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How Do Haemophilus Influenzae, Neisseria Meningitidis, And Streptococcus Pneumoniae Differ in Their Age-Specific Global Mortality Rates from Meningitis Between 2019 And 2023?

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Abstract- Background:
Bacterial meningitis remains a major cause of mortality in neonates and infants globally, with disease severity, mortality, and long-term outcomes varying by both causative pathogen and age. Haemophilus influenzae, Neisseria meningitidis, and Streptococcus pneumoniae account for a substantial proportion of cases worldwide, although their relative contribution varies across regions and vaccination settings. Despite this, comprehensive comparisons of age-specific mortality patterns across these pathogens using recent global burden estimates remain limited.
Methods:
Global Burden of Disease (GBD) 2019–2023 estimates were analysed to assess age-specific mortality rates attributable to Haemophilus influenzae, Neisseria meningitidis, and Streptococcus pneumoniae. Data were extracted for 25 standard GBD age groups, ranging from early neonatal (0–6 days) to ≥95 years, at the global level for both sexes combined. Descriptive analyses were performed to evaluate temporal trends and cross-pathogen differences across age strata.
Results:
Mortality burden was highest in neonates, peaking within the first week of life, and declined sharply after the first year. S. pneumoniae accounted for the greatest share across all age groups, followed by N. meningitidis and H. influenzae, a ranking that remained consistent throughout the life course. A secondary rise in mortality was observed in individuals aged 95 and older. Between 2019 and 2023, mortality rates declined across all three pathogens, with the most pronounced reduction seen in H. influenzae.

I. INTRODUCTION

Bacterial meningitis is a serious condition characterised by inflammation of the protective membranes surrounding the brain and spinal cord. It can lead to severe outcomes, including death and long-term complications such as hearing loss, cognitive impairment, and motor disabilities. Despite improvements in global healthcare, bacterial meningitis remains a significant public health concern, particularly in low- and middle-income regions where access to timely diagnosis and treatment is limited.

Over recent decades, the global burden of bacterial meningitis has declined. Between 1990 and 2021, incidence rates in children decreased substantially, alongside a marked reduction in mortality. However, the disease continues to cause considerable morbidity and mortality, with over one million cases and approximately 112,000 deaths reported in children in 2021 alone.[2]

The primary bacterial pathogens responsible for meningitis are Haemophilus influenzae, Neisseria meningitidis, and Streptococcus pneumoniae. The relative contribution of these pathogens varies by region, vaccination coverage, and age group. Differences in immune system maturity and pathogen characteristics influence which populations are most affected. For example, H. influenzae is more common in younger infants, while N. meningitidis and S. pneumoniae affect a broader age range.[2]

Vaccination programmes have played a key role in reducing the burden of disease. The introduction of

the Haemophilus influenzae type b (Hib) vaccine has led to a significant decline in infections [3], and pneumococcal vaccines have contributed to reductions in severe disease globally. [4,8] However, disparities persist across regions due to differences in healthcare access, vaccination coverage, and surveillance systems.

Although substantial data exist on bacterial meningitis, many studies focus on individual pathogens or specific age groups. Comprehensive comparisons of multiple pathogens across the full age spectrum using recent global data remain limited.

This study aims to compare age-specific global mortality patterns of meningitis attributable to Haemophilus influenzae, Neisseria meningitidis, and Streptococcus pneumoniae using Global Burden of Disease (GBD) estimates from 2019 to 2023. By examining these patterns across different stages of life, this analysis provides insights that may support age-targeted prevention strategies and improved disease surveillance.

II. LITERATURE REVIEW

Despite substantial progress, bacterial meningitis remains a significant global health burden, particularly among infants and elderly populations. Between 1990 and 2021, incidence and mortality rates declined considerably, with cases in children decreasing by nearly 60% and deaths by approximately 70%. However, the disease continues to have a major impact, with over one million cases and more than 112,000 deaths reported among children in 2021.[2] These trends highlight both progress and the ongoing need for improved prevention strategies.

Vaccination has played a critical role in reducing disease burden. Studies have shown that the introduction of pneumococcal vaccines in lower-income countries led to consistent declines in disease incidence, with reductions of approximately 8% per year following widespread implementation.[4] Similarly, the introduction of the Haemophilus influenzae type b (Hib) vaccine has significantly reduced infection rates [3]. However, disparities persist, with higher mortality observed in regions where vaccine access and healthcare infrastructure remain limited.

The contribution of individual pathogens varies across age groups and geographical regions. A global analysis of multiple studies found that Streptococcus pneumoniae and Neisseria meningitidis are the leading causes of bacterial meningitis, accounting for approximately 25.1–41.2% and 9.1–36.2% of cases, respectively. Regional differences are substantial; for example, pneumococcal meningitis accounts for a higher proportion of cases in Africa compared to Europe, while meningococcal infections are more prominent among children aged 1–5 years in Europe.[1]

Age-specific patterns further influence disease burden. Haemophilus influenzae is more common in very young infants, particularly those under five months of age, many of whom are either too young to be vaccinated or have not completed immunisation schedules.[5] In contrast, Neisseria meningitidis shows peaks in both early childhood and adolescence[6], while Streptococcus pneumoniae affects a broader age range, with increasing severity observed in older populations.[7] Mortality rates are highest in the youngest and oldest age groups, reflecting differences in immune system strength and vulnerability.

Although existing studies provide valuable insights into individual pathogens and specific populations, comprehensive comparisons across all three major pathogens and across the full age spectrum remain limited. Most research focuses on single organisms or restricted age groups, limiting the ability to understand overall patterns of disease burden.

This study addresses this gap by analysing age-specific global mortality patterns of meningitis attributable to Haemophilus influenzae, Neisseria meningitidis, and Streptococcus pneumoniae using Global Burden of Disease (GBD) 2023 estimates from 2019 to 2023. By examining these pathogens together across all stages of life, the study aims to provide a more integrated understanding of disease burden and support improved public health strategies.

III. METHODS

Looking at patterns over time, this work used numbers-based observation to explore how bacterial meningitis affected different age groups worldwide from 2019 to 2023. Three main causes were tracked: Haemophilus influenzae, Neisseria meningitidis, and Streptococcus pneumoniae. Rather than testing interventions, researchers compared existing health records across these microbes.

With an eye on shifts across years, the method followed changes in death rates and disability-adjusted life years – called 'DALYs' – for 25 separate age brackets. Each pathogen's impact unfolded side by side, revealing contrasts without interference. Since nothing was altered during data collection, findings emerged strictly from what already existed. Over five years, trends took shape through comparison rather than control.

Data for this analysis came from two sets created by the Global Burden of Disease 2023 project, released by the Institute for Health Metrics and Evaluation at the University of Washington. Known broadly for reliable global health figures, IHME's findings frequently appear in scientific journals and World Health Organization guidelines, along with national public health strategies across countries. One set included death rates linked to meningitis broken down by cause and age; meanwhile, the other listed disability-adjusted life year rates using identical classifications. Spanning 2019 to 2023, both covered 25 distinct age brackets – starting from newborns under one week old up to people aged 95 or more – at a worldwide summary scale. Each value arrived with high and low bounds reflecting statistical reliability tied to every estimate presented.

Though focused on different outcomes, this analysis treated pathogen type, age bracket, and year as key predictors. Mortality appeared as deaths per 100,000 people in each age segment, shaping one part of the picture. Another piece came through DALYs – also scaled per 100,000 – which combined time lost from early death with periods marked by illness-related disability. Because they fold in both fatal and ongoing health impacts, these units offer broader insight than death counts by themselves. Their use allows tracking how various forms of meningitis affect populations over time, regardless of whether the outcome is death or lasting impairment.

Getting started meant shaping up two separate sets before anything else. Though they arrived as Excel files, adjustments came early – column labels got aligned so everything matched neatly down the line.

From there, pieces scattered across several tabs in the mortality document were pulled together into one clear structure. A closer look showed some age ranges overlapped; notably, the broad label "under 28 days" was dropped because it repeated finer divisions already included. After trimming that overlap, attention shifted to isolating entries tied to just three specific germs. Each point was cross-checked through time, making sure nothing slipped out of view. When all checks finished, every number needed was complete – with no blanks found where estimates should have been.

With clean data in place, analysis was conducted using Microsoft Excel. Mean mortality and DALYs rates were first calculated for each pathogen-age group combination by averaging central estimate values across the five-year study period, producing stable burden estimates that reduce the influence of single-year fluctuations. Building on this, year-on-year trend analysis was performed by summing rates across all age groups per pathogen per year, enabling assessment of the directional change in overall burden between 2019 and 2023.

Cross-pathogen comparisons were then conducted across all 25 age groups simultaneously to identify at which life stages each pathogen carried the greatest relative burden and where dominance shifted between organisms. Finally, the proportion of total mortality burden concentrated in children under five years of age was calculated separately for each pathogen to quantify pediatric burden concentration. All findings were interpreted descriptively, with reference to uncertainty intervals where relevant.

One drawback lies in how the data combine worldwide figures – this means differences between nations or areas in infection levels, vaccine uptake, and medical care access go unnoticed, so results

might mask critical contrasts among poorer, middle-income, and wealthier regions. Though useful, these numbers come from statistical models instead of actual recorded cases, which ties reliability to how well each nation reports health events; places with less developed monitoring often show up poorly in such studies, creating gaps that could skew outcomes.

Another point: measures like DALYs and death rates fail to track how deadly an illness is per infected person, making it hard to judge real danger for individuals facing disease. Patterns spotted here suggest links, yet proving cause remains out of reach because age-related shifts in impact mix biology, immunity, and uneven healthcare – all tangled beyond what broad international totals can untangle.

IV. RESULTS

Across all three pathogens, the highest mortality burden was observed in neonates and young infants, with clear variation in magnitude across organisms (Figure 1). Streptococcus pneumoniae consistently showed the highest mortality rates, followed by Neisseria meningitidis and Haemophilus influenzae.

In the neonatal period (0–27 days), mortality rates were highest for all pathogens, with a pronounced peak in the first week of life (0–6 days). During this period, S. pneumoniae demonstrated the greatest burden, with substantially higher mortality rates compared to the other pathogens. Although mortality declined after the first week, the relative ranking of pathogens remained consistent.

During infancy, mortality rates decreased but remained elevated compared to later life stages. Notably, in the 6–11-month age group, N. meningitidis showed a burden comparable to S. pneumoniae, indicating a relatively stronger contribution during this stage (Figure 1).

Mortality rates declined markedly after the first year of life and remained low throughout childhood and adulthood across all three pathogens. However, a secondary increase in mortality was observed in the oldest age group (≥95 years), particularly for S. pneumoniae and N. meningitidis, suggesting increased vulnerability at both extremes of the age spectrum (Figure 1).

Analysis of temporal trends from 2019 to 2023 showed a gradual decline in mortality rates across all pathogens (Figure 2).

This decline was most pronounced for H. influenzae, indicating a relatively greater reduction in its contribution to global meningitis mortality over time. Heatmap visualisation further highlights the age-specific distribution of mortality, with the highest intensity concentrated in neonatal age groups and a clear decline across increasing age (Figure 3). The convergence of N. meningitidis and S. pneumoniae burden during late infancy is also visually evident.

When examining the relative contribution of each pathogen (Figure 4), S. pneumoniae accounted for the largest proportion of mortality across all age groups, typically contributing around half of the total burden.

Neisseria meningitidis represented a substantial proportion, particularly during infancy where its contribution approached that of S. pneumoniae. In contrast, Haemophilus influenzae consistently accounted for the smallest share across all age groups. This pattern indicates that while absolute mortality varies significantly with age, the relative dominance of pathogens remains broadly consistent across the life course.

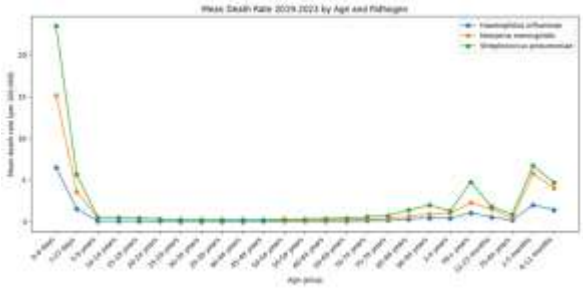

Figure 1. Age-specific mortality rates by pathogen (2019–2023 average)

This line plot shows how mortality rates change across the life course for the three pathogens.

- X axis: GBD age groups (0–6 days → 95+ years)
- Y axis: Death rate (per 100,000)

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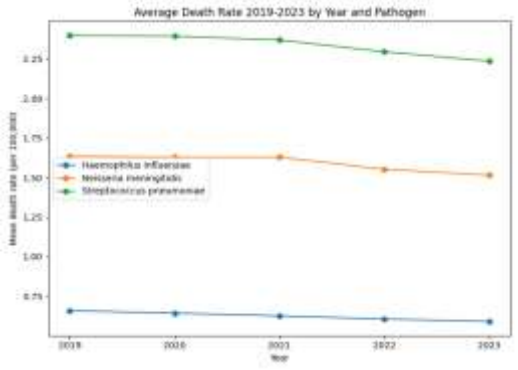

Figure 2. Temporal trends in global meningitis mortality (2019–2023)

This line plot shows how mortality rates changed over time when averaged across all age groups.

- X axis: Year (2019–2023)
- Y axis: Mean death rate (per 100,000)
- Lines: Three pathogens

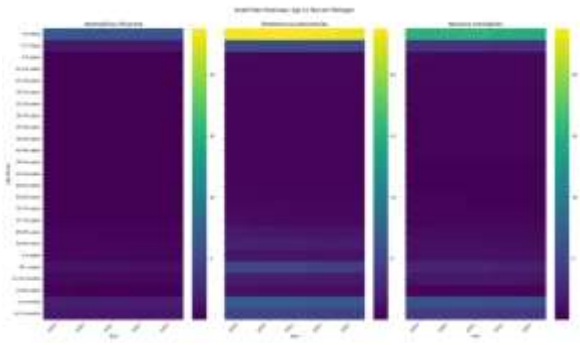

Figure 3. Heatmaps of age and year specific mortality rates

This figure contains three heatmaps, one per pathogen.

- Rows: Age groups
- Columns: Years (2019–2023)
- Colour intensity: Death rate (darker = higher)

These heatmaps make it easy to see:

- Concentration of mortality in neonates
- The convergence of N. meningitidis and S. pneumoniae during late infancy
- The low burden through most of childhood and adulthood

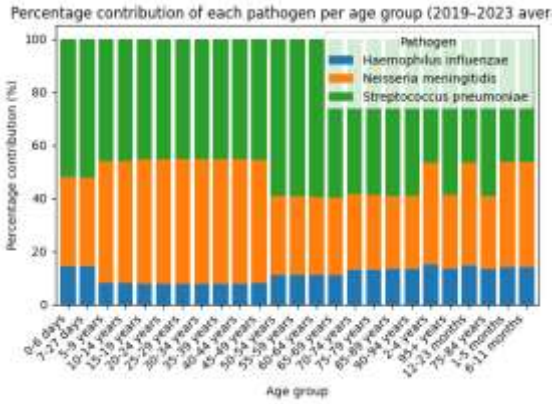

Figure 4. Percentage contribution of each pathogen to total meningitis mortality across age groups (2019–2023 average).

This stacked bar chart shows how much each pathogen contributes (in %) to total meningitis mortality within each age group.

- X axis: GBD age groups (0–6 days → 95+ years)
- Y axis: Percentage contribution (%)
- Colours:
- Haemophilus influenzae
- Neisseria meningitidis
- Streptococcus pneumoniae

V. CONCLUSION

This research reveals distinct trends in death and illness linked to Haemophilus influenzae, Neisseria meningitidis, and Streptococcus pneumoniae worldwide from 2019 to 2023, shaped strongly by age. While all three bacteria affect different groups, newborns and very young babies carry the heaviest load.

Despite variations among regions, Streptococcus pneumoniae stands out for causing more deaths and lost healthy years than the others at each phase of life. Most strikingly, infants and toddlers under five account for well over two-thirds of all fatalities - making early childhood far and away the most critical window for risk.

Mortality dropped fast beyond infancy yet climbed again among the very old, especially with S. pneumoniae - its death rate hitting 4.76 per 100,000 past age 95, almost double N. meningitidis and over fourfold higher than H. influenzae at that point.

Unlike the others, S. pneumoniae follows a U-shaped pattern over time, striking hardest when immunity is weakest: early or late in life. During late infancy, though, N. meningitidis played a larger role; its impact neared S. pneumoniae levels more closely here than anywhere else along the timeline, hinting that vaccines aimed at children aged 6 to 11 months may need extra emphasis on this pathogen due to its rising share.

Though numbers dropped for each pathogen during the study, the sharpest fall appeared in H. influenzae - down 10.27% - possibly because the Haemophilus vaccine reached more countries [4] earlier than vaccines for pneumococcus or meningococcus [8].

Prevention efforts gain strength when tailored to specific germs and certain age groups, especially within worldwide plans to reduce meningitis. To uncover differences hidden in broad global totals, coming studies ought to examine data at national and regional levels. Even with progress noted, bacterial meningitis still weighs heavily on populations around the globe; insights broken down by age and cause here can guide sharper immunization decisions and smarter use of public health funds.

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