from low back pain and neck pain to osteoarthritis, rheumatoid arthritis and gout^[2]. Although these diseases are generally considered to be non-fatal, their high prevalence and long-term disability make them the leading driver of the increase in years lived with disability (YLDs) and disability-adjusted life years (DALYs) worldwide^[3, 4]. At the individual level, MSK leads to long-term chronic pain and dysfunction, and significantly reduces the quality of life^[5]. At the societal level, it not only causes huge direct medical expenses, but also brings a heavy economic burden due to labor loss and decreased productivity^[6, 7]. Therefore, systematic assessment of the current situation and evolution of global MSK burden is of irreplaceable strategic significance for formulating precise public health strategies^[8].

However, current MSK research still faces multiple limitations and knowledge gaps. First of all, most previous studies are based on Global Burden of Disease (GBD) 2019 or earlier data versions, which cannot reflect the latest evolution of global health dynamics in the post-pandemic era^[9]. In particular, under the background of accelerated aging and the global rise of obesity rates, the epidemiological characteristics of musculoskeletal diseases are undergoing subtle and profound

changes^[10, 11]. Secondly, the existing literature often focuses on the analysis of a single disease (such as the study of low back pain or gout alone)^[12, 13], and there is a lack of cross-dimensional and cross-regional systematic comparison of the six major MSK diseases under the same research framework. Therefore, it is difficult for policy makers to identify the differences in sexual dimorphism, life course distribution, and geographical heterogeneity of different diseases from a global perspective. More importantly, simply describing the increase of disease burden is no longer enough to support precise intervention, and the academic community urgently needs to deeply explore the underlying driving force of the burden surge, that is, to quantify the respective roles of population growth, structural aging and epidemiological risk changes in the evolution of case number^[14].

Based on the latest results of the Global Burden of Disease 2023 (GBD 2023) study, this study conducted a comprehensive review and prospective assessment of the burden of musculoskeletal diseases in 204 countries and regions around the world from 1990 to 2023. We not only focus on the traditional incidence and prevalence indicators, but also introduce multi-dimensional policy evaluation tools. Average annual percent change (AAPC) and spatial-temporal trend analyses were used to capture the "acceleration" of different diseases, especially to identify the characteristics of osteoarthritis (OA) and gout outbreaks in rapidly industrializing regions. A cross-matrix between baseline burden and growth rate was used to classify global regions into different intervention levels to provide a scientific basis for resource allocation. In view of the little-known mortality risk of MSK, we also used

the age-specific pattern analysis in logarithmic axis to reveal the death law of MSK changing with the life course, breaking the inherent cognition that MSK is only a "non-fatal disease"^[15]. The core significance is that through rigorous attribution decomposition analysis, the social and demographic drivers of the increase of MSK burden in each region are dismantled. We not only quantify the contribution of population growth and aging to the total number of diseases, but also focus on how real epidemiological risks (such as pathological changes caused by metabolic factors) drive additional increases in disease burden at different levels of socioeconomic development^[16, 17]. This multi-dimensional in-depth analysis aims to reveal the uneven distribution of musculoskeletal diseases in different geographical units and social groups. The systematic evidence from this study is expected to provide policy makers with an integrated framework for action to address the growing challenges of musculoskeletal health and to shift the global health system towards a greater focus on long-term quality of life and healthy aging.

2. Methods

The data for this study was extracted entirely from the Global Burden of Disease Study 2023 (GBD 2023) database, maintained by the Institute for Health Statistics and Evaluation (IHME), Provides the most authoritative epidemiological estimates on a global scale^[18]. This study covered 204 countries and regions around the world, which were further grouped into 21 geographic regions and 7 super regions for in-depth comparison of spatial heterogeneity. In terms of disease classification, we

strictly follow the criteria of the tenth revision of the International Classification of Diseases (ICD-10) to lock down six core subtypes under the broad category of musculoskeletal diseases (MSK) : low back pain, osteoarthritis, neck pain, gout, rheumatoid arthritis and other categories of musculoskeletal diseases^[19]. To ensure the spatial and temporal comparability of data, this study spanned a long period from 1990 to 2023, and extracted multi-dimensional indicators including prevalence, incidence, disability-adjusted life years (DALYs) and mortality^[20].

In the quantitative processing of indicators, the calculation of age-standardized Rate (ASR) is a key step to eliminate the differences in population Age structure among different regions. We used GBD standard world population weights to standardize the incidence, prevalence and DALYs rate, which enables a fair comparison of disease burden in areas with severe aging and areas dominated by young people at the same scale^[21]. For the assessment of the burden of disability, this study focuses on the comprehensive indicator DALYs, which is the sum of years lived with premature death (YLLs) and years lived with disability (YLDs)^[22]. Given the extremely high disability weight and relatively low direct mortality of musculoskeletal diseases^[23], we further explored the spatial heterogeneity of disease severity by comparing the distribution of DALYs and prevalence. For the analysis of mortality patterns, this study evaluated the age-specific trajectories of all-cause and MSK-related mortality using a logarithmic coordinate system to reveal the unique risk characteristics of specific diseases in the aging population.

To assess the "speed" and "direction" of the evolution of the disease burden over

the 33 years, the average annual percentage change (AAPC) was introduced as the core statistic. AAPC was obtained by modeling the annual standardized rate by log-linear regression^[24], and its positive and negative values represent the continuous growth or improvement of burden, respectively. The absolute value of AAPC quantized the acceleration of this change. This dynamic assessment approach can not only identify which diseases are experiencing explosive growth (e.g., osteoarthritis and gout), but also visualize the evolution differences in different geographic units in the form of heat maps. In addition, this study innovatively applied a four-quadrant priority analysis matrix, with the baseline standardized DALY rate in 1990 as the horizontal axis, the total percentage change from 1990 to 2023 as the vertical axis, and the global median value as the dividing line. This methodology divided the subjects into four categories: "high burden-high growth (emergency intervention area)", "high burden-low growth (saturated management area)", "low burden-high growth (potential outbreak area)" and "low burden-low growth (relatively stable area)". Thus, complex epidemiological data can be directly transformed into a hierarchical management scheme with policy guiding significance^[25].

The advanced stage of our methodology lies in a deep dismantling of the growth dynamics of the burden of disease. We decomposed the absolute increase in the total number of cases between 1990 and 2023 in each region into three independent drivers using the log-mean Dili exponential decomposition (LMDI) or an analytical model based on the Das Gupta decomposition framework^[26]: Total population growth effect, population structure aging effect and real epidemiological risk change effect. By

comparing the difference between the standardized rate and the absolute number, this methodological logic can accurately quantify how much of the burden is caused by social-demographic expansion, and how much is caused by the real increase in disease risk driven by lifestyle and environmental exposure^[27]. Finally, all spatial mapping and statistical visualization were done in Python (version 3.6) and its advanced plotting libraries Seaborn, Matplotlib, and Pandas, ensuring that the graphs are scientific and rigorous when representing multi-dimensional, high-density data.

3. Results

3.1 Current panorama and geographical heterogeneity of the global burden of musculoskeletal diseases

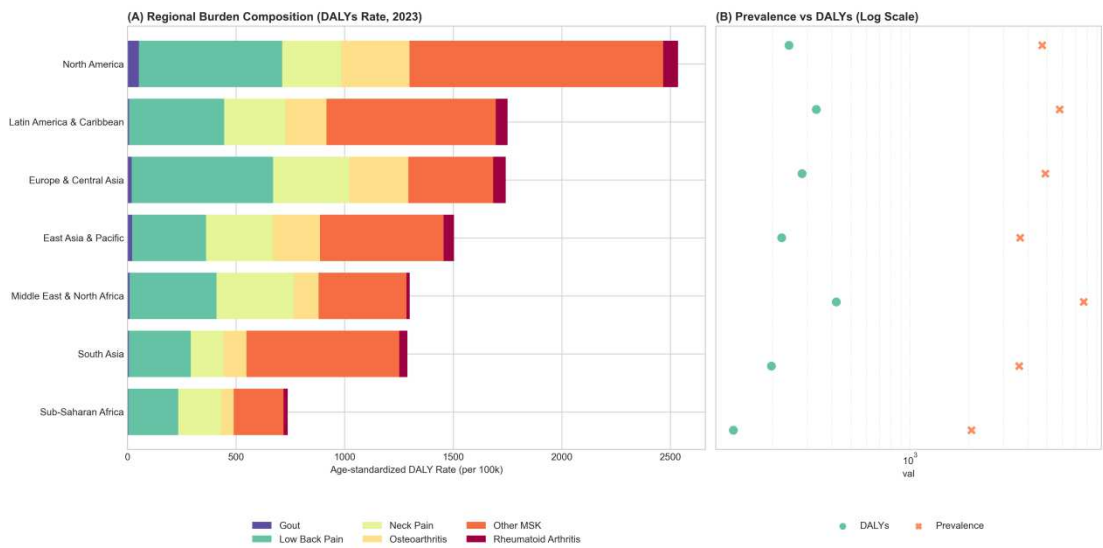


Figure 1. Global and regional burden of musculoskeletal disorders and the relationship between prevalence and

DALYs in 2023

Note: (A) Stacked bars show the composition of age-standardized DALY rates for the six major musculoskeletal diseases in the seven regions of the world in 2023. (B) Log-coordinate scatter plots revealed the association between age-standardized prevalence rates and DALY rates in different regions, reflecting the spatial differences in

disease burden severity.

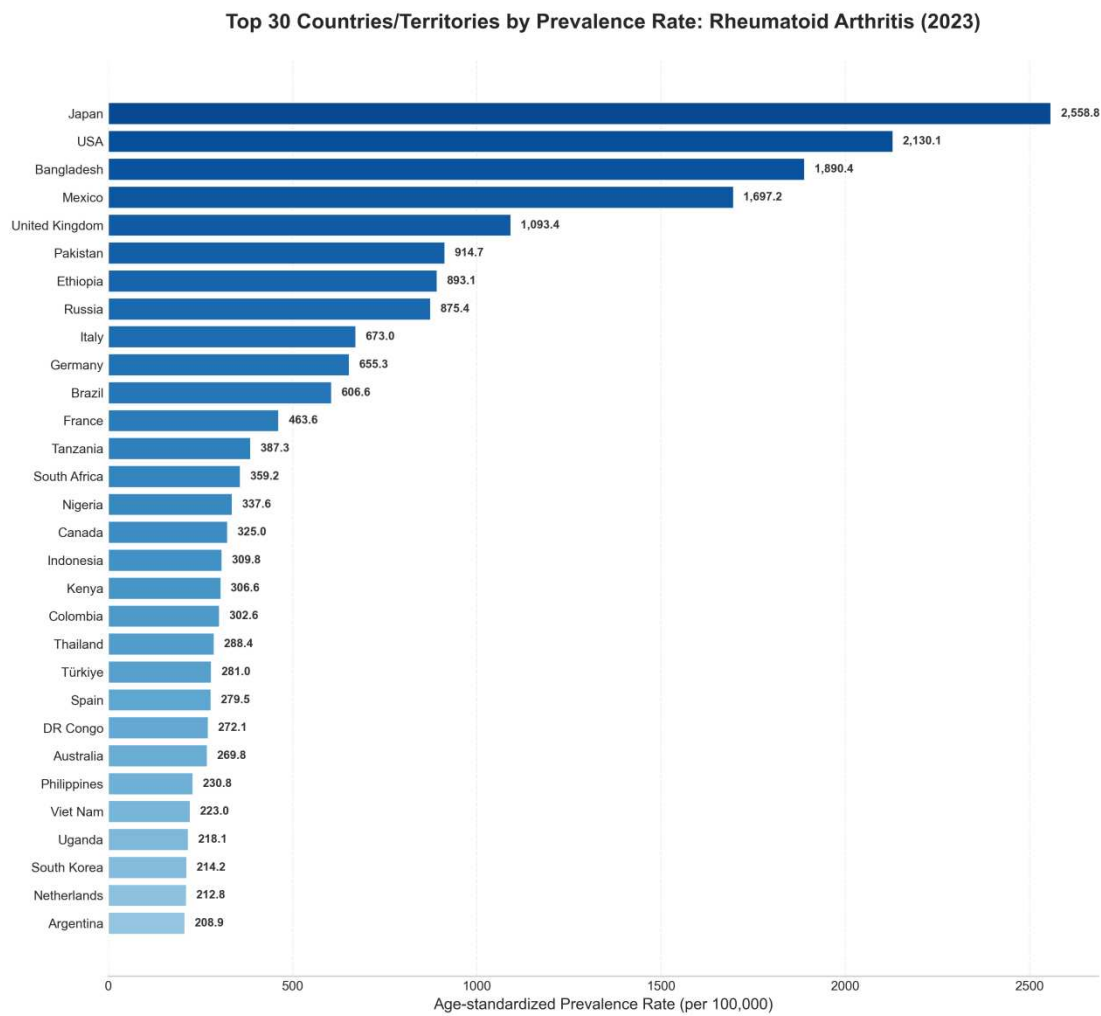


Figure 2. Top 30 countries and territories with the highest age-standardized prevalence rates of rheumatoid arthritis in 2023

Note: Horizontal bars rank countries globally by age-standardized prevalence per 100 000 population. The figure demonstrates the geographical heterogeneity of RA across the globe, with color gradients representing disease severity.

The global burden of musculoskeletal conditions (MSK) in 2023 shows significant geographical heterogeneity. In terms of age-standardized DALY rates, North America ranked first in the world, with a total burden that far exceeded that of other regions, while sub-Saharan Africa had a relatively low level (Figure 1A). In

terms of disease composition, although absolute values varied widely across regions, the internal structure showed a high degree of consistency, with "Other musculoskeletal disorders" (Other MSK) and "low back pain" accounting for the major share of DALYs in all geographic units (Figure 1A). Data from the association analysis between prevalence and DALYs showed not only higher prevalence but also a greater burden of disability per case in high-income regions (Figure 1B). At the country level, taking rheumatoid arthritis as an example, Japan and the United States showed the highest prevalence levels globally, with standardized prevalence rates of 2558.8 and 2130.1 per 100 000 population, respectively (Figure 2). Notably, a large number of developing countries (such as Bangladesh, Mexico, and Pakistan) also make it into the global top 30, which strongly refutes the traditional assumption that MSK is only a burden for wealthy societies, revealing its widespread threat to global health (Figure 2).

3.2 Population distribution of disease burden: sexual dimorphism and life-course patterns



Figure 3. Regional age-standardized prevalence rates of six musculoskeletal disorders by gender in 2023

Note: Disease burden in women (pink) versus men (blue) is contrasted by multi-panel paired bars. The "Avg F:M" value in the figure represents the global average female/male prevalence ratio, highlighting the female susceptibility to most MSK disorders except gout.

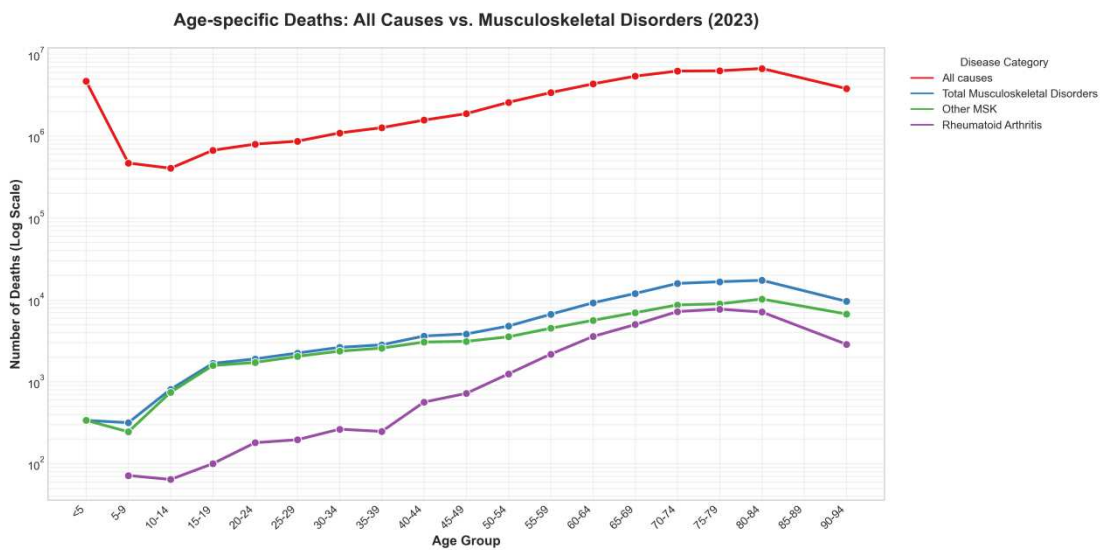


Figure 4. Global age-specific death numbers for all-cause and musculoskeletal disorders in 2023

Note: The log-coordinate line plots show the distribution of deaths by age group. The red line represents the

pattern of all causes of death, and the remaining color curves show a steep increase in the risk of death with aging for specific MSK diseases.

Musculoskeletal diseases show significant gender dimorphism. Figure 3 shows that the burden of the remaining five major MSK subtypes was significantly higher in women, except for gout, which showed a significant male predominance with a global average female/male prevalence ratio of only 0.4. The gender disparity in rheumatoid arthritis is the most dramatic, with approximately three times as many women as men globally; Osteoarthritis, neck pain, and low back pain were also associated with a 50%-70% higher risk in women. This gender imbalance is particularly pronounced in high-income regions such as North America and Europe, hinting at the complex effects of biologic differences and sex roles on disease exposure in different social Settings (Figure 3).

In the dimension of age, the mortality risk related to MSK showed a nonlinear increase law with the life course. As observed by the log-coordinate analysis in Figure 4, the mortality pattern of MSK was highly parallel to the global pattern of all causes of death, with the risk beginning to increase steeply after the age of 50 years and peaking at the age of 75 to 84 years. Notably, the slope of the age-specific mortality curve was steeper for rheumatoid arthritis (RA) than for other diseases, which strongly challenged the conventional perception of MSK as only a "non-fatal disability" (Figure 4).

3.3 Time evolution trend analysis and growth rate evaluation

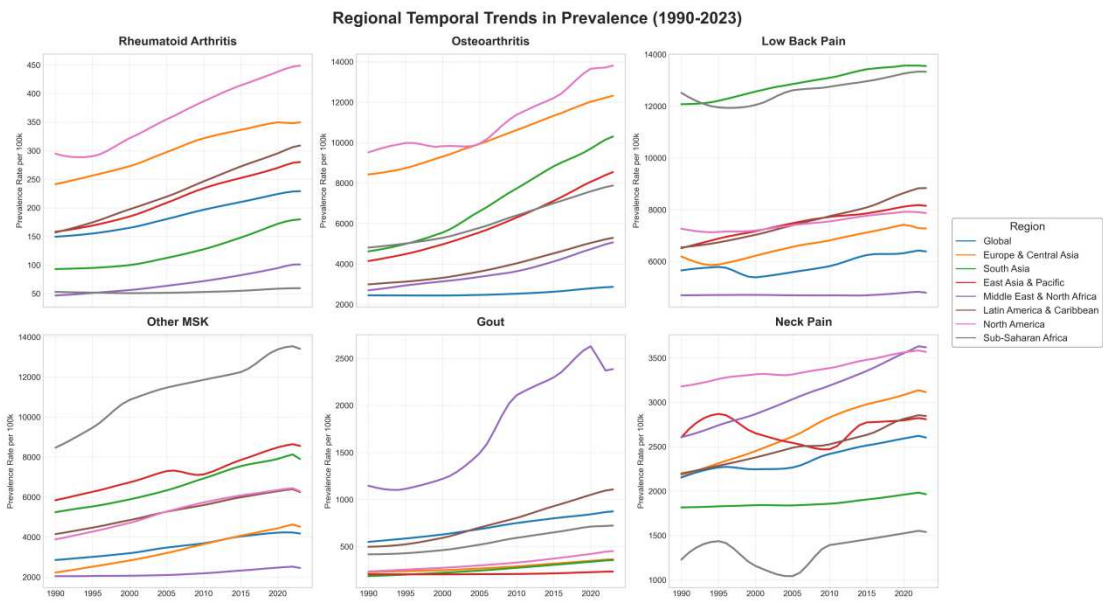


Figure 5. Regional trends in age-standardized prevalence rates of six musculoskeletal disorders from 1990 to 2023

Note: The line graph depicts the longitudinal trajectory of prevalence in each GBD region over the past 33 years.

Osteoarthritis and gout showed significant upward slopes in most regions.

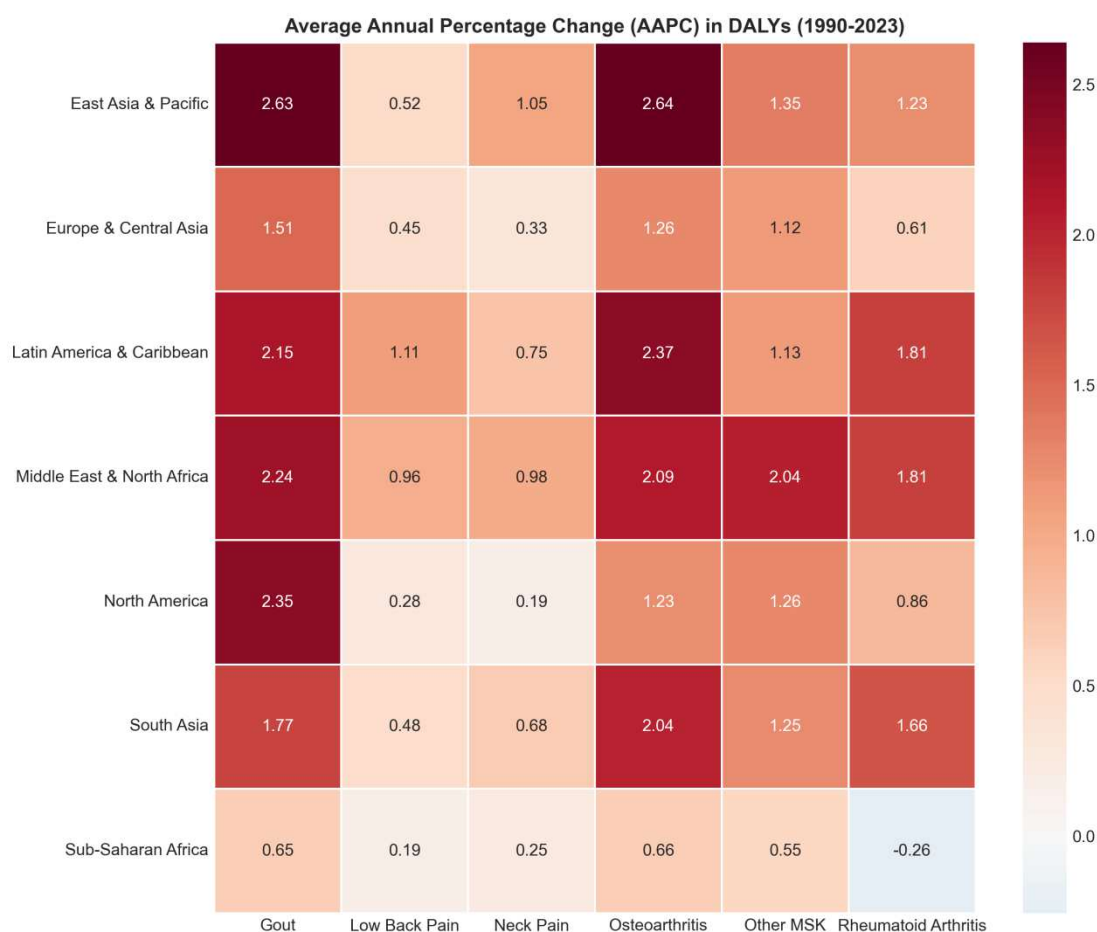


Figure 6. Heatmap of Average Annual Percentage Change (AAPC) in MSK age-standardized DALY rates by disease and region, 1990 - 2023

Note: Color shades quantify the acceleration in the growth of individual disease burden from 1990 to 2023. The dark red area represents the warning target of very high average annual growth rate, reflecting the rapid rise of epidemiological risk.

During the 33 years from 1990 to 2023, the trajectory of global MSK burden showed obvious disease differentiation. Osteoarthritis (OA) and gout are the "twin engines" driving the increase of burden. As shown in Figure 5, the prevalence curves of these two showed significant upward slopes in almost all regions, especially in East Asia, where the standardized prevalence of OA experienced an explosive increase during the study period. In contrast, low back pain showed a pattern of "high and

steady increase", and the South Asian region was always in the global leading position in this indicator (Figure 5).

This evolutionary "acceleration" can be more intuitively represented by the average annual percent change (AAPC) heat map of DALY rates. The rate of this increase is quantified by the depth of color in Figure 6: gout has now surpassed 2% AAPC in East Asia, North America, and the Middle East, making it the most rapidly expanding MSK subtype in recent years. In contrast, in parts of Europe, low back and neck pain increased at a more moderate rate and plateaued, as indicated by lighter patches in the heat map (Figure 6).

3.4 Dynamic attributable decomposition of the surge in musculoskeletal disease burden

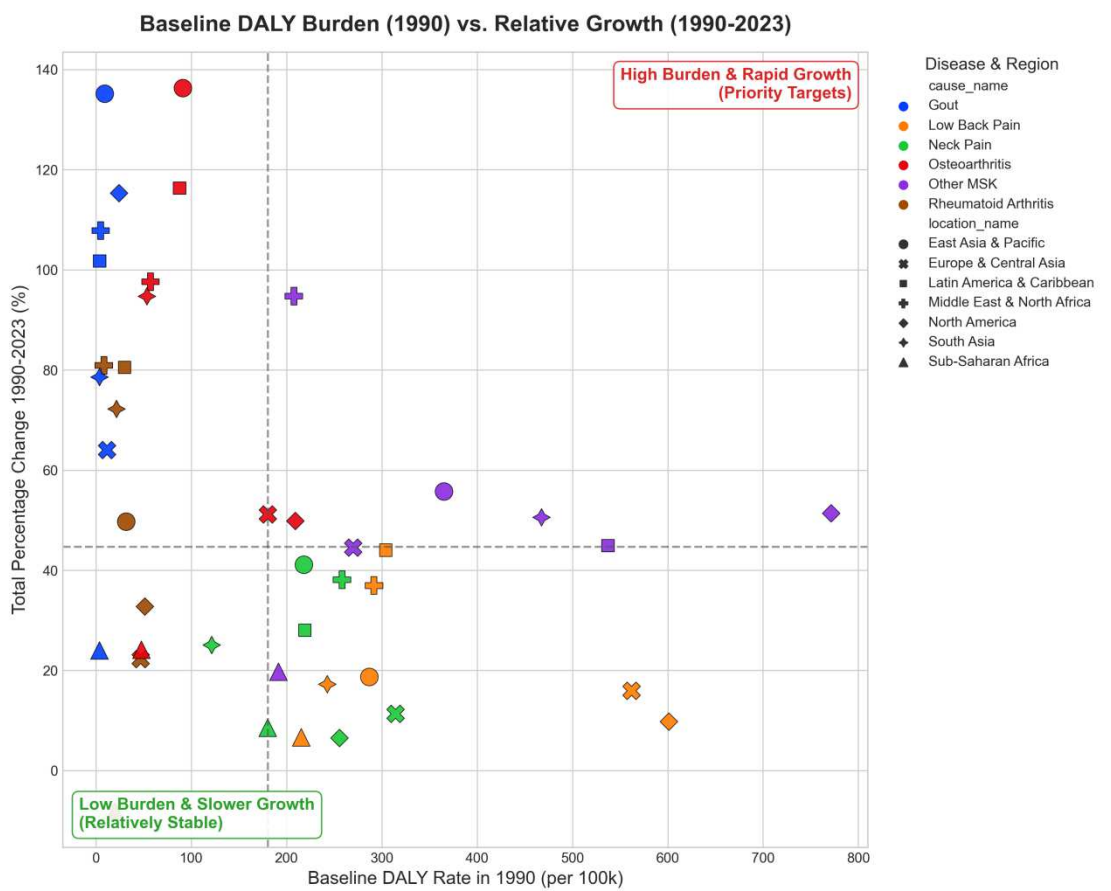


Figure 7. Quadrant analysis mapping: Baseline DALY burden (1990) vs. total percentage change (1990 – 2023)

Note: Based on the standardized DALY rate in 1990 and the 33-year growth rate, the scatter plot divided the regions into four dimensions. The red box in the upper right corner is the "high burden-high growth" quadrant, which is the highest priority area for public health intervention. The dashed line represents the global median value level.

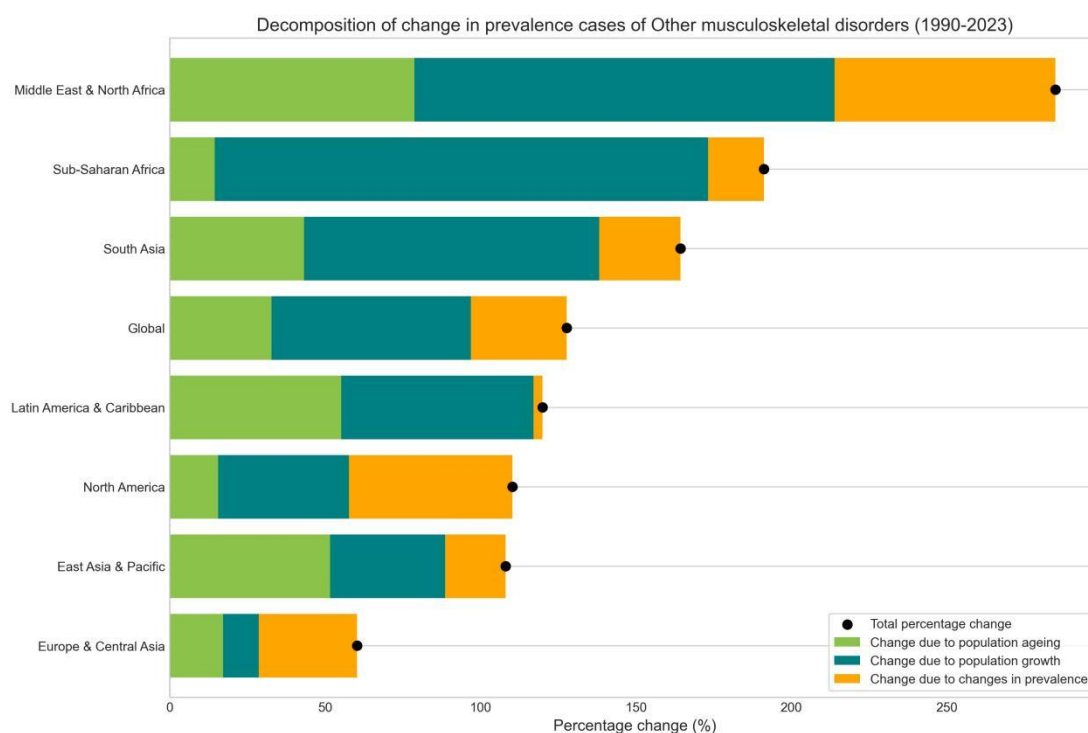


Figure 8. Decomposition analysis of changes in prevalence cases for other musculoskeletal disorders by region, 1990 – 2023

Note: This figure disaggregates the drivers of changes in the total number of cases. Dark green represents the population growth effect, light green represents the population ageing effect, and orange represents the epidemiological risk change effect. Black dots represent the total percentage change in cases in each region.

To identify priorities for intervention at the macro policy level, this study constructed a four-quadrant mapping matrix based on the 1990 baseline DALY burden and the total growth rate over the 33 years (FIG. 7). The distribution according to Figure 7 shows that the horizontal axis represents the starting burden level in 1990, the vertical axis represents the relative percentage change from 1990 to 2023, and the intersection of the two dashed lines corresponds to the global median value. The red labeled area in the upper right quadrant (High Burden & Rapid Growth), defined as "priority targets for intervention," is prominent for gout (blue dots) and osteoarthritis (red dots) in East Asia and for other musculoskeletal conditions in Latin America

(purple squares). These targets have a large base and are deteriorating rapidly. In contrast, the green regions in the lower left quadrant (Low Burden & Slower Growth) represent regions with relatively stable burdens. Notably, although some indicators in sub-Saharan Africa (the left-hand triangle) started from a low level of burden, the extremely high percentage increases on the ordinate point to substantial health system strains in the region ahead.

In view of the deep logic of the increase in the number of cases globally and in each region, this study used the attribution decomposition model to decompose the increment into three complementary effects, which were visualized in Figure 8. Black dots represent the total percentage change in cases by region, whereas the colors of the stacked bars correspond to different drivers: dark green for the effect of total population growth, light green for the effect of population structure aging, and orange for the effect of change in epidemiological risk. From the decomposition results in Figure 8, the increase in cases worldwide is mainly driven by demographic factors. In the Middle East and North Africa (MENA) and sub-Saharan Africa, the dark green bars dominate, accounting for more than 60% of the total growth, reflecting the dramatic population expansion. In contrast, North America, Europe, and East Asia showed significant increases in the proportions of light green bars (aging effect) and orange bars (epidemiologic risk effect). In particular, the increase in true disease risk, represented in orange, accounted for nearly one third of the increase in cases in high-income regions such as North America and East Asia, possibly owing to growing obesity epidemics, sedentary work patterns, and the rise in the metabolic syndrome.

This analysis of multidimensional driving forces emphasizes the urgency of lifestyle interventions to control epidemiological risks in the context of aging.

4. Discussion

Based on the latest data from the Global Burden of Disease 2023 (GBD 2023), this study provides a multi-dimensional analysis of the evolution of the global burden of musculoskeletal diseases (MSK) over the past 33 years. Research results clearly reveal that musculoskeletal diseases are no longer the exclusive burden of high-income countries, and their global expansion shows significant spatial and temporal heterogeneity^[28]. The core finding is that although the standardized prevalence of each disease subtype has maintained varying degrees of growth, the surge in the absolute total number of cases is mainly due to the rapid expansion of the global population and its profound aging transition. This trend is particularly pronounced in East and South Asia, reflecting the rapid economic growth that these regions are experiencing and the associated strains on their health systems. The early warning area of "high burden-high growth" established by the four-quadrant analysis provides a quantitative scientific basis for the reallocation of global health resources, suggesting that policy makers must shift the prevention and control of MSK from "marginal non-lethal management" to "mainstream strategic response to aging".

As the "twin engines" with the fastest growth rate, gout and osteoarthritis reflect the epidemiological risk changes that deserve further consideration. In this study, the AAPC of gout was significantly higher in East Asia and North America, which was

highly consistent with the prevalence of metabolic syndrome, obesity and high-purine dietary habits in these regions in recent years^[29, 30]. The outbreak of gout is not only a local problem of the musculoskeletal system, but also a side reflection of global overnutrition and metabolic disorders. At the same time, the rapid growth of osteoarthritis in East Asia, in addition to the contribution of population aging^[31], is more likely to be related to the accumulation of occupational strain injuries and drastic changes in physical activity patterns during the process of industrialization in the region^[32]. This real increase at the epidemiological level means that it is difficult to curb the spread of the burden by relying on the existing clinical treatment alone, and it is necessary to reduce the overall exposure risk of the population through upstream interventions such as obesity control and occupational ergonomics improvement from the perspective of the whole life cycle.

The prevalence of sexual dimorphism in MSK is another important finding of this study. Females showed a higher burden in almost all MSK subtypes except gout, with a staggering F:M ratio of 3.0 in rheumatoid arthritis. This significant gender bias not only involves the biological regulation of sex hormones (such as estrogen) on the autoimmune system and cartilage metabolism^[33, 34], but also reflects the inequality of social gender roles in labor exposure, housework burden, and medical seeking behavior^[35]. This gender gap is more significant in high-income regions, which may be due to better diagnostic systems in these regions, which capture the hidden burden of more female patients, but it may also indicate that women face more physical discomfort and cumulative damage effects in developed societies^[36]. Therefore, future

health policies should be more gender sensitive and deeply integrate early screening of MSK with women's health management plans.

Through the decomposition analysis, this study provides solid evidence on why the burden is increasing, which has important reference value at the health planning level. We found that in most low - and middle-income regions, the increase in case numbers was driven almost entirely by population growth, whereas in high-income countries and East Asia, population ageing and a rise in true epidemiologic risk predominated. This finding shattens the blind optimism that as rates fall, burdens fall, and reveals a harsh reality: even if standardized prevalence remains stable, natural evolution in population size and structure will force health systems to confront exponentially growing patient populations in the coming decades. In addition, the analysis of MSK-related death patterns demonstrated the hidden lethality of such diseases in the elderly population. Diseases such as rheumatoid arthritis have a surge in mortality risk after the age of 75 years, suggesting that MSK is often intertwined with severe comorbidities such as cardiovascular diseases^[37, 38] and respiratory diseases^[39], thus creating a synergistic lethal effect in the context of aging.

Although this study provides a comprehensive panorama, there are some limitations. First of all, the estimation of GBD largely depends on the quality of the original surveillance data of each country. In some sub-Saharan Africa and Central Asia, the missing data caused by the weak health information system may cause the deviation of the model estimation^[40]. Secondly, due to the wide variety of diseases covered by MSK, the classification of some "Other musculoskeletal disorders (Other

MSK)" is too general, which masks the uniqueness of some specific diseases. Future studies should further explore the specific contribution rate of specific risk factors such as obesity and sedentary behavior^[41] to MSK burden in different cultural contexts in combination with longitudinal cohort data. Overall, this study highlights the urgent position of musculoskeletal health in the global health agenda and calls on countries to include MSK prevention and treatment in the core category of universal health coverage (UHC)^[42], and to achieve proactive responses to the challenge of global ageing through differentiated strategies that distinguish between "risk-driven" and "population-driven".

5. Conclusion

This systematic assessment of the global burden of musculoskeletal diseases from 1990 to 2023 provides evidence that musculoskeletal health is no longer a marginal issue on the global health agenda, but a central challenge that directly affects the global healthy ageing process. In the past three decades, the global burden of musculoskeletal diseases has shown a significant expansion, especially the explosive growth of osteoarthritis and gout, reflecting not only the profound impact of population aging, but also the epidemiological threat caused by metabolic risk and modern lifestyle changes. Through the four-quadrant priority matrix and attribution decomposition model, it was clearly pointed out that although population growth and structural aging were the main drivers for the surge in case number, the real increase of epidemiological risk in many high-burden regions also contributed to the

non-negligible increment. In addition, the significant gender difference and the steep increase in mortality risk associated with MSK among older people further reveal the profound impact of this disease on health inequalities. The evidence chain from this study clearly indicates that future health planning must break away from the traditional focus on deadly diseases and establish an integrated prevention and control framework. It is necessary not only to strengthen early interventions against modifiable risk factors such as obesity and sedentary behavior, but also to integrate musculoskeletal health management into the universal health coverage (UHC) system and aging strategies. Only through differentiated strategies that distinguish "population-driven" from "risk-driven" and adopt gender-sensitive interventions can the global health system effectively address the growing challenge of musculoskeletal conditions.

Declarations

Ethics approval and consent to participate

Not applicable. This secondary analysis was based on the publicly accessible Global Burden of Disease (GBD) database. All data were anonymized and desensitized before publication by the Institute for Health Metrics and Evaluation (IHME). Therefore, ethical approval and informed consent were waived for this study.

Consent for publication

Not applicable.

Availability of data and materials

During this study analysis of the data set is available in global health data exchange (GHDx) repository publicly available, the database is the global burden of disease (GBD), official figures portal link: (<https://www.healthdata.org/research-analysis/gbd>).

Competing interests

The authors declare that they have no competing interests (or conflicts of interest).

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