Global, regional, and national burden of meningitis and its aetiologies, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019

*GBD 2019 Meningitis and Antimicrobial Resistance Collaborators**

Summary

Background Although meningitis is largely preventable, it still causes hundreds of thousands of deaths globally each year. WHO set ambitious goals to reduce meningitis cases by 2030, and assessing trends in the global meningitis burden can help track progress and identify gaps in achieving these goals. Using data from the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2019, we aimed to assess incident cases and deaths due to acute infectious meningitis by aetiology and age from 1990 to 2019, for 204 countries and territories.

Methods We modelled meningitis mortality using vital registration, verbal autopsy, sample-based vital registration, and mortality surveillance data. Meningitis morbidity was modelled with a Bayesian compartmental model, using data from the published literature identified by a systematic review, as well as surveillance data, inpatient hospital admissions, health insurance claims, and cause-specific meningitis mortality estimates. For aetiology estimation, data from multiple causes of death, vital registration, hospital discharge, microbial laboratory, and literature studies were analysed by use of a network analysis model to estimate the proportion of meningitis deaths and cases attributable to the following aetiologies: *Neisseria meningitidis*, *Streptococcus pneumoniae*, *Haemophilus influenzae*, group B *Streptococcus*, *Escherichia coli*, *Klebsiella pneumoniae*, *Listeria monocytogenes*, *Staphylococcus aureus*, viruses, and a residual other pathogen category.

Findings In 2019, there were an estimated 236 000 deaths (95% uncertainty interval [UI] 204 000–277 000) and 2·51 million (2·11–2·99) incident cases due to meningitis globally. The burden was greatest in children younger than 5 years, with 112 000 deaths (87 400–145 000) and 1·28 million incident cases (0·947–1·71) in 2019. Age-standardised mortality rates decreased from 7·5 (6·6–8·4) per 100 000 population in 1990 to 3·3 (2·8–3·9) per 100 000 population in 2019. The highest proportion of total all-age meningitis deaths in 2019 was attributable to *S pneumoniae* (18·1% [17·1–19·2]), followed by *N meningitidis* (13·6% [12·7–14·4]) and *K pneumoniae* (12·2% [10·2–14·3]). Between 1990 and 2019, *H influenzae* showed the largest reduction in the number of deaths among children younger than 5 years (76·5% [69·5–81·8]), followed by *N meningitidis* (72·3% [64·4–78·5]) and viruses (58·2% [47·1–67·3]).

Interpretation Substantial progress has been made in reducing meningitis mortality over the past three decades. However, more meningitis-related deaths might be prevented by quickly scaling up immunisation and expanding access to health services. Further reduction in the global meningitis burden should be possible through low-cost multivalent vaccines, increased access to accurate and rapid diagnostic assays, enhanced surveillance, and early treatment.

Funding Bill & Melinda Gates Foundation.

Lancet Neurol 2023; 22: 685–711

See **Comment** page 646

*Collaborators are listed at the end of the Article

Correspondence to:
Dr Hmwe Hmwe Kyu, Institute for Health Metrics and Evaluation, University of Washington, Seattle, WA 98105, USA
hmwekyu@uw.edu

Introduction

Meningitis is a disease defined by inflammation of the meninges, the layers of membranes that cover the brain and spinal cord.[1] In addition to mortality, meningitis can result in long-term sequelae such as cognitive impairment, hearing loss, motor weakness or paralysis, incoordination, and epilepsy.[2,3] Bacterial and viral infections are key causes of acute meningitis. Viral meningitis is more common than bacterial meningitis but is associated with lower rates of mortality and complications.[4] By contrast, bacterial meningitis is more likely to be associated with a poor prognosis and require prompt treatment.[5,6]

A systematic review published in 2018 found that the aetiologies responsible for the highest proportion of bacterial meningitis cases in all regions globally were *Streptococcus pneumoniae* and *Neisseria meningitidis* (or meningococcus), with *Haemophilus influenzae* also posing a high burden in selected regions.[7] Although vaccines can prevent infections due to these three aetiologies, not all countries have fully immunised their populations. For example, global infant third-dose vaccine coverage for *H influenzae* type b (Hib) is 72%, and third-dose vaccine coverage for *S pneumoniae* is estimated to be only 51%.[8] Rates of meningitis incidence and mortality are highest in the meningitis belt, which consists of 26 countries in Africa spanning from Senegal to Ethiopia. This region has historically reported epidemics of *N meningitidis* serogroup A.[9] To reduce the incidence rate of meningitis, 24 of the 26 countries in the meningitis belt had introduced meningococcal serogroup

Research in context

Evidence before this study

The global burden of meningitis and the burden attributable to a subset of aetiologies have been estimated by multiple groups, including WHO and the Maternal and Child Epidemiology Estimation Group (WHO-MCEE) and the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD). We searched PubMed with the search terms "meningitis" [MeSH] AND ("mortality" OR "incidence") AND "global", with no language restrictions, for articles published from database inception to April 26, 2023. We did not identify any studies that evaluated global levels of and trends in meningitis burden attributable to a comprehensive set of aetiologies across countries.

Added value of this study

This study uses data from GBD 2019 and improves upon previous GBD estimates in several ways. First, we added many new data sources on meningitis morbidity and mortality since GBD 2017. Second, we used a standardised approach to enhance the comparability of non-fatal data sources using a novel Bayesian meta-regression tool. Third, we produced estimates of meningitis burden attributable to ten different aetiologies (*Escherichia coli, Haemophilus influenzae, Klebsiella pneumoniae, Listeria monocytogenes, Neisseria meningitidis, Staphylococcus aureus*, group B *Streptococcus, Streptococcus pneumoniae,* viruses, and a residual other pathogen category), six of which are new inclusions to GBD. Finally, we address a key limitation of earlier GBD reports by producing non-fatal and fatal aetiology proportions that are linked to each other, using location-specific, age-specific, year-specific, and aetiology-specific case-fatality ratio estimates.

Implications of all the available evidence

There has been considerable progress in reducing the burden of infectious meningitis since 1990. However, the reduction has not been equal across locations, and countries in the African meningitis belt and south Asia still have a large burden. Meningitis attributable to *S pneumoniae*, which has a high case-fatality ratio, is responsible for more deaths than any other bacterial aetiology. There is a need to maintain and increase coverage of pneumococcal, *H influenzae* type b, and multivalent meningococcal vaccines. For all aetiologies, improved surveillance systems, early diagnosis (through low-cost, accurate, and rapid tests), and improvements in health-care access and treatment are necessary to reduce the burden of meningitis and track progress. Our analysis highlights the importance of controlling bacterial meningitis not attributable to vaccine-preventable aetiologies. *K pneumoniae* was associated with more mortality than other aetiologies that do not have an available vaccine and was the third-largest cause of deaths attributable to infectious meningitis overall. New vaccines and vaccine programmes are in development for *K pneumoniae*, group B *Streptococcus,* and other forms of bacterial meningitis. The development of, and access to, vaccines are essential in reducing the global meningitis burden and in preventing the over-reliance on antibiotics that worsens antimicrobial resistance.

A conjugate vaccine (MACV [MenAfriVac]) campaigns by the end of 2021.[10,11] Globally, 53 countries have meningococcal conjugate vaccines in their routine immunisation schedule, including 27 countries with quadrivalent meningococcal ACYW vaccines and nine countries with meningococcal serogroup B vaccines.[12]

Reducing meningitis incidence and death rates is the focus of WHO's Defeating Meningitis by 2030 global roadmap, a plan developed in a global collaboration between key country stakeholders (ie, representatives from governments, global health organisations, public health bodies, academia, the private sector, and civil society) and international organisations.[13] The global roadmap outlines three main goals: eliminating bacterial meningitis epidemics, reducing cases of and deaths from vaccine-preventable bacterial meningitis, and reducing disability and improving quality of life after recovery from acute meningitis.[13] Robust and comparable estimates of meningitis incidence and mortality are invaluable in tracking progress and identifying gaps towards achieving these goals.

Here, we present results from the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2019, synthesised with results from the global burden of antimicrobial resistance study done by collaborators of the Global Research on Antimicrobial Resistance project, describing the burden and trends of acute infectious meningitis and ten aetiologies for 204 countries and territories from 1990 to 2019. Notable limitations of GBD 2016 and GBD 2017 were the divergent methods used for estimation of fatal and non-fatal aetiology proportions for *S pneumoniae*, *N meningitidis*, and Hib, and the absence of estimates for other important pathogens.[2,14,15] As part of the study assessing the global burden of antimicrobial resistance, we developed a new method of pathogen estimation that addresses the limitations of these earlier GBD publications[16] and provide the first estimates of meningitis burden attributable to a comprehensive set of pathogens. This manuscript was produced as part of the GBD Collaborator Network and in accordance with the GBD Protocol.

Methods

Modelling overview

GBD 2019 produces estimates of meningitis mortality and morbidity by age and sex for 204 countries and territories, for the years between 1990 and 2019. The study investigating the global burden of antimicrobial resistance produced estimates of the aetiology-specific fatal and non-fatal burden of selected infectious syndromes, including

meningitis, between 1990 and 2019. Modelling was done at the 1000 draw level, and 95% uncertainty intervals (UIs) were computed as the 25th and 975th ranked values of 1000 draws. We used the GBD 2019 global population age standard to calculate age-standardised rates. Below, we summarise key methods from GBD 2019 and the study of the global burden of antimicrobial resistance for estimation of the burden of meningitis and its aetiologies. More details of these methods, including a flowchart for estimation of meningitis mortality and non-fatal burden, are provided in appendix 1 (pp 3, 8). Full descriptions of GBD 2019 and the study estimating the global burden of antimicrobial resistance have been previously published.[16,17] We present our results stratified by Socio-Demographic Index (SDI) quintiles. SDI is a composite indicator computed based on three variables (income per capita, average years of schooling, and total fertility rate) for each country.[18] All count data are presented to three significant figures and all proportions and rates are presented to one decimal place.

Mortality estimation

The data used for estimation of mortality due to meningitis originated from vital registration, verbal autopsy, sample-based vital registration, minimally invasive tissue sampling from the Child Health and Mortality Prevention Surveillance (CHAMPS),[19] and epidemiological surveillance, comprising a total of 24726 site-years (21852 site-years from vital registration, 825 site-years from sample-based vital registration, 1432 site-years from verbal autopsy, 611 site-years from surveillance sources, and six site-years from minimally invasive tissue sampling). The data were processed with a set of standard algorithms accounting for incompleteness, misclassification of the underlying cause of death, garbage coding, and stochastic variability. The International Classification of Diseases ninth revision (ICD-9) and ICD-10 codes mapped to meningitis are provided in appendix 1 (p 4).

We estimated overall meningitis mortality using the Cause of Death Ensemble model (CODEm), which has widely been used to produce global estimates of cause-specific mortality.[14,17,20] We modelled mortality separately for children aged 0–4 years and those aged 5 years and older because these two populations have very different meningitis mortality distributions and trends. The CODEm strategy evaluates various potential models with different combinations of covariates and model classes (mixed-effects linear models and spatiotemporal Gaussian process regression models).[21] A full list of covariates is provided in appendix 1 (p 4). For this analysis, 26 countries in sub-Saharan Africa listed by WHO as being at risk for meningitis epidemics are considered meningitis belt countries.[22] Models were weighted with out-of-sample predictive validity and combined in one ensemble model. Meningitis mortality estimates are scaled in a process called CoDCorrect so that all-cause mortality and the sum of cause-specific mortality are consistent.[17,23]

Morbidity estimation

The data used for morbidity estimation originated from published studies identified via a systematic review (appendix 1 p 9), surveillance data, cause-specific meningitis mortality estimates (calculated as described above), claims data, and inpatient data. We estimated overall meningitis morbidity using DisMod-MR (version 2.1), a Bayesian meta-regression tool that includes a compartmental model to estimate prevalence, incidence, remission, and mortality.[17] Before modelling in DisMod-MR (version 2.1), we enhanced data comparability by applying a standardised approach to adjust claims and surveillance data to the level of inpatient data. More details of the adjustments are provided in appendix 1 (p 10).

See Online for appendix 1

Aetiology-specific estimation

Data used for aetiology estimation originated from multiple cause of death vital registration data, hospital discharge data, microbial laboratory data, and published studies from the literature. We calculated mortality and morbidity estimates for each of ten aetiologies of meningitis: *Escherichia coli, H influenzae, Klebsiella pneumoniae, Listeria monocytogenes, N meningitidis, Staphylococcus aureus*, group B *Streptococcus, S pneumoniae,* viruses, and a residual other pathogen category. The ICD-9 and ICD-10 codes mapped to each aetiology are listed in appendix 1 (p 11). A key methodological improvement compared with GBD 2016 and GBD 2017 that we made in this study was to estimate the aetiologies using consistent methods for non-fatal and fatal proportions (ie, fatal aetiology proportions were derived from non-fatal aetiology proportions in combination with case-fatality ratio (CRF) estimates, as described below).

First, CFRs for each pathogen were modelled with the Bayesian meta-regression tool MR-BRT (meta-regression Bayesian, regularised, trimmed).[24] CFRs were calculated as a function of age group, pathogen, and the Healthcare Access and Quality (HAQ) Index, with random effects on data source.[16,24,25] The HAQ Index is a composite indicator of 32 causes of amenable mortality that measures healthcare access and quality over time. We additionally controlled for data provided only from intensive care units (which would be biased towards higher CFRs) and modelled the effects of the proportion of pneumococcal conjugate vaccine (PCV) and Hib vaccinations among individuals aged 15 years or younger on the CFRs for *S pneumoniae* and *H influenzae,* respectively. The modelled CFRs were used to back-calculate case quantities from data sources that reported only deaths. Next, incidence proportions were estimated with multinomial estimation[16] as part of a network analysis model, which allows for the inclusion of data sources that are considered partial observations (ie, which do not contain all ten pathogen groups modelled in the study). More details of this approach are provided in the online appendix of the published study on the global burden of antimicrobial resistance (pp 39–44).[16]

	Mortality				Incidence				Percentage change (1990–2019)			
	1990 counts	Age-standardised rate (per 100 000), 1990	2019 counts	Age-standardised rate (per 100 000), 2019	1990 counts	Age-standardised rate (per 100 000), 1990	2019 counts	Age-standardised rate (per 100 000), 2019	Mortality	Age-standardised mortality rate	Incidence	Age-standardised incidence rate
Global	433 000 (376 000 to 494 000)	7·5 (6·6 to 8·4)	236 000 (204 000 to 277 000)	3·3 (2·8 to 3·9)	3 290 000 (2 700 000 to 4 000 000)	55·3 (45·9 to 66·7)	2 510 000 (2 110 000 to 2 990 000)	35·4 (29·6 to 42·5)	−45·4% (−53·5 to −35·8)	−56·0% (−62·5 to −48·3)	−23·8% (−26·5 to −20·4)	−35·9% (−37·0 to −34·6)
Low SDI	164 000 (137 000 to 196 000)	24·8 (21·5 to 28·5)	129 000 (106 000 to 157 000)	11·2 (9·6 to 13·2)	1 050 000 (864 000 to 1 280 000)	145·4 (125·0 to 168·7)	1 100 000 (914 000 to 1 330 000)	82·3 (70·3 to 96·0)	−21·4% (−35·5 to −3·2)	−54·7% (−61·8 to −46·1)	4·8% (2·0 to 7·9)	−43·4% (−44·4 to −42·6)
Low-middle SDI	148 000 (129 000 to 170 000)	11·7 (10·5 to 13·2)	65 800 (57 800 to 75 400)	4·1 (3·6 to 4·6)	1 070 000 (876 000 to 1 310 000)	77·1 (64·8 to 91·4)	725 000 (606 000 to 860 000)	42·1 (35·4 to 50·0)	−55·5% (−62·5 to −47·2)	−65·3% (−70·2 to −59·7)	−32·4% (−35·7 to −28·3)	−45·4% (−46·7 to −43·8)
Middle SDI	86 200 (76 800 to 96 700)	4·8 (4·3 to 5·4)	29 400 (26 300 to 33 100)	1·4 (1·2 to 1·6)	715 000 (573 000 to 890 000)	37·7 (30·8 to 46·3)	425 000 (349 000 to 508 000)	20·5 (16·8 to 24·7)	−65·9% (−70·8 to −59·8)	−71·6% (−75·5 to −66·8)	−40·5% (−44·4 to −35·3)	−45·6% (−47·7 to −43·0)
High-middle SDI	27 400 (25 000 to 30 000)	2·6 (2·4 to 2·8)	8520 (7840 to 9170)	0·6 (0·6 to 0·7)	306 000 (250 000 to 368 000)	28·2 (23·0 to 34·2)	166 000 (135 000 to 197 000)	14·9 (12·0 to 18·0)	−68·9% (−72·8 to −64·8)	−76·6% (−79·7 to −73·2)	−45·9% (−49·5 to −41·4)	−47·0% (−49·6 to −44·1)
High SDI	6590 (6370 to 6810)	0·8 (0·8 to 0·8)	3300 (3090 to 3480)	0·3 (0·2 to 0·3)	147 000 (118 000 to 178 000)	20·7 (16·5 to 25·2)	91 800 (74 600 to 110 000)	11·1 (8·9 to 13·5)	−49·9% (−52·4 to −47·5)	−68·8% (−70·5 to −67·2)	−37·5% (−41·5 to −32·3)	−46·2% (−48·2 to −43·5)
Central Europe, eastern Europe, and central Asia	8190 (7840 to 8550)	2·2 (2·1 to 2·3)	2700 (2440 to 2960)	0·6 (0·6 to 0·7)	130 000 (107 000 to 155 000)	34·3 (28·3 to 40·7)	70 800 (57 000 to 86 000)	20·9 (16·6 to 25·6)	−67·0% (−70·3 to −63·3)	−71·4% (−74·5 to −67·9)	−45·7% (−48·6 to −42·5)	−39·2% (−43·1 to −35·5)
Central Asia	3030 (2790 to 3290)	3·7 (3·5 to 4·0)	638 (552 to 752)	0·7 (0·6 to 0·8)	41 100 (34 500 to 48 400)	49·9 (42·2 to 58·6)	27 500 (22 000 to 33 800)	28·9 (23·1 to 35·6)	−79·0% (−82·2 to −74·7)	−81·2% (−83·9 to −77·5)	−33·2% (−39·2 to −27·6)	−42·1% (−47·0 to −37·4)
Central Europe	1740 (1670 to 1830)	1·6 (1·6 to 1·7)	421 (357 to 484)	0·3 (0·3 to 0·3)	22 600 (18 400 to 27 100)	21·5 (17·5 to 25·9)	10 300 (8220 to 12 300)	12·2 (9·6 to 15·1)	−75·8% (−79·6 to −71·9)	−81·7% (−84·8 to −78·5)	−54·6% (−57·2 to −50·9)	−43·2% (−46·7 to −39·7)
Eastern Europe	3420 (3280 to 3570)	1·7 (1·6 to 1·8)	1640 (1480 to 1800)	0·7 (0·6 to 0·8)	66 700 (54 000 to 79 800)	34·5 (27·8 to 41·6)	33 000 (26 700 to 39 800)	19·9 (15·7 to 24·4)	−52·0% (−57·3 to −46·7)	−58·5% (−62·9 to −54·0)	−50·5% (−53·2 to −47·4)	−42·5% (−46·0 to −38·7)
High income	7690 (7460 to 7930)	0·9 (0·9 to 0·9)	3820 (3570 to 4010)	0·3 (0·3 to 0·3)	164 000 (132 000 to 200 000)	21·3 (17·0 to 25·9)	96 000 (78 200 to 114 000)	10·8 (8·7 to 13·1)	−50·3% (−52·8 to −48·2)	−68·9% (−70·7 to −67·3)	−41·5% (−45·2 to −37·0)	−49·1% (−51·2 to −46·5)
Australasia	125 (117 to 134)	0·7 (0·6 to 0·7)	59 (54 to 64)	0·2 (0·2 to 0·2)	4460 (3560 to 5500)	25·1 (19·7 to 31·1)	3490 (2790 to 4280)	15·3 (11·9 to 19·2)	−53·0% (−57·6 to −48·1)	−72·1% (−75·5 to −68·5)	−21·7% (−26·4 to −16·1)	−39·3% (−43·5 to −34·9)
High-income Asia Pacific	1220 (1170 to 1280)	0·8 (0·7 to 0·8)	491 (427 to 531)	0·1 (0·1 to 0·1)	45 600 (35 500 to 57 300)	31·8 (24·8 to 39·9)	27 700 (22 200 to 33 600)	21·2 (16·7 to 26·5)	−59·9% (−64·6 to −56·6)	−82·5% (−83·9 to −81·0)	−39·3% (−44·7 to −32·3)	−33·3% (−38·0 to −28·0)
High-income North America	1960 (1870 to 2080)	0·7 (0·7 to 0·7)	1240 (1170 to 1280)	0·3 (0·3 to 0·3)	29 800 (23 500 to 36 700)	11·6 (9·1 to 14·5)	16 300 (13 600 to 19 300)	4·4 (3·7 to 5·2)	−37·0% (−40·7 to −33·9)	−58·9% (−61·5 to −56·7)	−45·2% (−52·5 to −36·4)	−61·9% (−66·4 to −56·1)
Southern Latin America	1190 (1140 to 1250)	2·5 (2·3 to 2·6)	580 (524 to 631)	0·8 (0·7 to 0·9)	11 400 (9500 to 13 700)	22·7 (18·9 to 27·0)	6780 (5550 to 8200)	11·4 (9·2 to 13·9)	−51·4% (−56·3 to −46·0)	−66·8% (−70·4 to −63·0)	−40·7% (−44·7 to −36·4)	−49·9% (−52·9 to −46·7)

(Table 1 continues on next page)

	Mortality				Incidence				Percentage change (1990–2019			
	1990 counts	Age-standardised rate (per 100 000), 1990	2019 counts	Age-standardised rate (per 100 000), 2019	1990 counts	Age-standardised rate (per 100 000), 1990	2019 counts	Age-standardised rate (per 100 000), 2019	Mortality	Age-standardised mortality rate	Incidence	Age-standardised incidence rate
(Continued from previous page)												
Western Europe	3180 (3080 to 3300)	0·8 (0·8 to 0·9)	1450 (1350 to 1550)	0·2 (0·2 to 0·3)	72 900 (59 400 to 87 100)	23·8 (19·3 to 28·9)	41 700 (34 000 to 49 600)	12·5 (10·0 to 15·2)	−54·3% (−57·1 to −51·7)	−71·4% (−73·5 to −69·5)	−42·7% (−45·3 to −39·7)	−47·4% (−49·2 to −45·4)
Latin America and Caribbean	18 100 (16 700 to 19 600)	4·1 (3·9 to 4·4)	5560 (4720 to 6510)	1·0 (0·9 to 1·2)	140 000 (115 000 to 166 000)	31·2 (25·9 to 36·5)	93 000 (76 000 to 111 000)	16·8 (13·7 to 20·0)	−69·2% (−74·8 to −63·0)	−75·2% (−79·7 to −70·3)	−33·5% (−39·8 to −25·8)	−46·3% (−49·9 to −42·3)
Andean Latin America	1320 (1150 to 1530)	2·9 (2·6 to 3·4)	395 (314 to 494)	0·6 (0·5 to 0·8)	7020 (5830 to 8360)	14·7 (12·5 to 17·1)	4400 (3590 to 5270)	6·9 (5·7 to 8·3)	−70·0% (−77·4 to −60·7)	−77·9% (−83·2 to −71·4)	−37·3% (−42·5 to −31·8)	−52·7% (−56·2 to −48·9)
Caribbean	3470 (2930 to 4080)	8·9 (7·6 to 10·4)	1420 (1080 to 1860)	3·4 (2·5 to 4·5)	14 200 (12 000 to 16 600)	36·3 (31·2 to 42·0)	10 000 (8390 to 11 700)	23·4 (19·4 to 27·6)	−59·0% (−70·7 to −43·6)	−62·1% (−73·2 to −47·6)	−29·3% (−32·8 to −25·5)	−35·6% (−39·0 to −32·5)
Central Latin America	4720 (4400 to 5070)	2·6 (2·4 to 2·7)	1670 (1370 to 2030)	0·7 (0·6 to 0·9)	37 300 (30 000 to 45 400)	18·8 (15·6 to 22·5)	19 900 (16 000 to 24 200)	8·4 (6·7 to 10·2)	−64·6% (−71·9 to −56·2)	−72·9% (−78·4 to −66·5)	−46·6% (−51·1 to −41·1)	−55·4% (−58·1 to −52·6)
Tropical Latin America	8550 (7700 to 9660)	5·3 (4·8 to 5·9)	2070 (1870 to 2290)	1·0 (0·9 to 1·1)	81 500 (66 200 to 96 600)	48·7 (40·1 to 57·4)	58 700 (47 800 to 70 600)	28·1 (22·8 to 34·0)	−75·7% (−79·4 to −71·7)	−80·8% (−83·7 to −77·6)	−28·0% (−36·3 to −18·3)	−42·4% (−47·9 to −36·7)
North Africa and Middle East	17 500 (14 400 to 21 500)	4·2 (3·6 to 5·1)	6280 (5330 to 7400)	1·2 (1·0 to 1·4)	143 000 (118 000 to 171 000)	35·7 (30·5 to 41·2)	129 000 (107 000 to 153 000)	22·5 (18·9 to 26·4)	−64·1% (−72·2 to −54·5)	−71·6% (−77·1 to −64·9)	−9·9% (−16·3 to −1·9)	−37·0% (−39·9 to −33·9)
South Asia	131 000 (113 000 to 150 000)	11·2 (10·0 to 12·5)	55 500 (48 400 to 64 400)	3·5 (3·0 to 4·0)	1 150 000 (935 000 to 1 410 000)	85·9 (71·6 to 103·0)	742 000 (610 000 to 883 000)	43·6 (36·2 to 52·3)	−57·5% (−65·0 to −49·0)	−69·0% (−74·0 to −63·3)	−35·3% (−38·7 to −31·2)	−49·2% (−50·7 to −47·5)
Southeast Asia, east Asia, and Oceania	76 800 (65 800 to 88 900)	4·5 (3·9 to 5·2)	18 200 (16 300 to 20 500)	1·0 (0·9 to 1·2)	452 000 (357 000 to 575 000)	25·7 (20·4 to 32·6)	177 000 (147 000 to 212 000)	10·9 (8·8 to 13·3)	−76·3% (−80·3 to −71·7)	−77·4% (−81·2 to −73·2)	−60·9% (−63·5 to −57·6)	−57·6% (−59·3 to −55·3)
East Asia	38 600 (33 800 to 43 700)	3·4 (3·0 to 3·8)	6790 (5940 to 7680)	0·5 (0·5 to 0·6)	234 000 (182 000 to 302 000)	19·7 (15·4 to 25·3)	50 700 (41 600 to 60 300)	4·8 (3·9 to 6·0)	−82·4% (−85·4 to −78·7)	−85·0% (−87·5 to −81·9)	−78·4% (−80·4 to −75·8)	−75·4% (−77·0 to −73·7)
Oceania	783 (599 to 1000)	9·3 (7·4 to 11·5)	693 (497 to 937)	4·4 (3·3 to 5·7)	5530 (4580 to 6530)	74·5 (64·7 to 84·9)	6690 (5650 to 7860)	46·0 (39·6 to 52·8)	−11·5% (−38·6 to 28·1)	−52·7% (−65·5 to −34·4)	21·1% (14·0 to 30·2)	−38·2% (−41·3 to −34·5)
Southeast Asia	37 400 (30 300 to 46 800)	6·9 (5·7 to 8·4)	10 700 (9320 to 12 400)	1·8 (1·6 to 2·1)	213 000 (169 000 to 266 000)	38·1 (30·9 to 47·3)	120 000 (98 900 to 144 000)	20·1 (16·6 to 24·4)	−71·3% (−77·6 to −63·2)	−73·1% (−78·8 to −66·2)	−43·7% (−47·9 to −38·0)	−47·2% (−49·8 to −43·8)
Sub-Saharan Africa	174 000 (143 000 to 208 000)	29·3 (25·4 to 33·8)	144 000 (117 000 to 176 000)	14·3 (12·2 to 16·7)	1 110 000 (920 000 to 1 350 000)	167·3 (143·4 to 194·1)	1 200 000 (998 000 to 1 450 000)	96·3 (82·6 to 111·7)	−17·0% (−32·2 to 3·7)	−51·3% (−58·6 to −42·0)	7·8% (4·8 to 11·2)	−42·4% (−43·4 to −41·5)
Central sub-Saharan Africa	14 500 (11 400 to 18 300)	19·6 (15·9 to 23·7)	9990 (7720 to 12 900)	8·9 (6·8 to 11·2)	107 000 (88 200 to 128 000)	135·3 (116·9 to 155·9)	128 000 (108 000 to 153 000)	87·2 (75·6 to 99·6)	−31·1% (−49·4 to −10·9)	−54·6% (−65·4 to −42·7)	19·8% (11·8 to 29·0)	−35·5% (−38·6 to −32·0)

(Table 1 continues on next page)

See Online for appendix 2

	Mortality			Incidence			Percentage change (1990–2019)				
	1990 counts	Age-standardised rate (per 100 000), 1990	2019 counts	Age-standardised rate (per 100 000), 2019	1990 counts	Age-standardised rate (per 100 000), 1990	2019 counts	Age-standardised rate (per 100 000), 2019	Mortality	Age-standardised mortality rate	Incidence	Age-standardised incidence rate
(Continued from previous page)												
Eastern sub-Saharan Africa	69 000 (57 800 to 81 900)	32·7 (28·1 to 37·4)	42 400 (35 800 to 50 700)	13·2 (11·5 to 15·1)	429 000 (354 000 to 519 000)	171·7 (146·6 to 198·2)	436 000 (364 000 to 525 000)	97·3 (83·4 to 112·3)	−38·5% (−50·1 to −24·2)	−59·5% (−65·1 to −52·5)	1·8% (−3·0 to 6·8)	−43·4% (−45·0 to −41·7)
Southern sub-Saharan Africa	4070 (3500 to 4610)	8·0 (7·0 to 8·9)	4130 (3520 to 4770)	6·1 (5·3 to 6·9)	33 200 (27 700 to 39 600)	59·6 (51·0 to 69·0)	34 000 (29 000 to 39 500)	45·8 (39·3 to 52·6)	1·4% (−15·9 to 23·0)	−24·0% (−35·8 to −10·7)	2·5% (−3·1 to 9·2)	−23·2% (−25·6 to −20·5)
Western sub-Saharan Africa	86 200 (69 300 to 107 000)	34·7 (29·1 to 41·2)	87 600 (68 300 to 110 000)	18·4 (15·0 to 22·1)	544 000 (447 000 to 665 000)	198·8 (170·6 to 230·9)	602 000 (494 000 to 737 000)	105·8 (90·1 to 124·1)	1·6% (−19·7 to 31·2)	−47·0% (−56·2 to −35·3)	10·6% (8·1 to 13·2)	−46·8% (−47·6 to −45·8)

Data in parentheses are 95% uncertainty intervals. Count data are presented to three significant figures and rates are presented to one decimal place. SDI=Socio-demographic Index. GBD=Global Burden of Diseases, Injuries, and Risk Factors Study.

Table 1: **All-age meningitis incidence and mortality counts and age-standardised rates in 1990 and 2019, and percentage change in deaths, cases, and age-standardised incidence and mortality rates between 1990 and 2019, by SDI quintile, globally, and for the seven GBD super-regions and 21 GBD regions**

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or the writing of the report.

Results

Non-fatal and fatal burden of meningitis

In 2019, 2·51 million (95% UI 2·11–2·99) new cases of meningitis occurred globally among all age groups (table 1), of which 1·28 million (0·947–1·71) occurred in children younger than 5 years (table 2). Age-standardised incidence rates per 100 000 population were highest in western sub-Saharan Africa, with an incidence rate of 105·8 (90·1–124·1) per 100 000 population, followed by eastern sub-Saharan Africa with an incidence rate of 97·3 (83·4–112·3) per 100 000 population and central sub-Saharan Africa with an incidence rate of 87·2 (75·6–99·6) per 100 000 population. Overall, the age-standardised global incidence rate was 35·4 (29·6–42·5) cases per 100 000 population, varying from 4·3 (3·6–5·1) per 100 000 population in the USA to 257·1 (221·2–297·7) per 100 000 population in South Sudan (appendix 2 pp 2–19). Globally, in 2019, the incidence rate in children younger than 5 years (hereafter referred to as the under-5 incidence rate) was 192·4 (142·8–258·6) per 100 000 population, down from 312·0 (231·6–418·6) per 100 000 population in 1990, representing a 38·3% (37·0–39·5) decrease (table 2). By SDI quintile, under-5 incidence rates in 2019 ranged from 34·4 (23·5–49·9) per 100 000 population in high SDI quintiles to 400·2 (302·8–529·4) per 100 000 population in low SDI quintiles (table 2). Globally, in 2019, the incidence rate of children aged 0–27 days (neonates) was 854·8 (609·2–1183·3) per 100 000 population, down from 1301·2 per (932·4–1767·2) per 100 000 population in 1990, representing a 34·3% (32·7–35·8) decrease (table 3).

In 2019, 236 000 deaths (95% UI 204 000–277 000) were attributable to meningitis globally (table 1), of which 112 000 (87 400–145 000) were in children younger than 5 years (table 2). Western sub-Saharan Africa had the highest age-standardised mortality rate (18·4 [15·0–22·1] per 100 000 population), followed by eastern sub-Saharan Africa (13·2 [11·5–15·1] per 100 000 population) and central sub-Saharan Africa (8·9 [6·8–11·2] per 100 000 population; table 1). Overall, the age-standardised mortality rate globally was 3·3 (2·8–3·9) per 100 000 population, down from 7·5 (6·6–8·4) per 100 000 population in 1990, representing a 56·0% (48·3–62·5) decrease. In 2019, rates varied from 0·1 (0·1–0·1) deaths per 100 000 population in Singapore to 26·3 (18·4–38·7) deaths per 100 000 population in Somalia (figure 1; appendix 2 pp 2–19). Worldwide in 2019, the mortality rate in children younger than 5 years (hereafter referred to as the under-5 mortality rate) due to meningitis was 16·9 (13·2–21·9) per 100 000 population, down from 45·0 (37·4–53·6) per 100 000 population

	Mortality				Incidence				Percentage change (1990–2019)			
	1990 counts	Mortality rate (per 100 000), 1990	2019 counts	Mortality rate (per 100 000), 2019	1990 counts	Incidence rate (per 100 000), 1990	2019 counts	Incidence rate (per 100 000), 2019	Mortality	Mortality rate	Incidence	Incidence rate
Global	284 000 (237 000 to 339 000)	45·0 (37·4 to 53·6)	112 000 (87 400 to 145 000)	16·9 (13·2 to 21·9)	1 970 000 (1 460 000 to 2 650 000)	312·0 (231·6 to 418·6)	1 280 000 (947 000 to 1 710 000)	192·4 (142·8 to 258·6)	−60·5% (−69·2 to −49·8)	−62·3% (−70·6 to −52·1)	−35·3% (−36·5 to −34·0)	−38·3% (−39·5 to −37·0)
Low SDI	118 000 (94 200 to 146 000)	122·3 (97·5 to 151·4)	77 600 (59 100 to 102 000)	45·4 (34·6 to 59·8)	719 000 (549 000 to 938 000)	744·8 (568·8 to 971·2)	684 000 (517 000 to 904 000)	400·2 (302·8 to 529·4)	−34·3% (−49·2 to −14·0)	−62·9% (−71·3 to −51·4)	−4·9% (−7·6 to −2·1)	−46·3% (−47·8 to −44·7)
Low-middle SDI	93 100 (76 600 to 114 000)	55·3 (45·6 to 67·8)	24 400 (19 000 to 31 500)	14·1 (11·0 to 18·3)	639 000 (473 000 to 854 000)	380·0 (281·0 to 507·6)	348 000 (254 000 to 466 000)	202·0 (147·2 to 270·2)	−73·8% (−80·3 to −65·0)	−74·4% (−80·7 to −65·9)	−45·6% (−47·4 to −43·6)	−46·8% (−48·6 to −44·9)
Middle SDI	55 600 (47 000 to 65 500)	27·1 (22·9 to 32·0)	8320 (6680 to 10 400)	4·5 (3·6 to 5·6)	420 000 (301 000 to 572 000)	205·0 (147·0 to 279·4)	175 000 (125 000 to 243 000)	95·0 (68·1 to 132·2)	−85·0% (−88·4 to −80·9)	−83·4% (−87·1 to −78·8)	−58·3% (−59·7 to −56·6)	−53·7% (−55·2 to −51·7)
High-middle SDI	15 400 (13 400 to 17 800)	14·7 (12·8 to 17·0)	1560 (1310 to 1860)	1·9 (1·6 to 2·2)	147 000 (107 000 to 202 000)	140·4 (102·2 to 192·9)	49 900 (35 100 to 70 900)	60·4 (42·5 to 85·8)	−89·9% (−92·1 to −87·2)	−87·2% (−90·0 to −83·8)	−66·0% (−67·8 to −63·9)	−57·0% (−59·3 to −54·4)
High SDI	1710 (1610 to 1840)	3·0 (2·8 to 3·2)	296 (256 to 334)	0·6 (0·5 to 0·6)	45 900 (32 100 to 65 800)	79·7 (55·6 to 114·1)	18 000 (12 300 to 26 100)	34·4 (23·5 to 49·9)	−82·7% (−85·2 to −80·5)	−81·0% (−83·7 to −78·5)	−60·7% (−62·2 to −59·5)	−56·8% (−58·5 to −55·4)
Central Europe, eastern Europe, and central Asia	4180 (3880 to 4520)	11·7 (10·9 to 12·7)	450 (368 to 565)	1·6 (1·3 to 2·0)	55 800 (42 300 to 75 600)	156·7 (118·6 to 212·2)	21 200 (15 100 to 30 200)	77·1 (54·8 to 109·5)	−89·2% (−91·4 to −86·2)	−86·0% (−88·8 to −82·1)	−62·0% (−65·0 to −58·4)	−50·8% (−54·8 to −46·2)
Central Asia	1900 (1680 to 2130)	20·0 (17·7 to 22·5)	186 (142 to 269)	1·9 (1·5 to 2·8)	20 200 (15 800 to 26 200)	213·2 (166·7 to 276·3)	10 100 (7290 to 14 100)	105·6 (76·1 to 147·5)	−90·2% (−92·7 to −85·0)	−90·3% (−92·8 to −85·2)	−50·0% (−55·6 to −42·7)	−50·5% (−56·1 to −43·3)
Central Europe	801 (737 to 882)	9·0 (8·3 to 9·9)	42 (32 to 52)	0·7 (0·6 to 0·9)	8680 (6440 to 11 800)	97·2 (72·1 to 132·5)	2530 (1780 to 3660)	44·8 (31·4 to 64·8)	−94·8% (−96·1 to −93·3)	−91·8% (−93·9 to −89·4)	−70·8% (−73·2 to −67·6)	−53·8% (−57·6 to −48·8)
Eastern Europe	1480 (1370 to 1620)	8·6 (8·0 to 9·4)	223 (183 to 267)	1·8 (1·5 to 2·2)	26 900 (19 600 to 37 300)	156·4 (113·6 to 216·6)	8600 (5920 to 12 500)	69·7 (48·0 to 101·2)	−84·9% (−88·1 to −81·8)	−78·9% (−83·4 to −74·6)	−68·1% (−70·4 to −65·4)	−55·4% (−58·7 to −51·6)
High income	2230 (2110 to 2390)	3·6 (3·4 to 3·9)	380 (327 to 435)	0·7 (0·6 to 0·8)	51 600 (36 600 to 73 000)	84·0 (59·6 to 118·9)	19 000 (13 100 to 27 100)	33·4 (23·0 to 47·7)	−83·0% (−85·6 to −80·5)	−81·7% (−84·4 to −79·0)	−63·2% (−64·7 to −61·9)	−60·3% (−61·9 to −58·9)
Australasia	51 (44 to 58)	3·3 (2·9 to 3·8)	12 (9 to 15)	0·7 (0·5 to 0·8)	1640 (1180 to 2250)	106·2 (76·4 to 146·0)	1040 (706 to 1530)	57·1 (38·8 to 84·0)	−76·6% (−82·6 to −69·8)	−80·2% (−85·2 to −74·3)	−36·5% (−44·6 to −28·2)	−46·2% (−53·0 to −39·1)
High-income Asia Pacific	228 (195 to 265)	2·2 (1·9 to 2·6)	17 (14 to 19)	0·2 (0·2 to 0·3)	10 600 (7160 to 15 700)	103·2 (69·8 to 153·0)	3320 (2230 to 4820)	45·5 (30·6 to 66·1)	−92·7% (−94·0 to −91·0)	−89·7% (−91·6 to −87·4)	−68·6% (−70·5 to −66·7)	−55·9% (−58·5 to −53·2)
High-income North America	587 (539 to 662)	2·7 (2·5 to 3·1)	137 (122 to 152)	0·7 (0·6 to 0·7)	9940 (6380 to 15 300)	46·2 (29·7 to 71·3)	2200 (1490 to 3200)	10·5 (7·1 to 15·2)	−76·7% (−80·0 to −73·3)	−76·1% (−79·5 to −72·6)	−77·9% (−79·5 to −75·4)	−77·3% (−79·0 to −74·8)

(Table 2 continues on next page)

	Mortality				Incidence				Percentage change (1990–2019)			
	1990 counts	Mortality rate (per 100 000), 1990	2019 counts	Mortality rate (per 100 000), 2019	1990 counts	Incidence rate (per 100 000), 1990	2019 counts	Incidence rate (per 100 000), 2019	Mortality	Mortality rate	Incidence	Incidence rate
(Continued from previous page)												
Southern Latin America	552 (499 to 608)	10·7 (9·7 to 11·8)	81 (60 to 105)	1·7 (1·2 to 2·2)	5620 (4360 to 7460)	108·9 (84·5 to 144·5)	2180 (1550 to 3100)	44·8 (32·0 to 63·8)	−85·3% (−89·4 to −80·3)	−84·4% (−88·8 to −79·1)	−61·3% (−66·0 to −56·2)	−58·8% (−63·9 to −53·4)
Western Europe	817 (760 to 894)	3·6 (3·3 to 3·9)	134 (111 to 157)	0·6 (0·5 to 0·7)	23 800 (17 200 to 33 000)	103·7 (74·8 to 143·7)	10 300 (7150 to 14 800)	46·7 (32·5 to 67·1)	−83·6% (−86·9 to −80·7)	−82·9% (−86·3 to −79·8)	−56·9% (−59·3 to −54·7)	−55·0% (−57·6 to −52·7)
Latin America and Caribbean	12 400 (11 200 to 14 000)	24·8 (22·4 to 28·0)	2040 (1520 to 2630)	4·2 (3·2 to 5·5)	71 600 (54 000 to 95 400)	143·2 (107·9 to 190·6)	25 000 (18 000 to 35 100)	52·1 (37·4 to 73·1)	−83·6% (−88·2 to −78·2)	−82·9% (−87·7 to −77·3)	−65·0% (−67·3 to −61·9)	−63·6% (−66·0 to −60·3)
Andean Latin America	868 (715 to 1050)	15·9 (13·1 to 19·3)	112 (80 to 161)	1·8 (1·3 to 2·5)	4500 (3480 to 5790)	82·5 (63·9 to 106·3)	2120 (1540 to 2900)	33·5 (24·4 to 45·8)	−87·1% (−91·1 to −80·7)	−88·9% (−92·4 to −83·4)	−52·9% (−57·7 to −47·2)	−59·5% (−63·6 to −54·6)
Caribbean	2600 (2080 to 3190)	62·9 (50·2 to 77·0)	947 (633 to 1350)	24·0 (16·0 to 34·2)	8470 (6590 to 10 800)	204·7 (159·2 to 260·3)	5070 (3750 to 6730)	128·4 (95·0 to 170·3)	−63·6% (−77·2 to −44·2)	−61·9% (−76·1 to −41·5)	−40·1% (−44·9 to −35·4)	−37·3% (−42·2 to −32·3)
Central Latin America	2970 (2670 to 3300)	13·0 (11·7 to 14·4)	365 (261 to 490)	1·7 (1·2 to 2·3)	21 400 (15 900 to 28 700)	93·5 (69·5 to 125·4)	6930 (4870 to 9940)	32·0 (22·5 to 45·9)	−87·7% (−91·5 to −83·1)	−87·0% (−91·1 to −82·2)	−67·6% (−70·2 to −64·1)	−65·8% (−68·5 to −62·1)
Tropical Latin America	5980 (5130 to 7090)	34·1 (29·2 to 40·4)	613 (472 to 767)	3·8 (2·9 to 4·8)	37 300 (27 500 to 50 200)	212·4 (156·9 to 285·9)	10 900 (7730 to 15 900)	67·7 (47·9 to 98·5)	−89·7% (−92·5 to −86·4)	−88·8% (−91·8 to −85·2)	−70·7% (−73·5 to −67·4)	−68·1% (−71·1 to −64·5)
North Africa and Middle East	12 500 (9850 to 16 400)	23·5 (18·5 to 30·7)	2310 (1740 to 3100)	3·9 (2·9 to 5·2)	84 700 (63 700 to 112 000)	158·8 (119·4 to 210·1)	48 800 (35 500 to 67 700)	81·7 (59·4 to 113·4)	−81·5% (−87·0 to −74·1)	−83·5% (−88·4 to −76·9)	−42·4% (−46·7 to −37·5)	−48·5% (−52·4 to −44·2)
South Asia	77 100 (62 300 to 93 300)	47·6 (38·5 to 57·7)	21 400 (16 200 to 28 200)	13·0 (9·9 to 17·1)	659 000 (479 000 to 893 000)	407·1 (296·0 to 551·8)	338 000 (245 000 to 461 000)	205·7 (148·8 to 280·3)	−72·3% (−80·3 to −62·2)	−72·7% (−80·6 to −62·9)	−48·7% (−51·0 to −46·5)	−49·5% (−51·7 to −47·4)
Southeast Asia, east Asia, and Oceania	54 100 (44 300 to 66 300)	30·0 (24·6 to 36·8)	6500 (5300 to 7950)	4·6 (3·8 to 5·7)	277 000 (194 000 to 385 000)	153·4 (107·6 to 213·8)	80 600 (57 400 to 110 000)	57·4 (40·9 to 78·6)	−88·0% (−90·8 to −84·6)	−84·6% (−88·2 to −80·3)	−70·9% (−71·9 to −69·6)	−62·6% (−63·9 to −60·9)
East Asia	25 700 (21 300 to 30 300)	21·4 (17·7 to 25·3)	1510 (1210 to 1840)	1·8 (1·4 to 2·2)	131 000 (88 100 to 191 000)	109·1 (73·6 to 159·1)	21 200 (14 500 to 30 300)	25·2 (17·2 to 36·1)	−94·1% (−95·6 to −92·2)	−91·7% (−93·7 to −88·9)	−83·8% (−84·9 to −82·6)	−76·9% (−78·4 to −75·2)
Oceania	579 (413 to 785)	58·9 (42·0 to 79·9)	469 (305 to 687)	25·3 (16·5 to 37·1)	3270 (2480 to 4220)	333·0 (252·2 to 428·9)	3780 (2920 to 4840)	204·2 (157·6 to 261·6)	−18·9% (−49·7 to 32·1)	−56·9% (−73·3 to −29·8)	15·4% (6·1 to 28·4)	−38·7% (−43·6 to −31·8)
Southeast Asia	27 900 (20 900 to 37 200)	46·8 (35·2 to 62·6)	4520 (3510 to 5800)	8·3 (6·4 to 10·6)	143 000 (104 000 to 193 000)	239·6 (175·2 to 324·9)	55 600 (40 200 to 75 600)	102·1 (73·8 to 138·7)	−83·8% (−88·5 to −77·4)	−82·3% (−87·4 to −75·3)	−61·0% (−62·8 to −58·9)	−57·4% (−59·4 to −55·1)
Sub-Saharan Africa	122 000 (95 800 to 155 000)	135·7 (106·9 to 172·5)	79 200 (59 200 to 104 000)	47·8 (35·8 to 63·0)	773 000 (591 000 to 1010 000)	862·9 (659·9 to 1126·3)	743 000 (561 000 to 982 000)	448·3 (338·6 to 592·9)	−34·9% (−49·7 to −13·1)	−64·8% (−72·8 to −53·0)	−4·0% (−6·8 to −0·9)	−48·0% (−49·6 to −46·4)
Central sub-Saharan Africa	10 100 (7230 to 13 700)	93·5 (67·3 to 127·6)	3400 (2240 to 5270)	16·4 (10·8 to 25·5)	74 100 (56 500 to 94 300)	689·4 (525·4 to 876·8)	70 500 (53 700 to 93 600)	340·6 (259·4 to 452·4)	−66·2% (−77·2 to −50·1)	−82·5% (−88·2 to −74·1)	−4·9% (−12·6 to 4·3)	−50·6% (−54·6 to −45·8)

(Table 2 continues on next page)

in 1990, representing a 62·3% (52·1–70·6) decrease (table 2). Worldwide in 2019, the neonatal mortality rate due to meningitis was 137·2 (109·5–177·8) per 100 000 population, down from 296·7 (257·2–350·9) per 100 000 population in 1990, representing a 53·8% (41·8–62·8) decrease (table 3). More detailed results on meningitis incidence and mortality for all age groups by sex, country, and year are available online via the GBD Results Tool.

Aetiology-specific results

In 2019, viral meningitis comprised 29·9% (95% UI 28·9–30·8) of total all-age meningitis cases, ranging regionally from 27·9% (26·9–29·0) in central sub-Saharan Africa to 37·4% (36·0–38·7) in the high-income Asia Pacific (appendix 2 pp 21–175). *N meningitidis* comprised 17·3% (16·5–18·0) of total cases, ranging from 8·5% (7·9–9·0) in Australasia to 21·4% (20·4–22·5) in central sub-Saharan Africa. *S pneumoniae* comprised 13·0% (12·4–13·6) of total cases, ranging from 10·4% (10·0–10·7) in eastern Europe to 14·7% (14·1–15·3) in Tropical Latin America. In the sub-Saharan African super-region, which has the highest incidence, viruses were estimated to be responsible for 28·6% (27·5–29·8) of cases, *N meningitidis* for 17·0% (15·8–18·1) of cases, and *S pneumoniae* for 13·6% (12·8–14·4) of cases. In 2019, the highest case burden in children younger than 5 years was attributable to viruses, comprising 25·1% (24·0–26·3) of total cases, followed by *N meningitidis* (16·9% [15·9–18·0]) and *S pneumoniae* (13·3% [12·5–14·0]). The highest case burden in neonates was attributable to viruses, comprising 37·1% (34·1–40·3) of total cases, followed by group B *Streptococcus* (20·4% [17·9–23·3]) and *N meningitidis* (9·7% [8·3–11·4]).

The largest proportion of total all-age meningitis deaths was attributable to *S pneumoniae*, comprising 18·1% (95% UI 17·1–19·2) of total all-age meningitis deaths, followed by *N meningitidis* (13·6% [12·7–14·4]) and *K pneumoniae* (12·2% [10·2–14·3]; figure 2; appendix 2 pp 21–175). In children younger than 5 years, the proportions of deaths due to *S pneumoniae*, *N meningitidis*, and *K pneumoniae* were similar to those for adults, but group B *Streptococcus* was responsible for a much larger fraction of deaths due to its high incidence proportion in neonates (appendix 2 pp 21–175). The largest proportion of deaths due to meningitis in 2019 in children younger than 5 years was attributable to *S pneumoniae*, comprising 17·3% (16·0–18·6) of total deaths due to meningitis in children younger than 5 years, followed by *N meningitidis* (12·9% [11·7–13·9]) and *K pneumoniae* (12·0% [9·7–14·8]). In 2019, the highest proportion of deaths due to meningitis in neonates was attributable to group B *Streptococcus* (22·8% [19·9–25·9]), followed by *K pneumoniae* (17·1% [13·6–21·1]) and viruses (15·3% [13·5–17·2]). Overall, 3200 (2420–4230) neonatal meningitis deaths were attributable to group B *Streptococcus* in 2019, down from 5920 (4870–7290) in 1990.

	Mortality			Incidence			Percentage change (1990–2019)			
	1990 counts	Mortality rate (per 100 000), 1990	2019 counts	Mortality rate (per 100 000), 2019	1990 counts	Incidence rate (per 100 000), 1990	2019 counts	Incidence rate (per 100 000), 2019	Mortality	Mortality rate	Incidence	Incidence rate
(Continued from previous page)												
Eastern sub-Saharan Africa	45 100 (35 600 to 56 200)	125·2 (98·9 to 156·1)	17 100 (12 700 to 23 000)	26·7 (19·8 to 35·9)	288 000 (217 000 to 378 000)	798·9 (603·6 to 1049·1)	245 000 (184 000 to 327 000)	382·0 (287·5 to 509·2)	−62·0% (−71·5 to −48·9)	−78·6% (−84·0 to −71·3)	−14·8% (−18·7 to −10·4)	−52·2% (−54·3 to −49·7)
Southern sub-Saharan Africa	1810 (1370 to 2270)	25·3 (19·1 to 31·7)	784 (571 to 1070)	9·7 (7·1 to 13·3)	15 900 (11 800 to 21 200)	222·0 (164·7 to 295·5)	11 300 (8330 to 15 200)	139·5 (102·9 to 187·2)	−56·7% (−69·8 to −36·1)	−61·6% (−73·2 to −43·4)	−29·1% (−32·5 to −25·2)	−37·2% (−40·2 to −33·7)
Western sub-Saharan Africa	64 600 (50 000 to 84 600)	181·2 (140·3 to 237·2)	57 800 (42 700 to 76 000)	79·5 (58·8 to 104·4)	396 000 (304 000 to 517 000)	1108·7 (853·4 to 1449·5)	416 000 (314 000 to 546 000)	571·7 (431·4 to 751·1)	−10·5% (−32·0 to 21·3)	−56·1% (−66·7 to −40·5)	5·1% (2·4 to 8·0)	−48·4% (−49·8 to −47·0)

Data in parentheses are 95% uncertainty intervals. Count data are presented to three significant figures and rates are presented to one decimal place. SDI=Socio-demographic Index. GBD=Global Burden of Diseases, Injuries, and Risk Factors Study.

Table 2: **Under-5 meningitis incidence and mortality rates and counts in 1990 and 2019, and percentage change in deaths, cases, and incidence and mortality rates between 1990 and 2019, by SDI quintile, globally, and for seven GBD super-regions and 21 GBD regions**

For the **GBD Results Tool** see http://ghdx.healthdata.org/gbd-results-tool

	Mortality				Incidence				Percentage change (1990–2019)			
	1990 counts	Mortality rate (per 100 000), 1990	2019 counts	Mortality rate (per 100 000), 2019	1990 counts	Incidence rate (per 100 000), 1990	2019 counts	Incidence rate (per 100 000), 2019	Mortality	Mortality rate	Incidence	Incidence rate
Global	30 600 (26 600 to 36 200)	296·7 (257·2 to 350·9)	14 000 (11 200 to 18 200)	137·2 (109·5 to 177·8)	134 000 (96 300 to 182 000)	1301·2 (932·4 to 1767·2)	87 300 (62 300 to 121 000)	854·8 (609·2 to 1183·3)	−54·2% (−63·1 to −42·4)	−53·8% (−62·8 to −41·8)	−35·0% (−36·5 to −33·4)	−34·3% (−35·8 to −32·7)
Low SDI	13 700 (11 700 to 16 600)	778·1 (661·5 to 942·2)	9330 (7290 to 12 200)	329·3 (257·2 to 429·4)	57 800 (42 400 to 77 200)	3278·8 (2403·4 to 4381·1)	52 800 (38 200 to 72 100)	1863·6 (1346·4 to 2545·6)	−31·9% (−46·5 to −13·3)	−57·7% (−66·8 to −46·1)	−8·6% (−12·0 to −5·3)	−43·2% (−45·3 to −41·1)
Low-middle SDI	9700 (7920 to 11 800)	342·3 (279·4 to 416·7)	3270 (2510 to 4330)	122·3 (94·0 to 161·8)	40 200 (28 600 to 55 100)	1419·6 (1007·7 to 1944·6)	22 000 (15 400 to 30 700)	822·4 (574·3 to 1149·1)	−66·3% (−75·2 to −53·3)	−64·3% (−73·7 to −50·5)	−45·3% (−47·1 to −43·3)	−42·1% (−44·0 to −39·9)
Middle SDI	5510 (4700 to 6680)	169·3 (144·5 to 205·4)	1170 (930 to 1470)	43·0 (34·2 to 54·2)	26 000 (18 000 to 36 100)	798·3 (553·2 to 1110·4)	9550 (6530 to 13 700)	351·6 (240·3 to 502·6)	−78·8% (−83·6 to −72·7)	−74·6% (−80·3 to −67·3)	−63·2% (−64·6 to −62·0)	−56·0% (−57·6 to −54·5)
High-middle SDI	1470 (1320 to 1690)	93·9 (83·9 to 107·4)	184 (152 to 225)	15·4 (12·7 to 18·8)	8150 (5730 to 11 500)	519·1 (364·9 to 730·6)	2240 (1540 to 3240)	186·7 (128·2 to 270·5)	−87·5% (−90·1 to −84·3)	−83·6% (−87·1 to −79·5)	−72·5% (−74·0 to −71·1)	−64·0% (−66·0 to −62·2)
High SDI	210 (193 to 229)	23·4 (21·4 to 25·5)	48 (41 to 56)	6·1 (5·2 to 7·1)	2130 (1530 to 2990)	236·8 (170·4 to 332·4)	690 (487 to 1000)	87·7 (61·8 to 127·1)	−77·3% (−80·9 to −73·2)	−74·0% (−78·2 to −69·4)	−67·6% (−69·2 to −66·0)	−63·0% (−64·9 to −61·2)
Central Europe, eastern Europe, and Central Asia	653 (606 to 719)	131·2 (121·8 to 144·5)	66 (53 to 83)	16·6 (13·4 to 20·8)	3150 (2360 to 4200)	633·8 (474·2 to 843·4)	826 (595 to 1170)	208·0 (149·7 to 293·6)	−89·9% (−92·0 to −87·3)	−87·4% (−90·0 to −84·1)	−73·8% (−76·0 to −71·6)	−67·2% (−70·0 to −64·4)
Central Asia	274 (244 to 309)	185·4 (165·3 to 209·2)	34 (26 to 48)	24·0 (18·1 to 33·2)	1400 (1100 to 1740)	948·8 (742·4 to 1182·4)	438 (326 to 598)	305·9 (227·7 to 417·6)	−87·4% (−90·7 to −82·1)	−87·0% (−90·4 to −81·6)	−68·7% (−72·6 to −64·0)	−67·8% (−71·8 to −62·9)
Central Europe	110 (99 to 127)	86·7 (77·5 to 99·5)	8 (6 to 11)	10·2 (7·8 to 13·0)	469 (355 to 613)	368·1 (279·0 to 481·9)	92 (68 to 130)	112·9 (83·0 to 158·3)	−92·4% (−94·3 to −90·1)	−88·2% (−91·1 to −84·6)	−80·3% (−81·8 to −78·5)	−69·3% (−71·7 to −66·6)
Eastern Europe	269 (243 to 312)	120·7 (108·9 to 140·2)	23 (19 to 28)	13·4 (10·8 to 16·4)	1280 (887 to 1820)	576·8 (398·6 to 819·2)	295 (201 to 435)	171·7 (116·7 to 252·9)	−91·4% (−93·7 to −89·3)	−88·9% (−91·8 to −86·2)	−77·0% (−78·8 to −75·6)	−70·2% (−72·5 to −68·4)
High income	275 (256 to 298)	28·8 (26·8 to 31·2)	58 (49 to 68)	6·8 (5·7 to 8·0)	2510 (1850 to 3450)	262·7 (193·5 to 360·8)	748 (537 to 1070)	87·4 (62·8 to 124·7)	−78·8% (−82·3 to −74·8)	−76·3% (−80·3 to −71·8)	−70·2% (−71·7 to −68·9)	−66·7% (−68·4 to −65·2)
Australasia	8 (6 to 9)	32·1 (26·7 to 38·2)	2 (2 to 3)	8·5 (6·5 to 11·0)	74 (52 to 102)	306·8 (217·7 to 423·4)	35 (25 to 50)	126·2 (89·8 to 178·8)	−69·2% (−77·9 to −57·9)	−73·5% (−81·0 to −63·8)	−52·2% (−59·2 to −45·8)	−58·9% (−64·9 to −53·3)
High-income Asia Pacific	39 (33 to 46)	25·8 (21·9 to 30·4)	3 (2 to 3)	2·6 (2·1 to 3·0)	401 (282 to 580)	267·3 (188·4 to 386·6)	88 (58 to 132)	83·3 (55·6 to 125·5)	−93·0% (−94·6 to −91·2)	−90·0% (−92·3 to −87·5)	−78·1% (−80·4 to −75·7)	−68·8% (−72·0 to −65·3)
High-income North America	59 (51 to 69)	16·9 (14·6 to 19·9)	21 (19 to 24)	6·6 (5·9 to 7·5)	431 (275 to 651)	123·6 (78·9 to 186·8)	111 (72 to 159)	34·6 (22·6 to 49·6)	−64·0% (−70·2 to −56·5)	−60·7% (−67·5 to −52·6)	−74·3% (−76·2 to −71·5)	−72·0% (−74·1 to −68·9)
Southern Latin America	71 (62 to 80)	89·0 (78·8 to 100·8)	9 (6 to 13)	12·5 (8·8 to 17·1)	391 (313 to 489)	493·2 (394·6 to 616·3)	101 (76 to 137)	137·6 (103·6 to 186·0)	−87·0% (−91·0 to −81·8)	−86·0% (−90·3 to −80·4)	−74·1% (−77·4 to −70·1)	−72·1% (−75·6 to −67·8)
Western Europe	100 (90 to 111)	28·2 (25·6 to 31·4)	23 (18 to 28)	7·0 (5·6 to 8·5)	1210 (898 to 1670)	343·2 (254·1 to 471·7)	413 (300 to 587)	125·6 (91·2 to 178·6)	−77·0% (−82·0 to −71·3)	−75·3% (−80·6 to −69·1)	−66·0% (−68·3 to −63·7)	−63·4% (−66·0 to −61·0)

(Table 3 continues on next page)

	Mortality				Incidence				Percentage change (1990–2019)			
	1990 counts	Mortality rate (per 100 000), 1990	2019 counts	Mortality rate (per 100 000), 2019	1990 counts	Incidence rate (per 100 000), 1990	2019 counts	Incidence rate (per 100 000), 2019	Mortality	Mortality rate	Incidence	Incidence rate
(Continued from previous page)												
Latin America and Caribbean	1280 (1120 to 1490)	160·0 (139·4 to 185·6)	304 (207 to 419)	41·1 (28·0 to 56·6)	4830 (3550 to 6440)	601·9 (442·4 to 802·6)	1350 (970 to 1840)	182·7 (131·2 to 248·6)	−76·3% (−84·3 to −65·4)	−74·3% (−82·9 to −62·4)	−72·0% (−73·6 to −70·6)	−69·7% (−71·4 to −68·1)
Andean Latin America	105 (83 to 137)	115·7 (91·7 to 150·4)	18 (13 to 27)	18·6 (12·8 to 26·7)	391 (296 to 505)	430·7 (325·4 to 556·1)	139 (103 to 184)	139·8 (103·9 to 185·0)	−82·4% (−88·7 to −73·9)	−83·9% (−89·7 to −76·2)	−64·4% (−68·0 to −60·7)	−67·5% (−70·8 to −64·2)
Caribbean	440 (313 to 603)	644·4 (459·0 to 883·3)	209 (127 to 318)	339·8 (206·2 to 515·9)	760 (576 to 978)	1113·3 (843·2 to 1431·9)	418 (302 to 552)	678·0 (490·2 to 896·2)	−52·4% (−73·0 to −19·1)	−47·3% (−70·1 to −10·3)	−45·1% (−49·9 to −38·9)	−39·1% (−44·5 to −32·3)
Central Latin America	384 (335 to 438)	102·6 (89·6 to 116·9)	52 (37 to 71)	15·6 (11·2 to 21·2)	1610 (1220 to 2090)	429·0 (325·0 to 557·7)	365 (272 to 489)	109·4 (81·5 to 146·5)	−86·4% (−90·6 to −81·3)	−84·8% (−89·4 to −79·1)	−77·2% (−78·6 to −75·4)	−74·5% (−76·0 to −72·5)
Tropical Latin America	355 (305 to 416)	131·9 (113·4 to 154·5)	24 (19 to 30)	9·8 (7·6 to 12·4)	2070 (1420 to 2920)	770·4 (525·7 to 1083·0)	429 (288 to 633)	175·5 (117·6 to 259·0)	−93·3% (−95·0 to −91·3)	−92·6% (−94·5 to −90·4)	−79·3% (−81·5 to −77·9)	−77·2% (−79·6 to −75·7)
North Africa and Middle East	1850 (1450 to 2390)	209·9 (164·9 to 271·3)	389 (276 to 541)	42·3 (30·0 to 58·8)	6320 (4560 to 8450)	718·6 (517·7 to 960·7)	2820 (2020 to 3960)	306·9 (219·6 to 430·6)	−79·0% (−85·9 to −68·4)	−79·9% (−86·5 to −69·7)	−55·3% (−58·9 to −51·7)	−57·3% (−60·7 to −53·8)
South Asia	7820 (6420 to 9470)	292·4 (240·1 to 353·7)	3120 (2320 to 4230)	123·6 (92·1 to 167·8)	35 800 (24 900 to 50 300)	1339·3 (929·6 to 1879·0)	18 500 (12 500 to 26 400)	733·7 (497·6 to 1046·4)	−60·2% (−72·5 to −43·7)	−57·7% (−70·8 to −40·2)	−48·4% (−50·6 to −46·2)	−45·2% (−47·5 to −42·8)
Southeast Asia, east Asia, and Oceania	4160 (3290 to 5450)	145·2 (114·6 to 190·3)	627 (489 to 805)	30·8 (24·0 to 39·5)	16 900 (11 500 to 23 700)	589·9 (401·5 to 826·0)	4500 (3090 to 6300)	221·3 (151·7 to 309·6)	−84·9% (−89·1 to −79·3)	−78·8% (−84·7 to −70·9)	−73·4% (−74·4 to −72·1)	−62·5% (−64·0 to −60·7)
East Asia	1400 (1150 to 1660)	73·5 (60·7 to 87·3)	128 (100 to 157)	10·9 (8·5 to 13·3)	6830 (4360 to 9950)	359·2 (229·5 to 523·7)	1000 (650 to 1450)	84·9 (55·3 to 122·8)	−90·8% (−93·2 to −88·1)	−85·2% (−89·1 to −80·8)	−85·4% (−86·2 to −84·5)	−76·4% (−77·8 to −75·0)
Oceania	46 (30 to 68)	274·6 (181·5 to 408·8)	46 (26 to 72)	149·6 (83·0 to 233·0)	249 (183 to 329)	1488·1 (1092·8 to 1962·6)	285 (204 to 387)	916·6 (657·5 to 1247·7)	0·9% (−46·5 to 78·6)	−45·5% (−71·1 to −3·6)	14·1% (0·7 to 29·5)	−38·4% (−45·7 to −30·1)
Southeast Asia	2720 (2000 to 3920)	286·3 (210·9 to 412·7)	453 (339 to 615)	54·7 (41·0 to 74·3)	9830 (6950 to 13 300)	1035·9 (732·0 to 1398·0)	3220 (2240 to 4470)	389·1 (270·2 to 540·3)	−83·3% (−88·7 to −75·1)	−80·9% (−87·1 to −71·4)	−67·3% (−68·8 to −65·6)	−62·4% (−64·2 to −60·5)
Sub-Saharan Africa	14 600 (12 200 to 18 400)	885·7 (738·5 to 1115·3)	9460 (7220 to 12 500)	344·0 (262·6 to 456·3)	64 800 (47 500 to 86 700)	3933·5 (2881·7 to 5263·3)	58 600 (42 500 to 80 100)	2130·9 (1546·7 to 2914·2)	−35·1% (−49·2 to −16·7)	−61·2% (−69·6 to −50·1)	−9·5% (−12·6 to −6·1)	−45·8% (−47·7 to −43·7)
Central sub-Saharan Africa	1540 (1040 to 2220)	769·5 (523·4 to 1111·4)	750 (484 to 1200)	223·8 (144·5 to 359·0)	6620 (4810 to 8760)	3317·3 (2410·4 to 4389·0)	5560 (4060 to 7590)	1660·4 (1210·6 to 2265·6)	−51·1% (−70·1 to −17·4)	−70·9% (−82·2 to −50·8)	−15·9% (−25·6 to −7·0)	−49·9% (−55·7 to −44·7)
Eastern sub-Saharan Africa	5990 (4930 to 7500)	900·9 (740·9 to 1127·4)	3000 (2230 to 4040)	282·6 (210·7 to 381·3)	24 300 (17 800 to 32 400)	3650·9 (2674·3 to 4876·7)	19 300 (13 900 to 26 900)	1819·8 (1309·6 to 2538·8)	−49·9% (−62·5 to −34·1)	−68·6% (−76·5 to −58·7)	−20·5% (−24·6 to −15·5)	−50·2% (−52·8 to −47·0)

(Table 3 continues on next page)

	Mortality			Incidence			Percentage change (1990–2019)			
	1990 counts	Mortality rate (per 100 000), 1990	2019 counts	Mortality rate (per 100 000), 2019	1990 counts	Incidence rate (per 100 000), 1990	2019 counts	Incidence rate (per 100 000), 2019	Mortality	Mortality rate	Incidence	Incidence rate
(Continued from previous page)												
Southern sub-Saharan Africa	195 (155 to 242)	168·1 (134·2 to 209·1)	110 (79 to 157)	87·8 (63·0 to 125·0)	1060 (758 to 1450)	912·5 (654·7 to 1255·2)	729 (516 to 1020)	581·1 (411·3 to 814·2)	−43·4% (−60·9 to −14·7)	−47·7% (−63·9 to −21·3)	−31·0% (−35·4 to −26·7)	−36·3% (−40·3 to −32·4)
Western sub-Saharan Africa	6870 (5600 to 8910)	1030·2 (840·1 to 1336·3)	5600 (4270 to 7490)	455·9 (347·7 to 609·3)	32 800 (24 200 to 43 700)	4924·8 (3634·3 to 6563·5)	33 000 (24 100 to 44 500)	2686·1 (1959·9 to 3622·4)	−18·4% (−37·6 to 7·3)	−55·7% (−66·2 to −41·8)	0·5% (−2·9 to 3·7)	−45·5% (−47·3 to −43·7)

Data in parentheses are 95% uncertainty intervals. Count data are presented to three significant figures and rates are presented to one decimal place. Neonates are defined as those aged 0–27 days. SDI=Socio-demographic Index. GBD=Global Burden of Diseases, Injuries, and Risk Factors Study.

Table 3: **Neonatal meningitis incidence and mortality rates and counts in 1990 and 2019, and percentage change in deaths, cases, and incidence and mortality rates between 1990 and 2019, by SDI quintile, globally, and for seven GBD super-regions and 21 GBD regions**

Between 1990 and 2019, the largest reduction in deaths was seen from *H influenzae* among children younger than 5 years (76·5% [69·5–81·8]), followed by *N meningitidis* (72·3% [64·4–78·5]) and viruses (58·2% [47·1–67·3]; appendix 2 pp 176–77).

Between 1990 and 2019, the largest reduction in both mortality and incidence was for meningitis attributable to *H influenzae*. In 1990, 435 000 (95% UI 340 000–561 000) global all-age cases and 38 000 (31 500–45 400) global all-age deaths were attributable to *H influenzae* meningitis; of these, 354 000 cases (260 000–475 000) and 32 200 deaths (26 100–39 200) occurred in children younger than 5 years (appendix 2 pp 176–77). In 2019, there were 187 000 (151 000–234 000) all-age cases attributable to *H influenzae*, corresponding to a reduction of 56·9% (54·1–59·5), and 11 100 (9080–13 500) total deaths attributable to *H influenzae*, corresponding to a reduction of 70·8% (64·2–76·2; appendix 2 pp 176–77).

Between 1990 and 2019, the second largest reduction in mortality and incidence was for meningitis attributable to *N meningitidis*. In 1990, 744 000 (95% UI 608 000–902 000) all-age cases and 80 900 (69 300–95 100) all-age deaths were attributable to *N meningitidis* meningitis globally; of these, 442 000 (329 000–588 000) cases and 52 300 (42 200–64 300) deaths occurred in children younger than 5 years (appendix 2 pp 176–77). In 2019, there were 433 000 (361 000–518 000) all-age *N meningitidis* cases, corresponding to a reduction of 41·7% (38·4–44·8), and 32 100 (27 600–38 200) all-age deaths, corresponding to a reduction of 60·2% (52·7–66·4; appendix 2 pp 176–77).

Meningitis belt results

A high burden of mortality and incidence is concentrated in the African meningitis belt, especially for children younger than 5 years. In 2019, there were 70 600 (95% UI 52 700–93 200) under-5 deaths attributed to meningitis in the meningitis belt, corresponding to 62·9% (57·5–67·8) of under-5 meningitis deaths globally; there were 637 000 (480 000–843 000) under-5 incident cases in the meningitis belt, corresponding to 50·0% (48·1–51·7) of under-5 meningitis cases globally (appendix 2 pp 178–79).

In 2019, age-standardised mortality rates in the meningitis belt ranged from 1·9 (95% UI 1·3–2·5) per 100 000 population in Sudan to 24·5 (17·5–32·9) per 100 000 population in Niger and 25·4 (19·0–33·3) per 100 000 population in Mali. Incidence rates ranged from 14·0 (11·9–16·4) per 100 000 population in Sudan to 257·1 (221·2–297·7) per 100 000 population in South Sudan (appendix 2 pp 2–19).

Even in the meningitis belt, which is at high risk of epidemics of meningococcal meningitis, *S pneumoniae* was responsible for the largest proportion of meningitis-related mortality in 2019, comprising 18·5% (95% UI 17·2–19·8) of total all-age meningitis deaths (121 000 [98 600–149 000]; appendix 2 pp 178, 180). The second largest proportion was attributed to *N meningitidis*,

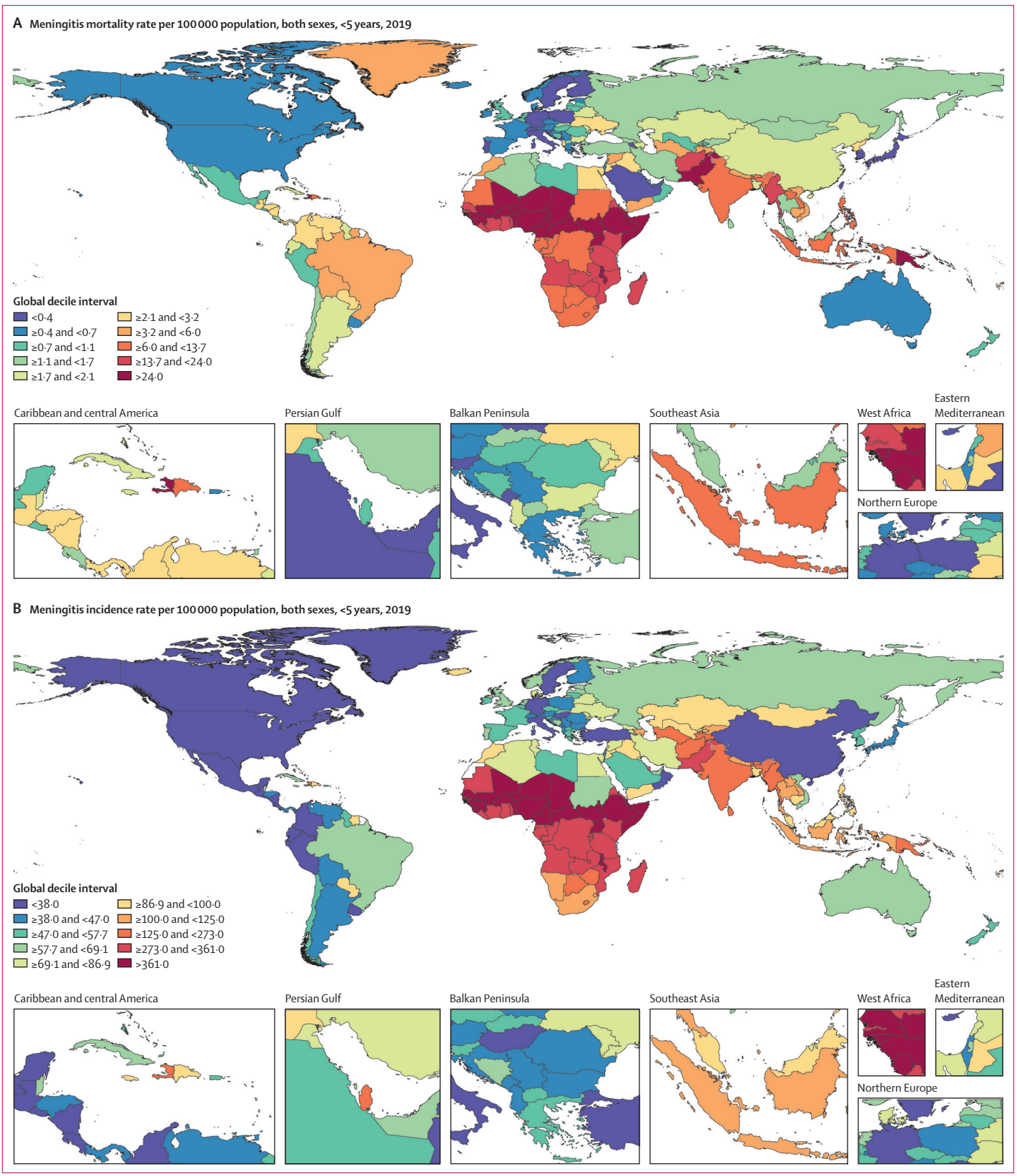

Figure 1: **Meningitis mortality (A) and incidence (B) rates per 100 000 population among children younger than 5 years in 2019**

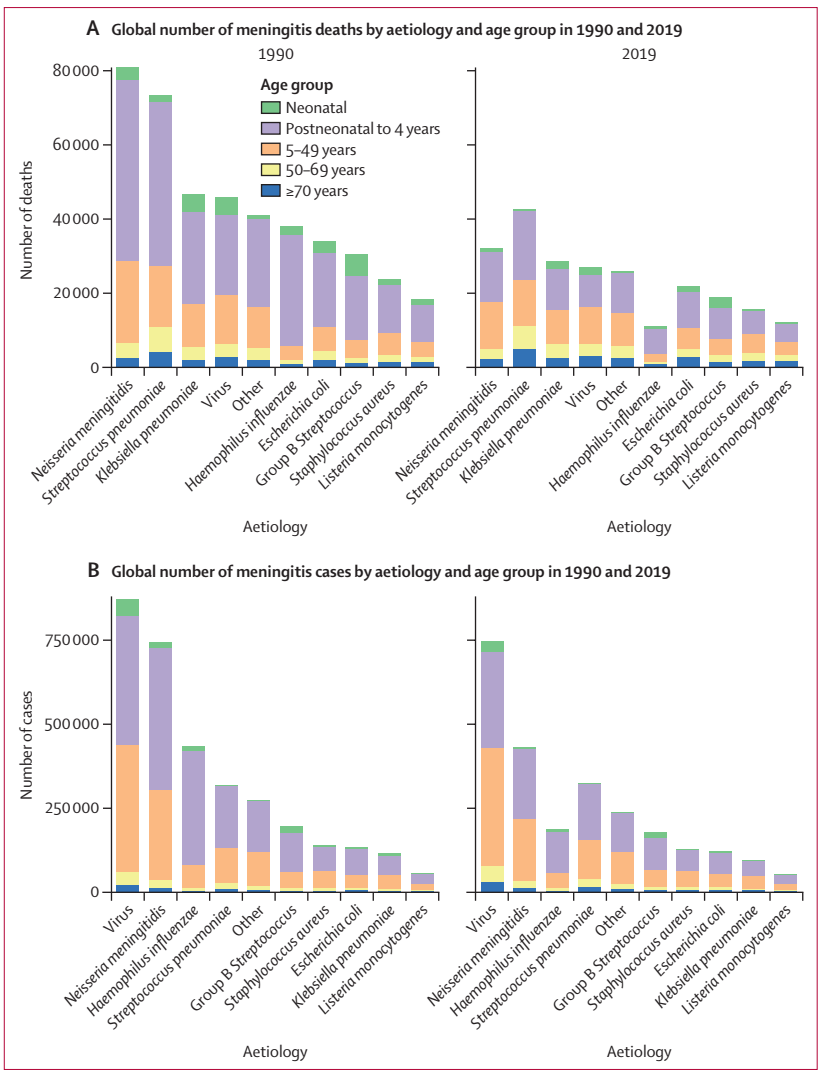

Figure 2: **Global number of meningitis deaths (A) and cases (B) by aetiology and age group in 1990 and 2019**

comprising 12·6% (11·4–13·8) of total all-age meningitis deaths. The all-age mortality rate due to *S pneumoniae* meningitis dropped in the meningitis belt, from 6·5 (5·3–8·0) per 100 000 population in 1990 to 2·6 (2·1–3·2) per 100 000 population in 2019, representing a 60·0% (50·6–68·0) decrease. The all-age mortality rate due to *N meningitidis* decreased from 7·4 (6·0–9·0) per 100 000 population in 1990 to 1·7 (1·4–2·2) per 100 000 population in 2019, representing a 76·2% (69·7–81·1) decrease (appendix 2 p 180).

Among children younger than 5 years, the largest proportion of meningitis-related mortality was attributed to *S pneumoniae* in the meningitis belt in 2019, comprising 17·7% (95% UI 16·2–19·2) of total under-5 meningitis deaths (70 600 [52 700–93 200]; appendix 2 pp 178, 180). The second largest proportion was attributed to *K pneumoniae*, comprising 12·0% (9·5–14·9) of total under-5 meningitis deaths. The under-5 meningitis mortality rate due to *S pneumoniae* dropped from 23·4 (17·9–30·4) per 100 000 population in 1990 to 9·2 (6·7–12·5) per 100 000 population in 2019, representing a 60·5% (47·6–70·8) decrease. Mortality rates due to *K pneumoniae* among children younger than 5 years decreased from 14·4 (10·0–20·2) per 100 000 population in 1990 to 6·2 (4·2–8·7) per 100 000 population in 2019, representing a 56·6% (42·4–67·7) decrease (appendix 2 p 180).

Discussion

This study presents what are to our knowledge the most comprehensive estimates of the meningitis burden attributable to a comprehensive set of pathogens by age group across countries, contributing to our understanding of the pathogen-specific burden of meningitis. In 2019, the highest proportion of meningitis deaths both in all age groups and in children younger than 5 years was attributable to *S pneumoniae*, followed by *N meningitidis* and *K pneumoniae*, and the highest proportion of deaths in neonates was attributable to group B *Streptococcus*. *S pneumoniae*, *N meningitidis*, and *H influenzae* are the three pathogens responsible for the most meningitis-related deaths among children younger than 5 years, and there have been large reductions in the number of deaths attributable to all three pathogens since 1990.

A reduction in the burden of these pathogens could be attributed to successful vaccination rollouts over the past 30 years, with the highly effective Hib, pneumococcal, and meningococcal conjugate vaccines playing a key role.[26] To achieve the goals of the WHO global roadmap to reduce cases of vaccine-preventable bacterial meningitis by 50% and deaths by 70% by 2030, continued vaccination against these pathogens is essential.[13] Progress towards the roadmap goal of eliminating meningitis epidemics, which most commonly occur in the meningitis belt, is largely attributable to the rollout of vaccination programmes: specifically, the highly successful MenAfriVac campaign.[27] An analysis of enhanced surveillance data from nine countries in the meningitis belt that completed MenAfriVac campaigns from 2005 to 2015 estimated that confirmed cases of *N meningitidis* serogroup A had declined by more than 99%.[27] Our modelled results for meningococcus, which include serogroup A and other serogroups not covered by the vaccine, estimate a 41·7% decline in cases. A key factor in the successful rollout of MenAfriVac is its much lower cost than other comparable conjugate vaccines, improving the feasibility of mass rollout and sustainable vaccination.[27–29]

Although MenAfriVac campaigns successfully reduced the incidence rate of *N meningitidis* serogroup A in the meningitis belt, both sporadic and epidemic cases due to serogroups W, X, and C have increased.[30,31] Niger, in particular, began reporting an increase in both the number and proportion of serogroup W cases in the same year as the introduction of MenAfriVac.[32] This observation underscores the need for an affordable multivalent meningococcal vaccine.[33] Serotype replacement is also an

issue for *S pneumoniae*: serotypes not covered by the 13-valent pneumococcal conjugate vaccine (PCV13), such as 12F and 23B, have resulted in a relative increase in the incidence of invasive disease in the post-vaccine era.[34] The fact that meningitis is multipathogenic and that only some of the pathogens are currently vaccine preventable might have contributed to a slower decline in under-5 mortality rates for meningitis between 1990 and 2019 (62·3% [95% UI 52·1–70·6]) compared with diseases that are caused by a vaccine-preventable single pathogen, such as measles (90·5% [87·6–93·0]) and tetanus (91·9% [86·3–94·2]).[17]

For the first time, we have quantified the global burden of meningitis attributable to *K pneumoniae* and have identified this pathogen as the third leading cause of meningitis mortality after *S pneumoniae* and *N meningitidis*. Unlike *S pneumoniae* and *N meningitidis*, which are the most common causes of community-acquired meningitis, *K pneumoniae* meningitis is usually hospital-acquired and has higher mortality rates, especially in patients older than 60 years with comorbidities.[1,35,36,37] A systematic review found that *K pneumoniae* is the leading cause of Gram-negative meningitis and bacteraemia in low-income and middle-income countries.[38] Despite its high fatal burden, *K pneumoniae* is not included as a priority pathogen in WHO's meningitis global roadmap,[13] possibly because of a scarcity of global data on meningitis due to *K pneumonaie* before this study. *K pneumoniae* is also not included in most commercially available PCR or rapid diagnostic tests.[39] Developing rapid diagnostic tests to detect this pathogen would improve tracking of this disease and its high burden.

The emerging shift in the cause of bacterial meningitis mortality to *K pneumoniae* emphasises the need for better control of hospital-acquired infections and antimicrobial stewardship. Many of these *K pneumoniae* strains have been reported to possess broad and threatening antimicrobial resistance genes, including extended-spectrum beta-lactamase with carbapenemase genes,[40,41] and these carbapenem-resistant strains are classified as critical on the WHO global priority antimicrobial resistance pathogen list.[42] Many vaccines for *K pneumoniae* are in development and in clinical trials, with one of the most promising being multicomponent conjugate vaccines.[42] These new vaccines might be able to protect against the multitude of infectious syndromes and antimicrobial resistance that *K pneumoniae* is known to produce.[43] The rollout of Hib and *S pneumoniae* conjugate vaccines has also been shown to reduce the need for antibiotic use and helped slow the development of antimicrobial resistance.[44]

Group B *Streptococcus* comprises the highest proportion of neonatal meningitis deaths, although the absolute number of meningitis deaths due to group B *Streptococcus* in neonates has decreased from 5920 (95% UI 4870–7290) in 1990 to 3200 (2420–4230) in 2019. Unlike the key pathogens responsible for post-neonatal childhood meningitis, group B *Streptococcus* is not vaccine preventable. Instead, prevention of neonatal group B *Streptococcus* currently relies on prenatal testing of the mother and intrapartum antibiotic prophylaxis.[45] A global meta-analysis found that the risk of early-onset group B *Streptococcus* in neonates was 1·1% in settings without an intrapartum antibiotic prophylaxis policy, and 0·3% in settings with an intrapartum antibiotic prophylaxis policy.[46] An analysis of global intrapartum antibiotic prophylaxis policies in 90 countries found that 40 of 44 high-income countries had a policy, while only three of 20 countries in sub-Saharan Africa and one of three in east Asia reported having such a policy.[47] Intrapartum antibiotic prophylaxis does not protect against late-onset group B *Streptococcus* disease occurring in infants aged 7–89 days,[48,49] which is responsible for about a third of the total neonatal group B *Streptococcus* cases. A maternal vaccine against group B *Streptococcus* might therefore be a solution, protecting against both early-onset and late-onset group B *Streptococcus*, and preventing frequent antibiotic use that can be associated with the development of antimicrobial resistance.[50] Such a vaccine is currently a WHO priority and is predicted to be a cost-effective, financially sustainable, and feasible intervention.[51] In addition to vaccination, reducing rates of short gestation and low birthweight might play an important role in preventing early-onset group B *Streptococcus*.[45]

Improvements to laboratory systems for both patient treatment and population surveillance are other key pillars in the WHO meningitis roadmap.[13,39] Specific microbial diagnosis guides appropriate treatment, including antibiotic selection. In the meningitis belt, population-level microbial surveillance enables the timely rollout of reactive vaccination campaigns against meningococcal strains other than serogroup A.[22,52,53] One such strategy to improve laboratory systems is to invest in infrastructure that reduces the transportation time of CSF samples and to reinforce safe-handling procedures between collection facilities and laboratories.[54,55] Another strategy is the development and rollout of next-generation rapid diagnostic tests (RDTs). Their low cost and ease of operation accelerate the diagnosis of meningitis in low-resource settings, substantially improving patient care, surveillance, and outbreak response;[39] development of next-generation RDTs is therefore a WHO priority.[56] However, downsides of existing RDTs include the absence of many pathogens in the test, the inability to distinguish between serotypes, and the inability to assess for antimicrobial resistance.[39,57] As the prevalence of antimicrobial resistance rises, especially in non-vaccine-preventable pathogens such as *K pneumoniae*, the need for global antimicrobial resistance surveillance systems grows. The WHO Global Antimicrobial Resistance and Use Surveillance System (GLASS),[58] which provides a standardised approach to collection, analysis, and sharing of clinical antimicrobial resistance data for surveillance, is expanding. In 2020, 251 surveillance sites in the WHO African region, where meningitis poses the highest burden, submitted data to GLASS, up from 35 surveillance

sites in 2017.[58] The concurrent expansion of next-generation RDTs for point-of-care decision making, and enhanced microbial surveillance systems, including antimicrobial resistance surveillance to support evidence-based antibiotic use, can help improve outcomes for patients with infectious meningitis globally.

Our estimates of meningitis mortality in children younger than 5 years differ from those produced by other groups, both for the overall burden and for the pathogen-specific burden.[59] The 2017 WHO and Maternal and Child Epidemiology Estimation Group (WHO-MCEE)[59] estimate for global under-5 deaths due to meningitis and encephalitis was 142 841, which is lower than, but within the uncertainty interval of, the GBD 2019 estimate published previously for meningitis and encephalitis combined in the same year (143 000 [95% UI 115 000–179 000];[17] WHO-MCEE combines meningitis and encephalitis, whereas GBD models them as mutually exclusive causes). A 2018 global systematic review by Oordt-Speets and colleagues[7] of 56 published studies found that *S pneumoniae* and *N meningitidis* were the most common all-age bacterial meningitis pathogens in all regions, with mean case proportions ranging from 25·1% to 41·2% for *S pneumoniae* and from 9·1% to 36·2% *N meningitidis*, across regions. Here, we estimate that *N meningitidis* comprised 17·3% (16·5–18·0) of global all-age meningitis cases in 2019, ranging from 8·5% in Australasia to 21·4% in central sub-Saharan Africa, while *S pneumoniae* comprised 13·0% (12·4–13·6) of global all-age meningitis cases in the same year, ranging from 10·4% in eastern Europe to 14·7% in Tropical Latin America (appendix 2 pp 21–175). Additionally, the systematic review by Oordt-Speets and colleagues[7] estimated that, in the African region, which had the most all-age data sources, *S pneumoniae* was responsible for 41·2% (34·1–48·4) of bacterial meningitis cases and *N meningitidis* was responsible for 36·2% (26·6–46·4) of bacterial meningitis cases. In our study, in the sub-Saharan African region, *S pneumoniae* was estimated to be responsible for 13·6% (12·8–14·4) of cases and *N meningitidis* was estimated to be responsible for 17·0% (15·8–18·1) of cases. Part of the reason for this discrepancy is that the previous systematic review only included 56 articles published between April 25, 2012, and April 25, 2017, whereas we include scientific literature published between 1990 and 2019, in addition to non-literature sources, such as multiple cause of death data and laboratory data. Owing to the historical importance and vaccine-preventable nature of *S pneumoniae, N meningitidis, and H influenzae,* many literature studies look specifically for these pathogens through rapid tests and assays that are not used for other pathogens, thus leading to a potential over-representation of these pathogens in literature.

This study has some limitations. First, the estimates of the overall meningitis and aetiology-specific burden are limited by data availability and quality, especially in areas of the meningitis belt where the burden is the greatest in settings with low health-care access. Even when data are available, heterogeneous data sources (eg, surveillance versus inpatient data) might not be directly comparable. We applied a standardised approach to adjust for systematic bias among different data sources before modelling. Locations with sparse or no data must rely on covariates and regional trends to predict estimates. Additionally, many of these locations rely on verbal autopsy data. A multisite validation study by Lozano and colleagues[60] shows that verbal autopsy of meningitis has only modest performance. Strong, population-based surveillance systems are preferred and needed to drive response, inform case management, assess vaccine impact, and track progress. Second, we directly apply meningitis aetiology proportions from the global burden of antimicrobial resistance study to GBD estimates of meningitis cases and deaths, even though the two studies have slightly different definitions of meningitis. More specifically, for fatal cases, the GBD definition of meningitis includes only instances in which meningitis was the underlying cause of death, whereas the antimicrobial resistance study definition includes any instance where meningitis was present in the causal chain, regardless of the underlying cause of death. Third, meningitis cases due to *Mycobacterium tuberculosis* or HIV-associated opportunistic infections, including *Cryptococcus neoformans,* were not included in the present study, as GBD classifies them with the underlying diseases tuberculosis and HIV, respectively. Fourth, due to the poor specificity of data documenting cases of viral meningitis, we modelled all viral aetiologies collectively, rather than distinguishing individual viruses of scientific interest, such as enteroviruses and herpes viruses. Fifth, we did not explicitly search for data sources that used molecular methods such as genome sequencing to identify viral pathogens, but such sources could be emphasised in a future systematic review. Sixth, we assumed the distribution of cases of meningitis with unknown aetiology (ie, those not identified through physician diagnosis or by microbiological means as either viral meningitis or a specified bacteria) was the same as the distribution of meningitis cases in which the aetiology was defined. This assumption could be violated if certain pathogens are more difficult to detect than others, or in cases where a pathogen is irregularly tested for within a laboratory. Seventh, age-standardised estimates allow for comparisons between populations with potentially different age distributions, but they should not be interpreted as actual rates. Meningitis incidence and mortality estimates that are not age-standardised are available online via the GBD Results Tool described above. Eighth, we did not assess risk factors for meningitis, but these could be the subject of future research. Finally, presenting *K pneumoniae* results for all children younger than 5 years might mask its higher burden in children younger than 1 year. We plan to report results for more detailed age groups in future GBD rounds.

Our study presents the burden of meningitis and its aetiologies before the COVID-19 pandemic. Evidence suggests that social distancing associated with COVID-19 has resulted in a lower incidence of meningitis and other invasive infections attributable to selected pathogens transmitted via the respiratory route, including *S pneumoniae, N meningitidis,* and *H influenzae*, during the pandemic, while the incidence of group B *Streptococcus* remained unchanged.[61,62] However, data for other pathogens remain unavailable. At the same time, the COVID-19 pandemic disrupted delivery of vaccines in 2020.[63] Although this disruption is unlikely to affect meningitis rates due to persistent herd immunity, growing vaccine hesitancy fuelled by the pandemic will pose a challenge to preventing and controlling meningitis in the years ahead.[64] As data become available for more countries and more pathogens, we will be able to comprehensively quantify the indirect effects of the pandemic on the incidence of meningitis and its aetiologies in future rounds of GBD.

Although meningitis incidence and mortality rates have decreased globally since 1990, progress lags behind that for other vaccine-preventable diseases. Moreover, although increased vaccine coverage in low-income and middle-income countries might have driven reductions in the meningitis burden, the reduction is not equal across locations. There is a continued need for low-cost multivalent vaccines as a preventive measure and for epidemic control in the meningitis belt. Further strengthening laboratory capacity to diagnose meningitis accurately and rapidly will also assist in the control of epidemics. Countries outside the African meningitis belt with high meningitis burdens, such as those in south Asia, are also affected by these policy needs. Additional enhanced surveillance data will improve country-specific burden estimates, which will help track progress towards reducing the global burden of meningitis by 2030.

GBD 2019 Meningitis and Antimicrobial Resistance Collaborators
Han Yong Wunrow*, Rose G Bender*, Avina Vongpradith, Sarah Brooke Sirota, Lucien R Swetschinski, Amanda Novotney, Authia P Gray, Kevin S Ikuta, Fablina Sharara, Eve E Wool, Amirali Aali, Sherief Abd-Elsalam, Ashkan Abdollahi, Jeza Muhamad Abdul Aziz, Hassan Abidi, Richard Gyan Aboagye, Hassan Abolhassani, Eman Abu-Gharbieh, Lawan Hassan Adamu, Tigist Demssew Adane, Isaac Yeboah Addo, Oyelola A Adegboye, Tayo Alex Adekiya, Mohammad Adnan, Qorinah Estiningtyas Sakilah Adnani, Saira Afzal, Shahin Aghamiri, Zahra Babaei Aghdam, Antonella Agodi, Bright Opoku Ahinkorah, Aqeel Ahmad, Sajjad Ahmad, Mohadese Ahmadzade, Ali Ahmed, Ayman Ahmed, Jivan Qasim Ahmed, Meqdad Saleh Ahmed, Karolina Akinosoglou, Addis Aklilu, Maxwell Akonde, Fares Alahdab, Tareq Mohammed Ali Al-Ahdal, Fahad Mashhour Alanezi, Ahmed Hassan Albelbeisi, Tsegaye Begashaw B Alemayehu, Kefyalew Addis Alene, Ayman Al-Eyadhy, Adel Ali Saeed Al-Gheethi, Abid Ali, Beriwan Abdulqadir Ali, Liaqat Ali, Syed Shujait Ali, Yousef Alimohamadi, Vahid Alipour, Syed Mohamed Aljunid, Sami Almustanyir, Rajaa M Al-Raddadi, Nelson Alvis-Guzman, Yaser Mohammed Al-Worafi, Hany Aly, Edward Kwabena Ameyaw, Robert Ancuceanu, Adnan Ansar, Golnoosh Ansari, Anayochukwu Edward Anyasodor, Jalal Arabloo, Aleksandr Y Aravkin, Demelash Areda, Anton A Artamonov, Judie Arulappan, Raphael Taiwo Aruleba, Muhammad Asaduzzaman, Kendalem Asmare Atalell, Seyyed Shamsadin Athari, Daniel Atlaw, Maha Moh'd Wahbi Atout, Sameh Attia, Tewachew Awoke, Melese Kitu Ayalew, Tegegn Mulatu Ayana, Alemu Degu Ayele, Sina Azadnajafabad, Khalil Azizian, Muhammad Badar, Ashish D Badiye, Nayereh Baghcheghi, Mahboube Bagheri, Sara Bagherieh, Saeed Bahadory, Atif Amin Baig, Aleksandra Barac, Shirin Barati, Mainak Bardhan, Zarrin Basharat, Azadeh Bashiri, Buddha Basnyat, Quique Bassat, Saurav Basu, Nebiyou Simegnew Bayileyegn, Neeraj Bedi, Amir Hossein Behnoush, Abebe Ayalew Bekel, Melaku Ashagrie Belete, Olorunjuwon Omolaja Bello, Akshaya Srikanth Bhagavathula, Dinesh Bhandari, Pankaj Bhardwaj, Sonu Bhaskar, Ajay Nagesh Bhat, Ali Bijani, Niloufar Bineshfar, Archith Boloor, Souad Bouaoud, Danilo Buonsenso, Katrin Burkart, Luis Alberto Cámera, Carlos A Castañeda-Orjuela, Achille Cernigliaro, Jaykaran Charan, Vijay Kumar Chattu, Patrick R Ching, Hitesh Chopra, Sonali Gajanan Choudhari, Devasahayam J Christopher, Dinh-Toi Chu, Rosa A S Couto, Natália Cruz-Martins, Omid Dadras, Xiaochen Dai, Lalit Dandona, Rakhi Dandona, Saswati Das, Nihar Ranjan Dash, Mohsen Dashti, Fernando Pio De la Hoz, Sisay Abebe Debela, Demeke Dejen, Hiwot Dejene, Dessalegn Demeke, Feleke Mekonnen Demeke, Berecha Hundessa Demessa, Andreas K Demetriades, Solomon Demissie, Diriba Dereje, Emina Dervišević, Hardik Dineshbhai Desai, Anteneh Mengist Dessie, Fikreab Desta, Kuldeep Dhama, Shirin Djalalinia, Thanh Chi Do, Masoud Dodangeh, Milad Dodangeh, Regina-Mae Villanueva Dominguez, Deepa Dongarwar, Haneil Larson Dsouza, Oyewole Christopher Durojaiye, Arkadiusz Marian Dziedzic, Martin Herbas Ekat, Michael Ekholuenetale, Temitope Cyrus Ekundayo, Maysaa El Sayed Zaki, Hassan El-Abid, Muhammed Elhadi, Victor Gabriel El-Hajj, Waseem El-Huneidi, Amro A El-Sakka, Hawi Leul Esayas, Adeniyi Francis Fagbamigbe, Shahab Falahi, Jawad Fares, Ali Fatehizadeh, Syeda Anum Fatima Fatima, Nicholas A Feasey, Ginenus Fekadu, Getahun Fetensa, Desalegn Feyissa, Florian Fischer, Behzad Foroutan, Peter Andras Gaal, Muktar A Gadanya, Abduzhappar Gaipov, Balasankar Ganesan, Mesfin Gebrehiwot, Kahsu Gebrekirstos Gebrekidan, Teferi Gebru Gebremeskel, Getachew Muluye Gedef, Yibeltal Yismaw Gela, Urge Gerema, Bradford D Gessner, Motuma Erena Getachew, Keyghobad Ghadiri, Kazem Ghaffari, Seyyed-Hadi Ghamari, Reza Ghanbari, Ramy Mohamed Mohmaed Ghazy, Ghozali Ghozali, Admasu Belay AB Gizaw, Ekaterina Vladimirovna Glushkova, Mohamad Goldust, Mahaveer Golechha, Habtamu Alganeh Guadie, Rashid Abdi Guled, Mohak Gupta, Sapna Gupta, Veer Bala Gupta, Vijai Kumar Gupta, Vivek Kumar Gupta, Najah R Hadi, Arvin Haj-Mirzaian, Sebastian Haller, Samer Hamidi, Shafiul Haque, Harapan Harapan, Ahmed I Hasaballah, Ikramul Hasan, Hamidreza Hasani, Mohammad Hasanian, Hadi Hassankhani, Mohammed Bheser Hassen, Khezar Hayat, Mohammad Heidari, Mahsa Heidari-Foroozan, Reza Heidari-Soureshjani, Kamal Hezam, Ramesh Holla, Nobuyuki Horita, Md Mahbub Hossain, Mohammad-Salar Hosseini, Mehdi Hosseinzadeh, Sorin Hostiuc, Salman Hussain, Nawfal R Hussein, Segun Emmanuel Ibitoye, Olayinka Stephen Ilesanmi, Irena M Ilic, Milena D Ilic, Mohammad Tarique Imam, Kenneth Chukwuemeka Iregbu, Nahlah Elkudssiah Ismail, Chidozie C D Iwu, Chinwe Jaja, Mihajlo Jakovljevic, Elham Jamshidi, Amirreza Javadi Mamaghani, Javad Javidnia, Mohammad Jokar, Nabi Jomehzadeh, Nitin Joseph, Charity Ehimwenma Joshua, Jacek Jerzy Jozwiak, Zubair Kabir, Laleh R Kalankesh, Rohollah Kalhor, Vineet Kumar Kamal, Himal Kandel, Ibraheem M Karaye, André Karch, Hanie Karimi, Harkiran Kaur, Navjot Kaur, Mohammad Keykhaei, Himanshu Khajuria, Amirmohammad Khalaji, Ajmal Khan, Imteyaz A Khan, Maseer Khan, Taimoor Khan, Khaled Khatab, Moawiah Mohammad Khatatbeh, Hamid Reza Khayat Kashani, Jagdish Khubchandani, Min Seo Kim, Adnan Kisa, Sezer Kisa, Farzad Kompani, Hamid Reza Koohestani, Nikhil Kothari, Kewal Krishan, Yuvaraj Krishnamoorthy, Mukhtar Kulimbet, Manoj Kumar, Senthil D Kumaran, Ambily Kuttikkattu, Alexander Kwarteng, Tri Laksono, Iván Landires,

Dennis Odai Laryea, Basira Kankia Lawal, Thao Thi Thu Le, Caterina Ledda, Sang-woong Lee, Seung Lee, Gebretsadik Kiros Lema, Miriam Levi, Stephen S Lim, Xuefeng Liu, Graciliana Lopes, Ricardo Lutzky Saute, Pedro Henrique Machado Teixeira, Ata Mahmoodpoor, Mansour Adam Mahmoud, Elaheh Malakan Rad, Kashish Malhotra, Ahmad Azam Malik, Bernardo Alfonso Martinez-Guerra, Miquel Martorell, Vasundhara Mathur, Mahsa Mayeli, John Robert Carabeo Medina, Addisu Melese, Ziad A Memish, Alexios-Fotios A Mentis, Muayad Aghali Merza, Tomislav Mestrovic, Irmina Maria Michalek, Le Huu Nhat Minh, Alireza Mirahmadi, Omid Mirmosayyeb, Awoke Misganaw, Arup Kumar Misra, Javad Moghadasi, Nouh Saad Mohamed, Yousef Mohammad, Esmaeil Mohammadi, Shafiu Mohammed, Maryam Mojarrad Sani, Hoda Mojiri-forushani, Ali H Mokdad, Sara Momtazmanesh, Lorenzo Monasta, Mohammad Ali Moni, Elias Mossialos, Ebrahim Mostafavi, Majid Motaghinejad, Amin Mousavi Khaneghah, Sumaira Mubarik, Lorenzo Muccioli, Jibran Sualeh Muhammad, Francesk Mulita, Temesgen Mulugeta, Efrén Murillo-Zamora, Ghulam Mustafa, Saravanan Muthupandian, Ahamarshan Jayaraman Nagarajan, Firzan Nainu, Tapas Sadasivan Nair, Shumaila Nargus, Hasan Nassereldine, Zuhair S Natto, Biswa Prakash Nayak, Ionut Negoi, Ruxandra Irina Negoi, Seyed Aria Nejadghaderi, Hien Quang Nguyen, Phat Tuan Nguyen, Van Thanh Nguyen, Robina Khan Niazi, Nafise Noroozi, Hasti Nouraei, Virginia Nuñez-Samudio, Khan M Nuruzzaman, Vincent Ebuka Nwatah, Chimezie Igwegbe Nzoputam, Ogochukwu Janet Nzoputam, Bogdan Oancea, Rahman Md Obaidur, Ismail A Odetokun, Ropo Ebenezer Ogunsakin, Osaretin Christabel Okonji, Andrew T Olagunju, Latera Tesfaye Olana, Isaac Iyinoluwa Olufadewa, Yinka Doris Oluwafemi, Kemal Sherefa Oumer, Amel Ouyahia, Mahesh P A, Keyvan Pakshir, Padmavali Nanaji Palange, Shahina Pardhan, Romil R Parikh, Jay Patel, Urvish K Patel, Shankargouda Patil, Uttam Paudel, Shrikant Pawar, Umberto Pensato, João Perdigão, Marcos Pereira, Mario F P Peres, Ionela-Roxana Petcu, Marina Pinheiro, Zahra Zahid Piracha, Nayanum Pokhrel, Maarten J Postma, Elton Junio Sady Prates, Ibrahim Qattea, Pankaja Raghav Raghav, Leila Rahbarnia, Vafa Rahimi-Movaghar, Mosiur Rahman, Muhammad Aziz Rahman, Vahid Rahmanian, Niloufar Rahnavard, Hazem Ramadan, Premkumar Ramasubramani, Usha Rani, Indu Ramachandra Rao, Deepthi Rapaka, Zubair Ahmed Ratan, Salman Rawaf, Elrashdy Moustafa Mohamed Redwan, Robert C Reiner Jr, Nazila Rezaei, Abanoub Riad, Tércia Moreira Ribeiro da Silva, Tamalee Roberts, Gisela Robles Aguilar, Jefferson Antonio Buendia Rodriguez, Victor Daniel Rosenthal, Basema Saddik, Saeid Sadeghian, Umar Saeed, Azam Safary, Fatemeh Saheb Sharif-Askari, Narjes Saheb Sharif-Askari, Amirhossein Sahebkar, Monalisha Sahu, Seyed Aidin Sajedi, Morteza Saki, Saina Salahi, Sarvenaz Salahi, Mohamed A Saleh, Malik Sallam, Sara Samadzadeh, Abdallah M Samy, Rama Krishna Sanjeev, Maheswar Satpathy, Allen Seylani, Abubakar Sha'aban, Mahan Shafie, Pritik A Shah, Shayan Shahrokhi, Kiana Shahzamani, Masood Ali Shaikh, Sunder Sham, Mohammed Shannawaz, Aziz Sheikh, Suchitra M Shenoy, Pavanchand H Shetty, Jae Il Shin, Fereshteh Shokri, Seyed Afshin Shorofi, Sunil Shrestha, Migbar Mekonnen Sibhat, Emmanuel Edwar Siddig, Luís Manuel Lopes Rodrigues Silva, Harpreet Singh, Jasvinder A Singh, Paramdeep Singh, Surjit Singh, Robert Sinto, Anna Aleksandrovna Skryabina, Bogdan Socea, Anton Sokhan, Ranjan Solanki, Yonatan Solomon, Prashant Sood, Sergey Soshnikov, Andy Stergachis, Mu'awiyyah Babale Sufiyan, Rizwan Suliankatchi Abdulkader, Abida Sultana, Sree Sudha Ty, Ensiyeh Taheri, Elahe Taki, Jacques JL Lukenze Tamuzi, Ker-Kan Tan, Nathan Y Tat, Mohamad-Hani Temsah, Dufera Rikitu Terefa, Pugazhenthan Thangaraju, Nigusie Selomon Tibebu, Jansje Henny Vera Ticoalu, Tala Tillawi, Marius Belmondo Tincho, Imad I Tleyjeh, Razie Toghroli, Marcos Roberto Tovani-Palone, Derara Girma Tufa, Paul Turner, Irfan Ullah, Chukwuma David Umeokonkwo, Bhaskaran Unnikrishnan, Seyed Mohammad Vahabi, Asokan Govindaraj Vaithinathan, Rohollah Valizadeh, Shoban Babu Varthya, Theo Vos, Yasir Waheed, Mandaras Tariku Walde, Cong Wang, Kosala Gayan Weerakoon, Nuwan Darshana Wickramasinghe, Andrea Sylvia Winkler, Melat Woldemariam, Nahom Alemseged Worku, Claire Wright, Dereje Y Yada, Sajad Yaghoubi, Gahin Abdulraheem Tayib Yahya Yahya, Chalachew Yenew Yenew Yenew, Metin Yesiltepe, Siyan Yi, Vahit Yiğit, Yuyi You, Hadiza Yusuf, Fathiah Zakham, Muhammad Zaman, Sojib Bin Zaman, Iman Zare, Zahra Zareshahrabadi, Armin Zarrintan, Mikhail Sergeevich Zastrozhin, Haijun Zhang, Jingya Zhang, Zhi-Jiang Zhang, Peng Zheng, Mohammad Zoladl, Alimuddin Zumla, Simon I Hay, Christopher J L Murray†, Mohsen Naghavi†, and Hmwe Hmwe Kyu†.

*Co-first authors.

†Co-senior authors.

Affiliations

Department of Applied Mathematics (A Y Aravkin PhD), Institute for Health Metrics and Evaluation (H Wunrow MSc, R G Bender MSc, A Vongpradith BA, S B Sirota MA, L R Swetschinski MSc, A Novotney MPH, A P Gray BSc, K S Ikuta MD, E E Wool MPH, A Y Aravkin PhD, K Burkart PhD, X Dai PhD, Prof L Dandona MD, Prof R Dandona PhD, R V Dominguez BS, M Hassen BSc, Prof S S Lim PhD, T Mestrovic PhD, A H Mokdad PhD, H Nassereldine MD, L T Olana BSc, K S Oumer MSc, R C Reiner Jr PhD, Prof T Vos PhD, N A Worku MSc, D Y Yada MSc, P Zheng PhD, Prof S I Hay FMedSci, Prof C J L Murray DPhil, Prof M Naghavi PhD, H H Kyu PhD), Department of Health Metrics Sciences, School of Medicine (A Y Aravkin PhD, K Burkart PhD, X Dai PhD, Prof R Dandona PhD, Prof S S Lim PhD, A Misganaw PhD, A H Mokdad PhD, R C Reiner Jr PhD, Prof A Stergachis PhD, Prof T Vos PhD, P Zheng PhD, Prof S I Hay FMedSci, Prof C J L Murray DPhil, Prof M Naghavi PhD, H H Kyu PhD), Department of Pharmacy (Prof A Stergachis PhD), University of Washington, Seattle, WA, USA; Division of Infectious Diseases (K S Ikuta MD), Veterans Affairs Greater Los Angeles, Los Angeles, LA, USA; Independent Consultant (F Sharara MS), Seattle, WA, USA; Faculty of Medicine (A Aali MD, N Rahnavard MD), Applied Biomedical Research Center (A Sahebkar PhD), Biotechnology Research Center (A Sahebkar PhD), Mashhad University of Medical Sciences, Mashhad, Iran; Tropical Medicine Department (S Abd-Elsalam PhD), Tanta University, Tanta, Egypt; Cardiovascular Department (A Abdollahi MD), Radiology Department (G Ansari MD), Department of Cardiovascular Medicine (M Mojarrad Sani MD), Johns Hopkins University, Baltimore, MD, USA; Department of Medicine (A Abdollahi MD), Health Information Management (A Bashiri PhD), Department of Medical Mycology and Parasitology (H Nouraei MSc, Prof K Pakshir PhD, Z Zareshahrabadi PhD), Shiraz University of Medical Sciences, Shiraz, Iran; Medical Laboratory of Science (J M Abdul Aziz MSc), University of Human Development, Sulaymaniyah, Iraq; Baxshin Hospital (J M Abdul Aziz MSc), Baxshin Research center, Sulaymaniyah, Iraq; Laboratory Technology Sciences Department (H Abidi PhD), Department of Nursing (M Zoladl PhD), Yasuj University of Medical Sciences, Yasuj, Iran; Department of Family and Community Health (R G Aboagye MPH), University of Health and Allied Sciences, Ho, Ghana; Research Center for Immunodeficiencies (H Abolhassani PhD), Non-communicable Diseases Research Center (S Azadnajafabad MD, A Behnoush BS, S Ghamari MD, H Karimi MD, M Keykhaei MD, S Momtazmanesh MD, N Rezaei MD), School of Medicine (A Behnoush BS, A Khalaji BS, M Mayeli MD, S Momtazmanesh MD), Students' Scientific Research Center (SSRC) (M Keykhaei MD), Children's Medical Center (F Kompani MD), Department of Pediatric Cardiology (Prof E Malakan Rad MD), Faculty of Medicine (E Mohammadi MD), Cardiovascular Medicine (M Mojarrad Sani MD), Department of Pharmacology (N Noroozi DVM), Sina Trauma and Surgery Research Center (Prof V Rahimi-Movaghar MD), Department of Neurology (M Shafie MD), Department of Psychiatry (S Shahrokhi MD), Department of Microbiology (E Taki PhD), Faculty Of Medicine (S Vahabi MD), Tehran University of Medical Sciences, Tehran, Iran (R Heidari-Soureshjani MSc, E Mohammadi MD); Department of

Biosciences and Nutrition (H Abolhassani PhD), Karolinska University Hospital, Huddinge, Sweden; Clinical Sciences Department (E Abu-Gharbieh PhD, N Saheb Sharif-Askari PhD, M A Saleh PhD), Department of Basic Medical Sciences (W El-Huneidi PhD), Sharjah Institute for Medical Research (B Saddik PhD), Sharjah Institute of Medical Sciences (F Saheb Sharif-Askari PhD), University of Sharjah, Sharjah, United Arab Emirates; Department of Human Anatomy (L H Adamu PhD), Federal University Dutse, Dutse, Nigeria; Department of Clinical and Psychosocial Epidemiology (T D Adane MSc), University Medical Center Groningen (Prof M J Postma PhD), University of Groningen, Groningen, Netherlands; Centre for Social Research in Health (I Y Addo PhD), University of New South Wales, Sydney, NSW, Australia; Quality and Systems Performance Unit (I Y Addo PhD), Cancer Institute NSW, Sydney, NSW, Australia; Public Health and Tropical Medicine (O A Adegboye PhD), James Cook University, Townsville, QLD, Australia; Department of Pharmaceutical Sciences (T A Adekiya PhD), Howard University, Washington, DC, USA; Department of Neonatology (M Adnan MD), Indiana University Health Ball Memorial Hospital, Muncie, IN, USA; Faculty of Medicine (Q E S Adnani PhD), Center of Excellence in Higher Education for Pharmaceutical Care Innovation (Prof M J Postma PhD), Universitas Padjadjaran (Padjadjaran University), Bandung, Indonesia; Department of Community Medicine (Prof S Afzal PhD), King Edward Memorial Hospital, Lahore, Pakistan; Department of Public Health (Prof S Afzal PhD), Public Health Institute, Lahore, Pakistan; Department of Biotechnology (S Aghamiri PhD), Urology Department (M Ahmadzade MD), Department of Ophthalmology (N Bineshfar MD), Social Determinants of Health Research Center (S Ghamari MD), Department of Pharmacology (A Haj-Mirzaian MD), Obesity Research Center (A Haj-Mirzaian MD), Department of Medicine (M Heidari-Foroozan BSc), Functional Neurosurgery Research Center (E Jamshidi PharmD), Parasitology Department (A Javadi Mamaghani PhD), Department of Neurosurgery (H Khayat Kashani MD), Department of Orthopedics (A Mirahmadi MD), Chronic Respiratory Disease Research Center, National Research Institute of Tuberculosis and Lung Diseases (NRITLD) (M Motaghinejad PhD), School of Medicine (S Nejadghaderi MD), Shahid Beheshti University of Medical Sciences, Tehran, Iran; Medical Imaging Sciences Research Team (Z B Aghdam MD), Department of Radiology (M Dashti MD, A Zarrintan MD), School of Nursing and Midwifery (H Hassankhani PhD), Student Research Committee (M Hosseini MD), Department of Parasitology (A Javadi Mamaghani PhD), Anesthesiology and Critical Care (Prof A Mahmoodpoor MD), Infectious and Tropical Diseases Research Center (L Rahbarnia PhD), Connective Tissue Diseases Research Center (A Safary PhD), Tabriz University of Medical Sciences, Tabriz, Iran; Department of Medical and Surgical Sciences and Advanced Technologies "G.F. Ingrassia" (Prof A Agodi PhD), Clinical and Experimental Medicine (C Ledda PhD), University of Catania, Catania, Italy; School of Public Health (B O Ahinkorah MPhil), University of Technology Sydney, Sydney, NSW, Australia; Department of Medical Biochemistry (A Ahmad PhD), Department of Pediatrics (Prof G Mustafa MD), Shaqra University, Shaqra, Saudi Arabia; Department of Health and Biological Sciences (S Ahmad PhD), Abasyn University, Peshawar, Pakistan; School of Pharmacy (A Ahmed MPhil), Monash University, Bandar Sunway, Malaysia; Department of Pharmacy (A Ahmed MPhil), Quaid I Azam University Islamabad, Islamabad, Pakistan; Institute of Endemic Diseases (A Ahmed MSc), Faculty of Medical Laboratory Sciences (E E Siddig PhD), University of Khartoum, Khartoum, Sudan; Swiss Tropical and Public Health Institute (A Ahmed MSc), University of Basel, Basel, Switzerland; Department of Pathology and Microbiology (J Q Ahmed MSc, M S Ahmed MSc, G A Y Yahya MSc), Department of Internal Medicine (Prof M A Merza PhD), University of Duhok, Duhok, Iraq; Department of Internal Medicine (K Akinosoglou PhD), University of Patras Greece, Patras, Greece; Internal Medicine and Infectious Diseases (K Akinosoglou PhD), University General Hospital of Patras, Patras, Greece; Department of Medical Laboratory Sciences (A Aklilu MSc), School of Nursing (T M Ayana MSc), Department of Anatomy (S Demissie MSc), Department Midwifery (H L Esayas MSc), Department of Medical Laboratory Science (M Woldemariam MSc), Arba Minch University, Arba Minch, Ethiopia; Department of Epidemiology and Biostatistics (M Akonde MLS), University of South Carolina, Columbia, SC, USA; Mayo Evidence-based Practice Center (F Alahdab MSc), Mayo Clinic Foundation for Medical Education and Research, Rochester, MN, USA; Institute of Global Health (T M A AL-Ahdal MPH), Eijkman Institute for Molecular Biology, Heidelberg, Germany; Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia (F M Alanezi PhD); Health Sciences Department (A H Albelbeisi PhD), Israa University, Gaza Strip, Palestine; Inspection and Auditing Department (A H Albelbeisi PhD), Ministry of Health, Gaza Strip, Palestine; College of Medicine and Health Science, School of Medical Laboratory Science (T B B Alemayehu MSc), Hawassa University, Hawassa, Ethiopia; Faculty of Health Sciences (K A Alene MPH), Curtin University, Perth, WA, Australia; Wesfarmers Centre of Vaccines and Infectious Diseases (K A Alene MPH), Telethon Kids Institute, Perth, WA, Australia; Pediatric Intensive Care Unit (A Al-Eyadhy MD, M Temsah MD), Internal Medicine Department (Y Mohammad MD), King Saud University, Riyadh, Saudi Arabia; Micropollutant Research Centre (MPRC), Universiti Tun Hussein Onn Malaysia (A A S Al-Gheethi PhD), Batu Pahat, Malaysia; Camborne School of Mines, College of Engineering, Mathematics and Physical Sciences (A A S Al-Gheethi PhD), University of Exeter, Penryn, UK; Department of Zoology (A Ali PhD), Abdul Wali Khan University Mardan, Mardan, Pakistan; Erbil Technical Health College (B A Ali PhD), Erbil Polytechnic University, Erbil, Iraq; School of Pharmacy (B A Ali PhD), Tishk International University, Erbil, Iraq; Department of Biological Sciences (L Ali PhD), National University of Medical Sciences (NUMS), Rawalpindi, Pakistan; Centre for Biotechnology and Microbiology (S S Ali PhD), University of Swat, Swat, Pakistan; Health Research Center (Y Alimohamadi PhD), Baqiyatallah University of Medical Sciences, Tehran, Iran; Health Management and Economics Research Center (V Alipour PhD, J Arabloo PhD), Department of Health Economics (V Alipour PhD), School of Medicine (M Dodangeh MD), Minimally Invasive Surgery Research Center (S Salahi MD), Iran University of Medical Sciences, Tehran, Iran; Department of Health Policy and Management (Prof S M Aljunid PhD), Kuwait University, Kuwait, Kuwait; International Centre for Casemix and Clinical Coding (Prof S M Aljunid PhD), National University of Malaysia, Bandar Tun Razak, Malaysia; College of Medicine (S Almustanyir MD, Prof Z A Memish MD), Alfaisal University, Riyadh, Saudi Arabia; Research & Innovation Center (Prof Z A Memish MD), Ministry of Health, Riyadh, Saudi Arabia (S Almustanyir MD); Department of Community Medicine (R M Al-Raddadi PhD), Rabigh Faculty of Medicine (A A Malik PhD), Department of Dental Public Health (Z S Natto DrPH), King Abdulaziz University, Jeddah, Saudi Arabia; Research Group in Hospital Management and Health Policies (Prof N Alvis-Guzman PhD), Universidad de la Costa (University of the Coast), Barranquilla, Colombia; Research Group in Health Economics (Prof N Alvis-Guzman PhD), University of Cartagena, Cartagena, Colombia; Department of Medical Sciences (Prof Y M Al-Worafi PhD), Azal University for Human Development, Sana'a, Yemen; Clinical Sciences Department (Prof Y M Al-Worafi PhD), University of Science and Technology of Fujairah, Fujairah, United Arab Emirates; Department of Pediatrics (Prof H Aly MD), Department of Internal Medicine (M Gupta MD), Lerner Research Institute (X Liu PhD), Cleveland Clinic, Cleveland, OH, USA; School of Graduate Studies (E K Ameyaw MPhil), Lingnan University, Hong Kong, China; Faculty of Pharmacy (Prof R Ancuceanu PhD), Department of Legal Medicine and Bioethics (S Hostiuc PhD), Department of General Surgery (I Negoi PhD, B Socea PhD), Department of Anatomy and Embryology (R I Negoi PhD), Carol Davila University of Medicine and Pharmacy, Bucharest, Romania; School of Nursing and Midwifery (A Ansar PhD, M Rahman PhD), La Trobe University, Melbourne, VIC, Australia; Special Interest Group International Health (A Ansar PhD), Public Health Association of Australia, Canberra, ACT, Australia; School of Dentistry and Medical Sciences (A E Anyasodor PhD), Charles Sturt University, Orange, NSW, Australia; College of Art and Science

(D Areda PhD), Ottawa University, Surprise, AZ, USA; College of Liberal Arts and Sciences (D Areda PhD), Arizona State University, Tempe, AZ, USA; Department of Biophysics (A A Artamonov PhD), Russian Academy of Sciences, Moscow, Russia; Department of Maternal and Child Health (J Arulappan DSc), Sultan Qaboos University, Muscat, Oman; Department of Molecular and Cell Biology (R T Aruleba MSc), Department of Pathology (M B Tincho PhD), University of Cape Town, Cape Town, South Africa; Department of Community Medicine and Global Health (M Asaduzzaman MPH, S A F Fatima MPhil), Institute of Health and Society (Prof A S Winkler PhD), University of Oslo, Oslo, Norway; Department of Pediatrics and Child Health Nursing (K A Atalell MSc), Department of Midwifery (G M Gedef MSc), Department of Human Physiology (Y Gela MSc), University of Gondar, Gondar, Ethiopia; Department of Immunology (S Athari PhD), Zanjan University of Medical Sciences, Zanjan, Iran; Department of Biomedical Science (D Atlaw MSc), Madda Walabu University, Bale Robe, Ethiopia; Faculty of Nursing (M M W Atout PhD), Philadelphia University, Amman, Jordan; Oral and Maxillofacial Surgery (S Attia MSc), Justus Liebig University of Giessen, Giessen, Germany; Department of Medical Laboratory Sciences (T Awoke MSc, F M Demeke MSc, A Melese MSc), College of Medicine and Health Science (M K Ayalew MPH), Department of Biomedical Science (A A Bekel MSc), Department of Physiology (D Demeke MSc), Department of Health Informatics (H A Guadie MPH), Bahir Dar University, Bahir Dar, Ethiopia; Department of Epidemiology (M K Ayalew MPH), Eyu-ethiopia, Bahir Dar, Ethiopia; Department of Midwifery (A D Ayele MSc), Public Health, Reproductive Health (A M Dessie MPH), Pediatrics and Child Health Nursing (N S Tibebu MSc), Department of Public Health (C Y Y Yenew MSc), Debre Tabor University, Debre Tabor, Ethiopia; Department of Microbiology, Faculty of Medicine, Kurdistan University of Medical Sciences, Sanandaj, Iran (K Azizian PhD), Kurdistan University of Medical Sciences, Sanandaj, Iran; Gomal Center of Biochemistry and Biotechnology (M Badar PhD), Gomal University, Dera Ismail Khan, Pakistan; Department of Forensic Science (A D Badiye PhD), Government Institute of Forensic Science, Nagpur, India; Department of Nursing (N Baghcheghi PhD), Department of Anatomy (S Barati PhD), Social Determinants of Health Research Center (H Koohestani PhD), Saveh University of Medical Sciences, Saveh, Iran; Department of Food Science and Technology (M Bagheri PhD), Shahid Bahonar University of Kerman, Kerman, Iran; School of Medicine (S Bagherieh BSc), Department of Environmental Health Engineering (A Fatehizadeh PhD), Department of Neurology (O Mirmosayyeb MD), Department of Environmental Health Engineering, School of Health (E Taheri PhD), Isfahan University of Medical Sciences, Isfahan, Iran; Department of Parasitology (S Bahadory PhD), Tarbiat Modares University, Tehran, Iran; Department of Parasitology (S Bahadory PhD), Alborz University of Medical Sciences, Karaj, Iran; University Institute of Public Health (A A Baig PhD, A A Malik PhD, S Nargus PhD), The University of Lahore, Lahore, Pakistan; Clinic for Infectious and Tropical Diseases (A Barac PhD), Clinical Center of Serbia, Belgrade, Serbia; Faculty of Medicine (A Barac PhD, I M Ilic PhD), University of Belgrade, Belgrade, Serbia; Molecular Microbiology and Bacteriology (M Bardhan MD), National Institute of Cholera and Enteric Diseases, Kolkata, India; Molecular Microbiology (M Bardhan MD), Department of Biostatistics (V K Kamal PhD), Indian Council of Medical Research, New Delhi, India (Prof L Dandona MD); Jamil-ur-Rahman Center for Genome Research (Z Basharat PhD), Panjwani Center for Molecular Medicine and Drug Research, International Center for Chemical and Biological Sciences, University of Karachi, Karachi, Pakistan; Department of Medicine (B Basnyat MD), Oxford University, Kathmandu, Nepal; Tuberculosis Department (B Basnyat MD), Birat Nepal Medical Trust, Kathmandu, Nepal; Barcelona Institute for Global Health (Prof Q Bassat MD), University of Barcelona (Universitat de Barcelona), Barcelona, Spain; Catalan Institution for Research and Advanced Studies, Barcelona, Spain (Prof Q Bassat MD); Academics Department (S Basu MD), Indian Institute of Public Health, Gurgaon, India; Department of Surgery (N S Bayileyegn MD), Jimma University, Jimma, Ethiopia; School of Public Health (Prof N Bedi MD), Dr D Y Patil University, Mumbai, India; Research & Scientific Studies Unit (S Haque PhD), Epidemiology Department (M Khan MD), Jazan University, Jazan, Saudi Arabia (Prof N Bedi MD); Medical Laboratory Science (M A Belete MSc), Department of Environmental Health (M Gebrehiwot DSc), Wollo University, Dessie, Ethiopia; Department of Microbiology (O O Bello PhD), Department of Biological Sciences (T C Ekundayo PhD), University of Medical Sciences, Ondo, Ondo, Nigeria; Department of Health, Human Performance and Recreation (A S Bhagavathula PhD), University of Arkansas, Fayetteville, AR, USA; School of Public Health (D Bhandari PhD), University of Adelaide, Adelaide, SA, Australia; Public Health Research Laboratory (D Bhandari PhD), Faculty of Humanities and Social Sciences (U Paudel PhD), Tribhuvan University, Kathmandu, Nepal; Department of Community Medicine and Family Medicine (P Bhardwaj MD, Prof P R Raghav MD), School of Public Health (P Bhardwaj MD), Department of Pharmacology (J Charan MD, S Singh DM, S B Varthya MD), Anaesthesiology & Critical Care (N Kothari PhD), All India Institute of Medical Sciences, Jodhpur, India; Global Health Neurology Lab (S Bhaskar PhD), NSW Brain Clot Bank, Sydney, NSW, Australia; Department of Neurology and Neurophysiology (S Bhaskar PhD), South West Sydney Local Heath District and Liverpool Hospital, Sydney, NSW, Australia; Department of General Medicine (A N Bhat MD), Manipal Academy of Higher Education, Mangalore, India; Social Determinants of Health Research Center (A Bijani PhD), Babol University of Medical Sciences, Babol, Iran; Department of Internal Medicine (A Boloor MD), Forensic Medicine and Toxicology, Kasturba Medical College Mangalore (H L Dsouza MD), Department of Community Medicine (N Joseph MD), Department of Forensic Medicine (P H Shetty MD), Kasturba Medical College (Prof B Unnikrishnan MD), Manipal Academy of Higher Education, Mangalore, India; Department of Medicine (Prof S Bouaoud MD), Faculty of Medicine (Prof A Ouyahia PhD), University Ferhat Abbas of Setif, Setif, Algeria; Epidemiology and preventive medicine (Prof S Bouaoud MD), University Hospital Saadna Abdenour, Setif, Algeria; Department of Woman and Child Health and Public Health (D Buonsenso MD), Fondazione Policlinico Universitario A. Gemelli IRCCS (Agostino Gemelli University Polyclinic IRCCS), Rome, Italy; Global Health Research Institute (D Buonsenso MD), Università Cattolica del Sacro Cuore (Catholic University of Sacred Heart), Rome, Italy; Internal Medicine Department (Prof L A Cámera MD), Hospital Italiano de Buenos Aires (Italian Hospital of Buenos Aires), Buenos Aires, Argentina; Board of Directors (Prof L A Cámera MD), Argentine Society of Medicine, Buenos Aires, Argentina; Colombian National Health Observatory (C A Castañeda-Orjuela MD), National Institute of Health, Bogota, Colombia; Epidemiology and Public Health Evaluation Group (C A Castañeda-Orjuela MD), Department of Public Health (Prof F P De la Hoz PhD), National University of Colombia, Bogota, Colombia; Regional Epidemiological Observatory Department (A Cernigliaro MSc), Sicilian Regional Health Authority, Palermo, Italy; Department of Community Medicine (V Chattu MD), Datta Meghe Institute of Medical Sciences, Sawangi, India; Saveetha Medical College and Hospitals (V Chattu MD), Centre of Molecular Medicine and Diagnostics (COMManD) (Prof S Patil PhD), Saveetha University, Chennai, India; Division of Infectious Diseases (P R Ching MD), Washington University in St Louis, St Louis, MO, USA; Chitkara College of Pharmacy (H Chopra PhD), Chitkara Univeristy, Punjab, India; Department of Community Medicine (Prof S G Choudhari MD), Datta Meghe Institute of Medical Sciences, Wardha, India; Department of Pulmonary Medicine (Prof D J Christopher MD), Christian Medical College and Hospital, Vellore, India; Center for Biomedicine and Community Health (D Chu PhD), VNU-International School, Hanoi, Viet Nam; Department of Chemical Sciences (R A S Couto MD), Institute for Research and Innovation in Health (Prof N Cruz-Martins PhD), Department of Chemistry (M Pinheiro PhD), University of Porto, Porto, Portugal; Therapeutic and Diagnostic Technologies (Prof N Cruz-Martins PhD), Cooperativa de Ensino Superior Politécnico e Universitário (Polytechnic and University Higher Education Cooperative), Gandra, Portugal; Section Global Health and Rehabilitation (O Dadras DrPH), Western Norway University of Applied Sciences, Bergen, Norway; Department of Global Public Health and Primary Care (O Dadras DrPH), University of Bergen, Bergen, Norway; Public Health Foundation of India, Gurugram, India (Prof L Dandona MD, Prof R Dandona PhD, H Kaur MPH); Department

of Biochemistry (S Das MD), Ministry of Health and Welfare, New Delhi, India; Clinical Sciences Department (N R Dash MD), University of Sharjah, Sharjah, United Arab Emirates; School of Public Health (S Debela MPH), Public Health Department (D G Tufa MPH), Salale University, Fiche, Ethiopia; School of Public Health (D Dejen MPH), Wollo University, Woldia, Ethiopia; Amhara Regional Health Bureau CDC Project (D Dejen MPH), ACS Medical College and Hospital, Woldia, Ethiopia; Department of Public Health (H Dejene MPH), Salale University, Fitche, Ethiopia; USAID-JSI (B H Demessa MPH), Jimma University, Addis Ababa, Ethiopia; Department of Neurosurgery (A K Demetriades MD), Global Health Governance Programme (J Patel), Centre for Medical Informatics (Prof A Sheikh MD), University of Edinburgh, Edinburgh, UK; Department of Neurosurgery (A K Demetriades MD), National Health Service (NHS) Scotland, Edinburgh, UK; Department of Biomedical Sciences (D Dereje MSc), Department of Public Health (M E Getachew MPH), Department of Nursing (A B A Gizaw MSc), Department of Clinical Pharmacy (T Mulugeta MSc), Jimma University, Jimma, Ethiopia; University of Sarajevo, Bosnia and Herzegovina (E Dervišević PhD), Italian National Institute of Statistics (ISTAT), Sarajevo, Bosnia and Herzegovina; Department of Forensic Medicine, Faculty of Medicine (E Dervišević PhD), Universiti Kebangsaan Malaysia Medical Centre, Sarajevo, Bosnia and Herzegovina; Graduate Medical Education (H D Desai MD), Gujarat Adani Institute of Medical Sciences, Bhuj, India; Department of Public Health (F Desta MPH), Madda Walabu University, Goba, Ethiopia; Division of Pathology (K Dhama PhD), ICAR-Indian Veterinary Research Institute, Bareilly, India; Development of Research and Technology Center (S Djalalinia PhD), Ministry of Health and Medical Education, Tehran, Iran; Department of Medicine (T C Do MD), Pham Ngoc Thach University of Medicine, Ho Chi Minh City, Viet Nam; Department of Biostatistics (M Dodangeh Mcom), Independent Consultant, Tehran, Iran; Health Science Center (D Dongarwar MS), University of Texas, Houston, TX, USA; Forensic Medicine and Toxicology (H L Dsouza MD), Kasturba Medical College Mangalore, Mangalore, India; Infection and Tropical Medicine (O C Durojaiye MPH), University of Sheffield, Sheffield, UK; Department of Conservative Dentistry with Endodontics (A M Dziedzic DSc), Medical University of Silesia, Katowice, Poland; Infectious Diseases Unit (M Ekat MD), Service des Maladies Infectieuses, Brazzaville, Congo; Department of Epidemiology and Medical Statistics (M Ekholuenetale MSc, A F Fagbamigbe PhD), Faculty of Public Health (M Ekholuenetale MSc, I I Olufadewa MHS), Department of Health Promotion and Education (S E Ibitoye MPH), Department of Community Medicine (O S Ilesanmi PhD), University of Ibadan, Ibadan, Nigeria; Clinical Pathology Department (Prof M El Sayed Zaki PhD), Hygiene and Zoonoses Department (H Ramadan PhD), Department of Pharmacology and Toxicology (M A Saleh PhD), Mansoura University, Mansoura, Egypt; Direction de L'épidémiologie et la Lutte Contre les Maladies (Directorate of Epidemiology and Diseases Control) (H El-Abid PhD), Ministry of Health, Rabat, Morocco; Faculty of Medicine (M Elhadi MD), University of Tripoli, Tripoli, Libya; Department of Clinical Neuroscience (V El-Hajj), Karolinska Institute, Stockholm, Sweden; Department of Neurosurgery (V El-Hajj), Karolinska University Hospital, Stockholm, Sweden; Faculty of Medicine (A A El-Sakka MD), Suez Canal University, Ismailia, Egypt; Institute of Applied Health Sciences (A F Fagbamigbe PhD), University of Aberdeen, Aberdeen, UK; Zoonotic Disease Research Center (S Falahi PhD), Ilam University of Medical Sciences, Ilam, Iran; Department of Neurological Surgery (J Fares MD), Northwestern University, Chicago, IL, USA; Department of Bacteriologi (S A F Fatima MPhil), Norwegian Institute of Public Health, Oslo, Norway; Department of Clinical Sciences (Prof N A Feasey PhD), Liverpool School of Tropical Medicine, Liverpool, UK; Bacteria and Drug Resistant Infections Group (Prof N A Feasey PhD), Malawi Liverpool Wellcome Trust Clinical Research Programme, Blantyre, Malawi; School of Pharmacy (G Fekadu MSc), The Chinese University of Hong Kong, Hong Kong, China; Department of Pharmacy (G Fekadu MSc), Department of Nursing (G Fetensa MSc), Department of Public Health (M E Getachew MPH, D R Terefa MSc), Wollega University, Nekemte, Ethiopia; School of Pharmacy (D Feyissa MSc), Mizan-Tepi University, Mizan-Aman, Ethiopia; Institute of Public Health (F Fischer PhD), Charité Universitätsmedizin Berlin (Charité Medical University Berlin), Berlin, Germany; Department of Pharmacology (Prof B Foroutan PhD), Department of Clinical Microbiology (S Yaghoubi PhD), Iranshahr University of Medical Sciences, Iranshahr, Iran; Health Services Management Training Centre (P A Gaal PhD), Semmelweis University, Budapest, Hungary; Department of Applied Social Sciences (P A Gaal PhD), Sapientia Hungarian University of Transylvania, Târgu-Mureş, Romania; Community Medicine Department (Prof M A Gadanya FMCPH), Bayero University, Kano, Kano, Nigeria; Department of Community Medicine (Prof M A Gadanya FMCPH), Aminu Kano Teaching Hospital, Kano, Nigeria; Department of Medicine (A Gaipov PhD), Nazarbayev University School of Medicine, Nur-Sultan, Kazakhstan; School of Global Health (B Ganesan PhD), Institute of Health & Management, Melbourne, VIC, Australia; Department of Occupational Therapy (B Ganesan PhD), Mahatma Gandhi Occupational Therapy College, Jaipur, India; Department of Nursing (K G Gebrekidan PhD), Department of Reproductive Health (G Lema MPH), Department of Medical Microbiology and Immunology (S Muthupandian PhD), Mekelle University, Mekelle, Ethiopia; Discipline of Population Health (T G Gebremeskel MPH), Nursing and Health Sciences (S Shorofi PhD), Flinders University, Adelaide, SA, Australia; Department of Reproductive Health (T G Gebremeskel MPH), Aksum University, Aksum, Ethiopia; Department of Public Health (U Gerema MSc), Jimma University, Jimma, Oromia, Ethiopia; Pfizer Vaccines, Collegeville, PA, USA (B D Gessner MD); Agency of Preventive Medicine, Paris, France (B D Gessner MD); Infectious Disease Research Center (Prof K Ghadiri MD), Pediatric Department (Prof K Ghadiri MD), Kermanshah University of Medical Sciences, Kermanshah, Iran; Department of Laboratory Sciences (K Ghaffari MSc), Khomein University of Medical Sciences, Khomein, Iran; Department of Environmental Health Engineering (R Ghanbari PhD), Institute for Prevention of Non-communicable Diseases (R Kalhor PhD), Health Services Management Department (R Kalhor PhD), Qazvin University of Medical Sciences, Qazvin, Iran; Tropical Health Department (R M M Ghazy PhD), Alexandria University, Alexandria, Egypt; Emergency Department (R M M Ghazy PhD), WHO Regional Office for the Eastern Mediterranean, Cairo, Egypt; Department of Public Health (G Ghozali PhD), University of Muhammadiyah Kalimantan Timur, Samarinda, Indonesia; Department of Epidemiology and Evidence-Based Medicine (E V Glushkova PhD), I.M. Sechenov First Moscow State Medical University, Moscow, Russia; Department of Dermatology (M Goldust MD), Department of Genetics (S Pawar PhD), Yale University, New Haven, CT, USA; Health Systems and Policy Research (M Golechha PhD), Indian Institute of Public Health, Gandhinagar, India; College of Medicine and Health Science (R A Guled PhD), Jigjiga University, Jigjiga, Ethiopia; Toxicology Department (S Gupta MSc), Shriram Institute for Industrial Research, Delhi, Delhi, India; School of Medicine (V Gupta PhD), Deakin University, Geelong, VIC, Australia; Biorefining and Advanced Materials Research Center (V Gupta PhD), Scotland's Rural College, Edinburgh, UK; Faculty of Medicine Health and Human Sciences (Prof V K Gupta PhD), Macquarie Medical School (Y You PhD), Macquarie University, Sydney, NSW, Australia; Dept of Clinical Pharmacology and Medicine (Prof N R Hadi PhD), University of Kufa, Najaf, Iraq; Department of Infectious Disease Epidemiology (S Haller MD), Robert Koch Institute, Berlin, Germany; Department of Public Health (S Haller MD), Charité Insitute of Public Health, Berlin, Germany; School of Health and Environmental Studies (Prof S Hamidi DrPH), Hamdan Bin Mohammed Smart University, Dubai, United Arab Emirates; Medical Research Unit (H Harapan PhD), Universitas Syiah Kuala (Syiah Kuala University), Banda Aceh, Indonesia; Department of Zoology and Entomology (A I Hasaballah PhD), Al Azhar University, Cairo, Egypt; Department of Pharmaceutical Technology (I Hasan MPharm), University of Dhaka, Dhaka, Bangladesh; Department of Ophthalmology (H Hasani MD), Iran University of Medical Sciences, Karaj, Iran; Department of Radiology (M Hasanian MD), Arak University of Medical Sciences, Arak, Iran; Independent Consultant, Tabriz, Iran (H Hassankhani PhD); National Data Management Center for Health (M Hassen BSc, L T Olana BSc, N A Worku MSc, A Misganaw PhD), Ethiopian Public Health Institute, Addis Ababa, Ethiopia; Institute of Pharmaceutical Sciences (K Hayat MS), University of Veterinary and Animal Sciences,

Lahore, Pakistan; Department of Pharmacy Administration and Clinical Pharmacy (K Hayat MS), Xian Jiaotong University, Xian, China; Community-Oriented Nursing Midwifery Research Center (M Heidari PhD), Shahrekord University of Medical Sciences, Shahrekord, Iran; Department of Epidemiology (M Heidari-Foroozan BSc, S Nejadghaderi MD), Non-communicable Diseases Research Center (A Khalaji BS), Non-Communicable Diseases Research Center, Tehran, Iran; Department of Applied Microbiology (K Hezam PhD), Taiz University, Taiz, Yemen; Department of Microbiology (K Hezam PhD), Nankai University, Tianjin, China; Kasturba Medical College, Mangalore (R Holla MD), Department of Physiotherapy (S D Kumaran PhD), Department of Nephrology (I Rao DM), Manipal Academy of Higher Education, Manipal, India; Department of Pulmonology (N Horita PhD), Yokohama City University, Yokohama, Japan; National Human Genome Research Institute (N Horita PhD), National Institutes of Health, Bethesda, MD, USA; Social and Environmental Health Research (M Hossain MPH), Nature Study Society of Bangladesh, Khulna, Bangladesh; Department of Health Promotion and Community Health Sciences (M Hossain MPH), Texas A&M University, College Station, TX, USA; Pattern Recognition and Machine Learning Lab (M Hosseinzadeh PhD, Prof S Lee PhD), Gachon University, Seongnam, South Korea; Clinical Legal Medicine Department (S Hostiuc PhD), National Institute of Legal Medicine Mina Minovici, Bucharest, Romania; Czech National Centre for Evidence-Based Healthcare and Knowledge Translation (S Hussain PhD), Institute of Biostatistics and Analyses (S Hussain PhD), Department of Public Health (A Riad DDS), Czech National Centre for Evidence-based Healthcare and Knowledge Translation (A Riad DDS), Masaryk University, Brno, Czech Republic; Department of Biomolecular Sciences (N R Hussein PhD), University of Zakho, Zakho, Iraq; Department of Community Medicine (O S Ilesanmi PhD), University College Hospital, Ibadan, Ibadan, Nigeria; Department of Epidemiology (Prof M D Ilic PhD), University of Kragujevac, Kragujevac, Serbia; College Of Pharmacy (M Imam PhD), Prince Sattam Bin Abdulaziz University, Al Kharj, Saudi Arabia; Department of Medical Microbiology, College of Health Sciences (K C Iregbu MD), University of Abuja, Abuja, Nigeria; Department of Medical Microbiology (K C Iregbu MD), Department of Pediatrics (V E Nwatah MD), National Hospital, Abuja, Nigeria; Department of Clinical Pharmacy (Prof N Ismail PhD), MAHSA University, Bandar Saujana Putra, Malaysia; School of Health Systems and Public Health (C C D Iwu MPH), University of Pretoria, Pretoria, South Africa; Department of Global Health (C Jaja PhD), Department of Epidemiology (J J L Tamuzi MSc), Stellenbosch University, Cape Town, South Africa; Institute of Advanced Manufacturing Technologies (Prof M Jakovljevic PhD), Peter the Great St. Petersburg Polytechnic University, St Petersburg, Russia; Institute of Comparative Economic Studies (Prof M Jakovljevic PhD), Hosei University, Tokyo, Japan; Division of Pulmonary Medicine (E Jamshidi PharmD), Lausanne University Hospital, Lausanne, Switzerland; Department of Medical Mycology (J Javidnia PhD), Medical-Surgical Nursing (S Shorofi PhD), Mazandaran University of Medical Sciences, Sari, Iran; Zoonoses Research Center (M Jokar DVM), Department of Higher Education Management (J Moghadasi PhD), Islamic Azad University, Tehran, Iran; Department of Clinical Sciences (M Jokar DVM), Jahrom University of Medical Sciences, Jahrom, Iran; Department of Microbiology (N Jomehzadeh PhD), Department of Pharmacology (H Mojiri-forushani PhD), Abadan School of Medical Sciences, Abadan, Iran; Department of Economics (C E Joshua BSc), National Open University, Benin City, Nigeria; Department of Family Medicine and Public Health (J J Jozwiak PhD), University of Opole, Opole, Poland; School of Public Health (Z Kabir PhD), University College Cork, Cork, Ireland; Social Determinants of Health Research Center (L R Kalankesh PhD), Gonabad University of Medical Sciences, Gonabad, Iran; Division of Epidemiology and Biostatistics (V K Kamal PhD), National Institute of Epidemiology, Chennai, India, India; Save Sight Institute (H Kandel PhD, Y You PhD), Department of Public Health (K Nuruzzaman PhD), University of Sydney, Sydney, NSW, Australia; Sydney Eye Hospital (H Kandel PhD), South Eastern Sydney Local Health District, Sydney, NSW, Australia; School of Health Professions and Human Services (I M Karaye MD), Hofstra University, Hempstead, NY, USA; Institute for Epidemiology and Social Medicine (A Karch MD), University of Münster, Münster, Germany; Department of Otolaryngology (N Kaur MS), Adesh Institute of Medical Sciences and Research Bathinda, Bathinda, India; Amity Institute of Forensic Sciences (H Khajuria PhD, B P Nayak PhD), Amity Institute of Public Health (M Shannawaz PhD), Amity University, Noida, India; Natural and Medical Sciences Research Center (A Khan PhD), University of Nizwa, Oman, Nizwa, Oman; Department of Pediatrics (I A Khan MD), Rutgers University, New Brunswick, NJ, USA; Department of Radiation Oncology (T Khan PhD), Department of Bioengineering and Therapeutic Sciences (Prof M S Zastrozhin PhD), University of California San Francisco, San Francisco, CA, USA; Health and Wellbeing (Prof K Khatab PhD), Sheffield Hallam University, Sheffield, UK; Basic Medical Sciences (M M Khatatbeh PhD), Yarmouk University, Irbid, Jordan; Department of Public Health (Prof J Khubchandani PhD), New Mexico State University, Las Cruces, NM, USA; Department of Genomics and Digital Health (M Kim MD), Samsung Advanced Institute for Health Sciences & Technology, Seoul, South Korea; Public Health Center (M Kim MD), Ministry of Health and Welfare, Wando, South Korea; School of Health Sciences (Prof A Kisa PhD), Kristiania University College, Oslo, Norway; Department of International Health and Sustainable Development (Prof A Kisa PhD), Tulane University, New Orleans, LA, USA; Department of Nursing and Health Promotion (S Kisa PhD), Oslo Metropolitan University, Oslo, Norway; Department of Anthropology (Prof K Krishan PhD), Centre for Public Health (M Kumar PhD), Panjab University, Chandigarh, India; Department of Community Medicine (Y Krishnamoorthy MD), Employees' State Insurance Model Hospital, Chennai, India; Health Research Institute (M Kulimbet MSc), Al Farabi Kazakh National University, Almaty, Kazakhstan; Atchabarov Scientific-Research Institute of Fundamental Medicine (M Kulimbet MSc), Kazakh National Medical University, Almaty, Kazakhstan; School of Public Health (M Kumar PhD), Texila American University, Coimbatore, India; Department of Nephrology (A Kuttikkattu MD), Pushpagiri Institute of Medical Sciences and Research Centre, Thiruvalla, India; Department of Biochemistry and Biotechnology (A Kwarteng PhD), Kwame Nkrumah University of Science and Technology, Kumasi, Ghana; Department of Physiotherapy (T Laksono MS), Universitas Aisyiyah Yogyakarta, Yogyakarta, Indonesia; Institute of Allied Health Sciences (T Laksono MS), National Cheng Kung University, Tainan, Taiwan; Unit of Genetics and Public Health (Prof I Landires MD), Unit of Microbiology and Public Health (V Nuñez-Samudio PhD), Institute of Medical Sciences, Las Tablas, Panama; Department of Public Health (V Nuñez-Samudio PhD), Ministry of Health, Herrera, Panama (Prof I Landires MD); Disease Control Department (D O Laryea MD), Ghana Health Service, Accra, Ghana; Clinical Pharmacy and Pharmacy Management (B K Lawal PhD), Kaduna State University, Kaduna, Nigeria; University of Medicine and Pharmacy at Ho Chi Minh City (T T Le MD), Department of General Medicine (V T Nguyen MD), University of Medicine and Pharmacy at Ho Chi Minh City, Ho Chi Minh City, Viet Nam; Department of Precision Medicine (Prof S Lee MD), Sungkyunkwan University, Suwon-si, South Korea; Department of Prevention (M Levi PhD), USL Tuscany Center, Firenze, Italy; Department of Health Sciences (M Levi PhD), University of Florence, Florence, Italy; Department of Quantitative Health Science (X Liu PhD), Department of Neonatology (I Qattea MD), Case Western Reserve University, Cleveland, OH, USA; Interdisciplinary Centre of Marine and Environmental Research (G Lopes PhD), University of Porto, Matosinhos, Portugal; Department of Neurosciences and Behavioral Sciences (R Lutzky Saute MD), University of São Paulo, Ribeirão Preto, Brazil; Núcleo de Desenvolvimento de Pesquisa (P Machado Teixeira), Faculty of Medicine of Itajubá, Itajubá, Brazil; Department of Clinical and Hospital Pharmacy (M A Mahmoud PhD), Taibah University, Al-Madinah Al-Munawarrah, Saudi Arabia; Department of Internal Medicine (K Malhotra MBBS), Dayanand Medical College and Hospital, Ludhiana, India; Infectious Diseases (B A Martinez-Guerra MSc), Instituto Nacional de Ciencias Médicas y Nutrición Salvador Zubirán, Mexico City, Mexico; Department of Nutrition and Dietetics (M Martorell PhD), University of Concepcion, Concepción, Chile; Centre for Healthy Living (M Martorell PhD), University of Concepción, Concepción, Chile; Department of Orthopedic Surgery (V Mathur MD), Massachusetts General Hospital, Boston, MA,

USA; Department of Epidemiology and Biostatistics (J C Medina MD), University of the Philippines Manila, Manila, Philippines; Department of Global Health (J C Medina MD), University of the Ryukyus, Nishihara, Japan; International Dx Department (A A Mentis MD), BGI Genomics, Copenhagen, Denmark; University Centre Varazdin (T Mestrovic PhD), University North, Varazdin, Croatia; Polish National Cancer Registry (I Michalek PhD), Department of Pathology (I Michalek PhD), Maria Sklodowska-Curie National Research Institute of Oncology, Warsaw, Poland; College of Medicine (L Minh MD), Research Center for Artificial Intelligence in Medicine (L Minh MD), Taipei Medical University, Taipei, Taiwan; Department of Neurology (O Mirmosayyeb MD), State University of New York, Buffalo, USA; Department of Pharmacology (A K Misra MD), All India Institute of Medical Sciences, Mangalagiri, India; Molecular Biology Unit (N S Mohamed MSc), Bio-Statistical and Molecular Biology Department (N S Mohamed MSc), Sirius Training and Research Centre, Khartoum, Sudan; Health Systems and Policy Research Unit (S Mohammed PhD), Department of Community Medicine (M B Sufiyan MD), Ahmadu Bello University, Zaria, Nigeria; Department of Health Care Management (S Mohammed PhD), Technical University of Berlin, Berlin, Germany; Clinical Epidemiology and Public Health Research Unit (L Monasta DSc), Burlo Garofolo Institute for Maternal and Child Health, Trieste, Italy; School of Health & Rehabilitation Sciences (M Moni PhD), The University of Queensland, Brisbane, QLD, Australia; Department of Health Policy (Prof E Mossialos PhD), London School of Economics and Political Science, London, UK, UK; Department of Surgery and Cancer (Prof E Mossialos PhD), Department of Primary Care and Public Health (Prof S Rawaf MD), Imperial College London, London, UK; Department of Medicine (E Mostafavi PhD), Stanford Cardiovascular Institute (E Mostafavi PhD), Stanford University, Palo Alto, CA, USA; Department of Fruit and Vegetable Product Technology (Prof A Mousavi Khaneghah PhD), Prof Wacław Dąbrowski Institute of Agricultural and Food Biotechnology State Research Institute, Warsaw, Poland; Department of Epidemiology and Biostatistics (S Mubarik MS), School of Medicine (Z Zhang PhD), Wuhan University, Wuhan, China; Department of Biomedical and Neuromotor Sciences (L Muccioli MD), University of Bologna, Bologna, Italy; Department of Basic Medical Sciences (J Muhammad PhD), College of Medicine, University of Sharjah, Sharjah, United Arab Emirates; Department of Surgery (F Mulita PhD), General University Hospital of Patras, Patras, Greece; Medical School (F Mulita PhD), University of Thessaly, Larissa, Greece; Clinical Epidemiology Research Unit (E Murillo-Zamora PhD), Mexican Institute of Social Security, Villa de Alvarez, Mexico; Postgraduate in Medical Sciences (E Murillo-Zamora PhD), Universidad de Colima, Colima, Mexico; Department of Pediatrics & Pediatric Pulmonology (Prof G Mustafa MD), Institute of Mother & Child Care, Multan, Pakistan; Saveetha Dental College (S Muthupandian PhD), Saveetha Dental College and Hospitals (M R Tovani-Palone PhD), Saveetha Institute of Medical and Technical Sciences, Chennai, India; Research and Analytics Department (A J Nagarajan MTech), Initiative for Financing Health and Human Development, Chennai, India; Department of Research and Analytics (A J Nagarajan MTech), Bioinsilico Technologies, Chennai, India; Department of Pharmacy (F Nainu PhD), Hasanuddin University, Makassar, Indonesia; Health Workforce Department (T S Nair MD), World Health Organisation, Geneva, Switzerland; Department of Psychiatry (S Nargus PhD), Mashhad University of Medical Sciences, Mashad, Iran; Department of Health Policy and Oral Epidemiology (Z S Natto DrPH), Division of General Internal Medicine (Prof A Sheikh MD), Harvard University, Boston, MA, USA; Department of General Surgery (I Negoi PhD), Emergency Hospital of Bucharest, Bucharest, Romania; Department of Cardiology (R I Negoi PhD), Cardio-Aid, Bucharest, Romania; Cardiovascular Research Department (H Q Nguyen MD), Methodist Hospital, Merrillville, IL, USA; Department of Surgery (P T Nguyen MD), Danang Family Hospital, Danang, Viet Nam; International Islamic University Islamabad, Islamabad, Pakistan (R K Niazi PhD); Population Science Department (K Nuruzzaman PhD), Jatiya Kabi Kazi Nazrul Islam University, Mymensingh, Bangladesh; Department of International Public Health (V E Nwatah MD), University of Liverpool, Liverpool, UK; Center of Excellence in Reproductive Health Innovation (CERHI) (C I Nzoputam MPH), University of Benin, Benin City, Nigeria; Department of Physiology (O J Nzoputam PhD), University of Benin, Edo, Nigeria; Department of Physiology (O J Nzoputam PhD), Benson Idahosa University, Benin City, Nigeria; Department of Applied Economics and Quantitative Analysis (Prof B Oancea PhD), University of Bucharest, Bucharest, Romania; National Institute of Infectious Diseases (R M Obaidur PhD), Center for Surveillance, Immunization, and Epidemiologic Research, Tokyo, Japan; Center for Evidence-Based Medicine and Clinical Research, Dhaka, Bangladesh (R M Obaidur PhD); Department of Veterinary Public Health and Preventive Medicine (I A Odetokun PhD), University of Ilorin, Ilorin, Nigeria; Discipline of Public Health Medicine (R E Ogunsakin PhD), University of KwaZulu-Natal, Durban, South Africa; School of Pharmacy (O C Okonji MSc), University of the Western Cape, Cape Town, South Africa; Department of Psychiatry and Behavioural Neurosciences (A T Olagunju MD), McMaster University, Hamilton, ON, Canada; Department of Psychiatry (A T Olagunju MD), University of Lagos, Lagos, Nigeria; Slum and Rural Health Initiative Research Academy (I I Olufadewa MHS), Slum and Rural Health Initiative, Ibadan, Nigeria; Department of Microbiology (Y D Oluwafemi PhD), University of Medical Sciences, Ondo, Ondo City, Nigeria; Department of Infectious Diseases (Prof A Ouyahia PhD), University Hospital of Setif, setif, Algeria; Department of Respiratory Medicine (Prof M P A DNB), Jagadguru Sri Shivarathreeswara Academy of Health Education and Research, Mysore, India; Department of Microbiology (Prof P N Palange MD), Kaloji Narayana Rao University of Health Sciences, Adilabad, India; Vision and Eye Research Institute (Prof S Pardhan PhD), Anglia Ruskin University, Cambridge, UK; Epidemiology and Community Health, School of Public Health (R R Parikh MD), University of Minnesota School of Public Health, Minneapolis, MN, USA; School of Dentistry (J Patel), University of Leeds, Leeds, UK; Department of Neurology and Public Health (U K Patel MD), Icahn School of Medicine at Mount Sinai, New York, NY, USA; College of Dental Medicine (Prof S Patil PhD), Roseman University of Health Sciences, South Jordan, UT, USA; Research Section (U Paudel PhD), Research Department - Infectious Diseases (N Pokhrel MD), Nepal Health Research Council, Kathmandu, Nepal; Department of Neurology (U Pensato MD), IRCCS Humanitas Research Hospital, Milan, Italy; Pharmacy, Pharmacology and Health Technologies (Prof J Perdigão PhD), University of Lisbon, Lisbon, Portugal; Institute of Collective Health (Prof M Pereira PhD), Federal University of Bahia, Salvador, Brazil; Department of Psychiatry (Prof M F P Peres MD), University of São Paulo, São Paulo, Brazil; International Institute for Educational Planning (Prof M F P Peres MD), Albert Einstein Hospital, São Paulo, Brazil; Department of Statistics and Econometrics (I Petcu PhD), Bucharest University of Economic Studies, Bucharest, Romania; International Center of Medical Sciences Research, Islamabad, Pakistan (Z Z Piracha PhD); Department of Maternal and Child Nursing and Public Health (E J S Prates BS), Escola de Enfermagem da UFMG (Prof T M Ribeiro da Silva PhD), Federal University of Minas Gerais, Belo Horizonte, Brazil; Department of Population Science and Human Resource Development (M Rahman DrPH), University of Rajshahi, Rajshahi, Bangladesh; School of Nursing and Healthcare Professions (M Rahman PhD), Federation University Australia, Berwick, VIC, Australia; Department of Public Health (V Rahmanian PhD), Torbat Jam Faculty of Medical Sciences, Torbat Jam, Iran; Department of Community Medicine (P Ramasubramani MD), Mahatma Gandhi Medical College and Research Institute, Puducherry, India; Department of Health Innovation (U Rani PhD), Manipal Academy of Higher Education, Udupi, India; Andhra University College of Pharmaceutical Sciences (D Rapaka PhD), Andhra University, Visakhapatnam, India; Department of Biomedical Engineering (Z Ratan MSc), Khulna University of Engineering and Technology, Khulna, Bangladesh; School of Health and Society (Z Ratan MSc), University of Wollongong, Wollongong, NSW, Australia; Academic Public Health England (Prof S Rawaf MD), Public Health England, London, UK; Department Biological Sciences (Prof E M M Redwan PhD), King Abdulaziz University, Jeddah, Egypt; Department of Protein Research (Prof E M M Redwan PhD), Research and Academic Institution, Alexandria, Egypt; Centre for Tropical Medicine and Global Health, Nuffield Department of Medicine (T Roberts PhD), Nuffield Department of Primary Care Health Sciences

(T Tillawi MD), Oxford University, Oxford, UK; Department of Microbiology (T Roberts PhD), Lao-Oxford-Mahosot Hospital Wellcome Trust Research Unit, Vientiane, Laos; Nuffield Department of Medicine (G Robles Aguilar DPhil), Centre for Tropical Medicine and Global Health (P Turner PhD), University of Oxford, Oxford, UK; Department of Pharmacology and Toxicology (Prof J A B Rodriguez PhD), University of Antioquia, Medellin, Colombia; International Nosocomial Infection Control Consortium (V D Rosenthal MD), Independent Consultant, Buenos Aires, Argentina; Department of Pediatric Neurology (S Sadeghian MD), Department of Microbiology (M Saki PhD), Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran; Multidisciplinary Laboratory Foundation University School of Health Sciences (Prof U Saeed PhD), Foundation University, Islamabad, Pakistan; International Center of Medical Sciences Research, Islamabad, Pakistan (Prof U Saeed PhD); Department of Preventive & Social Medicine (M Sahu MD), Independent Consultant, Kolkata, India; Neurology Department (S Sajedi MD), Golestan University of Medical Sciences, Gorgan, Iran; Medical Laboratory (S Salahi BMedSc), Azad University of Medical Sciences, Tehran, Iran; Advanced Therapy Medicinal Products Department (S Salahi MD), Royan Institution, Tehran, Iran; Department of Pathology, Microbiology and Forensic Medicine (M Sallam PhD), Department of Clinical Laboratories and Forensic Medicine (M Sallam PhD), Independent Consultant, Amman, Jordan; Department of Neurology (S Samadzadeh MD), Charité University Medical Center Berlin, Berlin, Germany; Department of Neurology (S Samadzadeh MD), University of Southern Denmark, Odense, Denmark; Department of Entomology (A M Samy PhD), Medical Ain Shams Research Institute (A M Samy PhD), Ain Shams University, Cairo, Egypt; Department of Pediatrics (R K Sanjeev MD), Pravara Institute of Medical Sciences, Loni(BK), India; UGC Centre of Advanced Study in Psychology (M Satpathy PhD), Utkal University, Bhubaneswar, India; Udyam-Global Association for Sustainable Development, Bhubaneswar, India (M Satpathy PhD); National Heart, Lung, and Blood Institute (A Seylani BS), National Institute of Health, Rockville, MD, USA; Division of Population Medicine (A Sha'aban PhD), Cardiff University, Cardiff, UK; Infectious Diseases and Microbiology (P A Shah MBBS), Rajiv Gandhi University of Health Sciences, Bangalore, India; HepatoPancreatoBiliary Surgery and Liver Transplant (P A Shah MBBS), HealthCare Global Limited Cancer Care Hospital, Bangalore, India; Department of Neuroimmunology (S Shahrokhi MD), Universal Scientific Research Network, Tehran, Iran; Hepatitis Research Center (K Shahzamani PhD), Lorestan University of Medical Sciences, Khorram abad, Iran; Independent Consultant, Karachi, Pakistan (M A Shaikh MD); Pathology, Lenox Hill Hospital (S Sham MBBS), Northwell Health, New York, NY, USA; Department of Microbiology (S M Shenoy MD), Kasturba Medical College, Mangalore, India; College of Medicine (Prof J Shin MD), Yonsei University, Seoul, South Korea; Department of Epidemiology (F Shokri PharmD), Leiden University Medical Center, Leiden, Netherlands; School of Pharmacy (S Shrestha PharmD), Monash University, Selangor Darul Ehsan, Malaysia; Department of Pediatrics and Child Health Nursing (M M Sibhat MSc), Dilla University, Dilla, Ethiopia; Department of Medical Microbiology and Infectious Diseases (E E Siddig PhD), Erasmus University, Rotterdam, Netherlands; Center of Potential and Innovation of Natural Resources (Prof L M R Silva PhD), Polytechnic Institute of Guarda, Guarda, Portugal; Health Sciences Research Centre (Prof L M R Silva PhD), University of Beira Interior, Covilhã, Portugal; Department of Pulmonary and Critical Care Medicine (H Singh MD), Medical College of Wisconsin, Milwaukee, WI, USA; School of Medicine (Prof J A Singh MD), University of Alabama at Birmingham, Birmingham, AL, USA; Medicine Service (Prof J A Singh MD), US Department of Veterans Affairs, Birmingham, AL, USA; Department of Radiodiagnosis (P Singh MD), All India Institute of Medical Sciences, Bathinda, India; Department of Internal Medicine (R Sinto MD), University of Indonesia, Jakarta Pusat, Indonesia; Department of Internal Medicine (R Sinto MD), Dr Cipto Mangunkusumo National Hospital, Jakarta Pusat, Indonesia; Department of Infectious Diseases and Epidemiology (A A Skryabina MD), Pirogov Russian National Research Medical University, Moscow, Russia; Department of Surgery (B Socea PhD), Emergency Hospital of Saint Pantelimon, Bucharest, Romania; Department of Infectious Diseases (A Sokhan PhD), Kharkiv National Medical University, Kharkiv, Ukraine; Pathology, Medical Foundations (R Solanki MD), Ross University School of Medicine, Bridgetown, Barbados; Pathology Department (R Solanki MD), American University of the Caribbean School of Medicine, Cupecoy, Saint Martin; Department of Nursing (Y Solomon MSc), Dire Dawa University, Dire Dawa, Ethiopia; Department of Microbiology (P Sood PhD), All India Institute of Medical Sciences, Bilaspur, India; Public Health Department (S Soshnikov PhD), Bukhara State Medical Institute, Bukhara, Uzbekistan; Laboratory of Public Health Indicators Analysis and Health Digitalization (S Soshnikov PhD), Moscow Institute of Physics and Technology, Moscow, Russia; National Institute of Epidemiology (R Suliankatchi Abdulkader MD), Indian Council of Medical Research, Chennai, India; Mental Health Research (A Sultana MD), Independent Consultant, Khulna, Bangladesh; Division of Global Mental Health (A Sultana MD), EviSyn Health, Khulna, Bangladesh; Department of Pharmacology (S Ty MD), All India Institute of Medical Sciences, Deoghar, India; Department of Medicine (J J L Tamuzi MSc), Northlands Health Groups and Medical Research, Omuthiya, Namibia; Department of Surgery (K Tan PhD), Saw Swee Hock School of Public Health (S Yi PhD), National University of Singapore, Singapore; Department of Economics (N Y Tat MS), Rice University, Houston, TX, USA; Research and Innovation (N Y Tat MS), Enventure Medical Innovation, Houston, TX, USA; Outpatient Department (D R Terefa MSc), Wollega University, Bedele, Ethiopia; Department of Pharmacology (P Thangaraju MD), All India Institute of Medical Sciences, Raipur, India; Faculty of Public Health (J H V Ticoalu MPH), Universitas Sam Ratulangi, Manado, Indonesia; Biochemistry and Molecular Biology (M B Tincho PhD), University of Buea, Buea, Cameroon; Infectious Diseases Department (Prof I I Tleyjeh MD), King Fahad Medical City, Riyadh, Saudi Arabia; Division of Infectious Diseases (Prof I I Tleyjeh MD), Mayo Clinic, Rochester, MN, USA; Social Determinants of Health, (R Toghroli PhD), Hormozgan University of Medical Sciences, Bandar Abbas, Iran; Modestum, Eastbourne, UK (M R Tovani-Palone PhD); Angkor Hospital for Children (P Turner PhD), Cambodia Oxford Medical Research Unit, Siem Reap, Cambodia; Department of Life Sciences (I Ullah PhD), University of Management and Technology, Lahore, Pakistan; Department of Community Medicine (C D Umeokonkwo MPH), Alex Ekwueme Federal University Teaching Hospital Abakaliki, Abakaliki, Nigeria; College of Health and Sport Sciences (A G Vaithinathan MSc), University of Bahrain, Salmanya, Bahrain; Urmia University of Medical Sciences, Urmia, Iran (R Valizadeh PhD); Office of Research, Innovation, and Commercialization (Prof Y Waheed PhD), Shaheed Zulfiqar Ali Bhutto Medical University, Islamabad, Pakistan; Gilbert and Rose-Marie Chagoury School of Medicine (Prof Y Waheed PhD), Lebanese American University, Byblos, Lebanon; Department of Psychiatry (M T Walde MSc), Haramaya University, Harar, Ethiopia; Department of Medicine (C Wang MPH), Vanderbilt University, Nashville, TN, USA; Department of Parasitology (Prof K G Weerakoon PhD), Department of Community Medicine (N D Wickramasinghe MD), Rajarata University of Sri Lanka, Anuradhapura, Sri Lanka; Department of Neurology (Prof A S Winkler PhD), Technical University of Munich, Munich, Germany; Research, Evidence and Policy Department (C Wright MSc), Meningitis Research Foundation, Bristol, UK; Department of Public Health (C Y Y Yenew MSc), Biomedical Research Networking Center for Mental Health Network (CiberSAM), Debre Tabor, Ethiopia; Department of Pharmacology, Physiology & Neuroscience (M Yesiltepe PhD), Rutgers University, Newark, NJ, USA; Clinical Investigation Unit (M Yesiltepe PhD), Ankara City Hospital, Ankara, Türkiye; KHANA Center for Population Health Research (S Yi PhD), Khana, Phnom Penh, Cambodia; Department of Health Management (V Yiğit PhD), Süleyman Demirel Üniversitesi (Süleyman Demirel University), Isparta, Türkiye; Department of Clinical Pharmacy and Pharmacy Administration (H Yusuf PhD), University of Maiduguri, Maiduguri, Nigeria; Faculty of Medicine and Health Sciences (F Zakham PhD), Hodeidah University, Hodeidah, Yemen; Department of Virology (F Zakham PhD), University of Helsinki, Helsinki, Finland; Faculty of Pharmacy (M Zaman PhD), University of Central Punjab, Lahore, Pakistan; Department of Medicine (S Zaman MSc), Monash University, Melbourne, VIC, Australia; Maternal and Child Health Division (S Zaman MSc), International

Centre for Diarrhoeal Disease Research, Bangladesh, Dhaka, Bangladesh; Research and Development Department (I Zare BSc), Sina Medical Biochemistry Technologies, Shiraz, Iran; Addictology Department (Prof M S Zastrozhin PhD), Russian Medical Academy of Continuous Professional Education, Moscow, Russia; School of Public Health (H Zhang MS), Peking University, Beijing, China; School of Public Policy and Administration (J Zhang BA), Xi 'an Jiaotong University, Xi'an, China; Department of Infection (Prof A Zumla PhD), University College London, London, UK; NIHR-Biomedical Research Centre (Prof A Zumla PhD), University College London Hospitals, London, UK.

Contributors

Please see appendix 1 (pp 19–24) for more detailed information about individual author contributions to the research, divided into the following categories: managing the overall research enterprise; writing the first draft of the manuscript; primary responsibility for applying analytical methods to produce estimates; primary responsibility for seeking, cataloguing, extracting, or cleaning data; designing or coding figures and tables; providing data or critical feedback on data sources; developing methods or computational machinery; providing critical feedback on methods or results; drafting the manuscript or revising it critically for important intellectual content; and managing the estimation or publications process. Members of the core research team (H Wunrow, R G Bender, A Vongpradith, S B Sirota, L R Swetchinski, A P Gray, K S Ikuta, F Sharara, C J L Murray, M Naghavi, and H H Kyu) for this topic area had full access to the underlying data used to generate the estimates presented in this Article. All other authors had access to and reviewed the estimates as part of the research evaluation process, which included additional formal stages of review. H H Kyu and M Naghavi accessed and verified the underlying data reported in this study. The corresponding author had final responsibility for the decision to submit the manuscript for publication.

Declaration of interests

K Akinosoglou reports payment or honoraria for lectures, presentations, speakers' bureau fees, manuscript writing or educational events from Pfizer Hellas, Gilead Sciences, Merck Sharp and Dohme, Glaxosmithkline Greece, as payments to the University of Patras; and support for attending meetings or travel, or both, to Pfizer Hellas, Gilead Sciences, Merck Sharp and Dohme, Glaxosmithkline Greece, and Norma Hellas; all outside the submitted work. R Ancuceanu reports payment or honoraria for lectures, presentations, speakers' bureau fees, manuscript writing or educational events from AbbVie, Sandoz, B. Braun, and Laropharm, all outside the submitted work. S Bhaskar reports leadership or fiduciary roles in other board, society, committee or advocacy groups, paid or unpaid, with Rotary Club of Sydney, Australia as Board Director, with Rotary District 9675, Australia as Chair of Diversity Equity & Inclusion, and with Global Health Hub, Berlin as Founding Member/ Chair & Co-Manager, Global Health and Migration Hub Community, all outside the submitted work. D Buonsenso reports payment or honoraria for lectures, presentations, speakers bureau fees, manuscript writing or educational events and participation on an advisory board from Pfizer for the Pneumococcal 22 Vaccine Advisory Board 2022, outside the submitted work. A Demetriades reports payment or honoraria for speakers' bureau fees from Integra, Stryker, and Safe Orthopaedics; leadership or fiduciary roles, unpaid, as a board member (non-stipendiary) with the European Association of Neurosurgical Societies, Global Neuro Foundation and on the steering committee (non-stipendiary) of AO Spine Knowledge Forum Degenerative; all outside the submitted work. B D Gessner reports support for the present manuscript from Pfizer through salary payments; and stock or stock options through their employment with Pfizer; all outside the submitted work. N E Ismail reports a leadership or fiduciary role as an unpaid council member and bursar of the Malaysian Academy of Pharmacy, outside the submitted work. J J Jozwiak reports payment or honoraria for lectures, presentations, speakers' bureau fees, manuscript writing or educational events from Novartis and Adamed as personal payments, outside the submitted work. K Krishan reports non-financial support from the UGC Centre of Advanced Study, CAS II, Department of Anthropology, Panjab University, Chandigarh, India, outside the submitted work. A-F A Mentis reports grants or contracts from "MilkSafe: A novel pipeline to enrich formula milk using omics technologies", a research co financed by the European Regional Development Fund of the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH-CREATE - -INNOVATE (project code: T2EDK-02222), as well as from ELIDEK (Hellenic Foundation for Research and Innovation, MIMS-860); payment for expert testimony as a peer-reviewer for Fondazione Cariplo, Italy; leadership or fiduciary roles in other boards, societies, committees or advocacy groups, paid or unpaid, by serving as Editorial Board Member for the journals *Systematic Reviews* and *Annals of Epidemiology*, and as Associate Editor for *Translational Psychiatry*; stocks in a family winery; and other financial or non-financial interests as a scientific officer with the BGI Group; all outside the submitted work. M J Postma reports stock or stock options from Health-Ecore (Zeist NL, 25%) and PAG BV (Groningen, NL, 100%) outside the submitted work. S Shrestha reports other financial interests in the School of Pharmacy at Monash University Malaysia by receiving the Graduate Research Merit Scholarship to pursue his PhD, outside the submitted work. L Silva reports grants or contracts from CENTRO-04-3559-FSE-000162, Fundo Social Europeu, outside the submitted work. J A Singh reports consulting fees from Crealta/Horizon, Medisys, Fidia, PK Med, Two Labs, Adept Field Solutions, Clinical Care Options, Clearview Healthcare Partners, Putnam Associates, Focus Forward, Navigant Consulting, Spherix, MedIQ, Jupiter Life Science, UBM, Trio Health, Medscape, WebMD, and Practice Point Communications, the National Institutes of Health, and the American College of Rheumatology; payment or honoraria for speakers' bureau fees from Simply Speaking; support for attending meetings or travel from the steering committee of OMERACT; participation on a Data Safety Monitoring Board or Advisory Board with the US Food and Drug Administration Arthritis Advisory Committee; a leadership or fiduciary role in board, society, committee or advocacy group, paid or unpaid, with OMERACT as a steering committee member, with the Veterans Affairs Rheumatology Field Advisory Committee as Chair (unpaid), and with the UAB Cochrane Musculoskeletal Group Satellite Center on Network Meta-analysis and as editor and director (unpaid); stock or stock options in TPT Global Tech, Vaxart Pharmaceuticals, Aytu BioPharma, Adaptimmune Therapeutics, GeoVax Labs, Pieris Pharmaceuticals, Enzolytics, Seres Therapeutics, Tonix Pharmaceuticals, and Charlotte's Web Holdings, and previously owned stock options in Amarin, Viking, and Moderna Pharmaceuticals; all outside the submitted work. C Wright is an employee of Meningitis Research Foundation, which receives grants in support of their charitable objectives from GlaxoSmithKline, Pfizer, Sanofi Pasteur, Serum Institute, and the Tableau Foundation, outside the submitted work.

Data sharing

To download the data used in these analyses, please visit the Global Health Data Exchange GBD 2019 website.

Acknowledgments

This study was funded by the Bill & Melinda Gates Foundation. S Afzal acknowledges the Institutional support of King Edward Medical University in completing the research work, meeting the deadlines, and providing learning and knowledge resources. A Ahmad acknowledges the Shaqra University for supporting this work. S M Aljunid acknowledges the International Centre for Casemix and Clinical Coding, Faculty of Medicine, National University of Malaysia and Department of Community Medicine, School of Medicine, International Medical University, Malaysia, for the approval and support to participate in this research project. M M W Atout thanks Philadelphia University, Amman, Jordan. A Fatehizadeh acknowledges support from the Department of Environmental Health Engineering of Isfahan University of Medical Sciences, Isfahan, Iran. N A Feasey is funded by a NIHR Global Health Professorship. P A Gaal acknowledges support from the National Research, Development and Innovation Office of Hungary under grant RRF-2.3.1-21-2022-00006 (Data-driven Health Division of Health Security National Laboratory). V K Gupta acknowledges funding support from National Health and Medical Research Council, Australia. S Hussain acknowledges support from Operational Programme Research, Development and Education Project, Postdoc2MUNI (No.CZ.02.2.69/0.0 /0.0/18_053/0016952). M T Imam is supported via funding from Prince Sattam Bin Abdulaziz University (project number

PSAU/2023/R/1444). N E Ismail acknowledges institutional support from AIMST University, Malaysia. M Jakovljevic acknowledges co-financing through Grant OI 175 014 of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia. N Joseph acknowledges the Department of Community Medicine, Kasturba Medical College, Mangalore, Manipal Academy of Higher Education, Manipal, India for their support and encouragement in this research study. H Kandel is supported by the Kornhauser Research Fellowship at the University of Sydney. I Landires reports support from Sistema Nacional de Investigación, which is supported by Panama's Secretaría Nacional de Ciencia, Tecnología e Innovación. G Lopes was supported by national funds through the Fundação para a Ciência e Tecnologia under the Scientific Employment Stimulus–Individual Call (CEECIND/01768/2021). Z A Memish acknowledges support from the Division of infectious Diseases, Kyung Hee University, Korea. L Monasta received support from the Italian Ministry of Health (Ricerca Corrente 34/2017), payments made to the Institute for Maternal and Child Health IRCCS Burlo Garofolo. A Mousavi Khaneghah received support from the Department of Technology of Chemistry, Azerbaijan State Oil and Industry University, Baku, Azerbaijan. V Nuñez-Samudio acknowledges support from the Sistema Nacional de Investigación, which is supported by Panama's Secretaría Nacional de Ciencia, Tecnología e Innovación. J Perdigão is supported by Fundação para a Ciência e Tecnologia through Estímulo Individual ao Emprego Científico (CEECIND/00394/2017) and UID/DTP/04138/2019 and, by Associação para o Desenvolvimento do Ensino e Investigação da Microbiologia. M Pinheiro thanks the Fundação para a Ciência e Tecnologia for funding through program DL 57/2016-Norma transitória. Z Z Piracha acknowledges the International Center of Medical Sciences Research, Islamabad, Pakistan. I Qattea acknowledges support from the Cleveland Clinic Foundation and Nassau University Medical Center. E M M Redwan acknowledges support from King Abdulaziz University, Jeddah, and King Abdulaziz City for Science & Technology, Saudi Arabia, Science & Technology Development Fund, and US-Egypt Science & Technology joint Fund, The Academy of Scientific Research & Technology, Egypt. A Riad acknowledges support from the NPO "Systemic Risk Institute" number LX22NPO5101, funded by European Union - Next Generation EU (Ministry of Education, Youth and Sports, NPO: EXCELES). U Saeed acknowledges the International Center of Medical Sciences Research, Islamabad, Pakistan. A M Samy acknowledges support from Ain Shams University and the Egyptian Fulbright Mission Program. P A Shah acknowledges support from Bangalore Medical College and Research Institute and the Rajiv Gandhi University of Health Sciences, Karnataka, India. A Sheikh acknowledges support from Health Data Research UK. P H Shetty acknowledges the Department of Forensic Medicine and Toxicology, Kasturba Medical College, Mangalore, Manipal Academy Of Higher Education, Manipal, India. L M L R Silva was supported by the project code CENTRO-04-3559-FSE-000162, Fundo Social Europeu. M R Tovani-Palone acknowledges the Saveetha Institute of Medical and Technical Sciences for supporting this study. P Turner acknowledges institutional and personal salary support from the Wellcome core grant to the Mahidol Oxford Tropical Medicine Research Unit, Thailand (grant number 220211). B Unnikrishnan acknowledges support from Kasturba Medical College, Mangalore, Manipal Academy of Higher Education, Manipal. S B Zaman acknowledges receiving a scholarship from the Australian Government Research Training Program in support of his academic career. A Zumla acknowledges support from the EU European & Developing Countries Clinical Trials Partnership-funded Pan-African Network for Rapid Research, Response, Relief and Preparedness for infectious diseases epidemics (PANDORA-ID-NET) and the UK National Institutes for Health Research Senior Investigator award.

Editorial note: The Lancet Group takes a neutral position with respect to territorial claims in published maps and institutional affiliations.

References

1 van de Beek D, Brouwer M, Hasbun R, Koedel U, Whitney CG, Wijdicks E. Community-acquired bacterial meningitis. *Nat Rev Dis Primers* 2016; **2:** 16074.

2 Zunt JR, Kassebaum NJ, Blake N, et al. Global, regional, and national burden of meningitis, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet Neurol* 2018; **17:** 1061–82.

3 Edmond K, Clark A, Korczak VS, Sanderson C, Griffiths UK, Rudan I. Global and regional risk of disabling sequelae from bacterial meningitis: a systematic review and meta-analysis. *Lancet Infect Dis* 2010; **10:** 317–28.

4 Hudson JA, Broad J, Martin NG, et al. Outcomes beyond hospital discharge in infants and children with viral meningitis: a systematic review. *Rev Med Virol* 2020; **30:** e2083.

5 Mount HR, Boyle SD. Aseptic and bacterial meningitis: evaluation, treatment, and prevention. *Am Fam Physician* 2017; **96:** 314–22.

6 Wall EC, Chan JM, Gil E, Heyderman RS. Acute bacterial meningitis. *Curr Opin Neurol* 2021; **34:** 386–95.

7 Oordt-Speets AM, Bolijn R, van Hoorn RC, Bhavsar A, Kyaw MH. Global etiology of bacterial meningitis: a systematic review and meta-analysis. *PLoS One* 2018; **13:** e0198772.

8 WHO. Immunization coverage. July 14, 2022. https://www.who.int/news-room/fact-sheets/detail/immunization-coverage (accessed Dec 27, 2022).

9 Molesworth AM, Thomson MC, Connor SJ, et al. Where is the meningitis belt? Defining an area at risk of epidemic meningitis in Africa. *Trans R Soc Trop Med Hyg* 2002; **96:** 242–49.

10 Bwaka A, Bita A, Lingani C, et al. Status of the rollout of the meningococcal serogroup A conjugate vaccine in African meningitis belt countries in 2018. *J Infect Dis* 2019; **220** (suppl 4)**:** S140–47.

11 Bender RG, Shen J, Aravkin A, et al. Meningococcal A conjugate vaccine coverage in the meningitis belt of Africa from 2010 to 2021: a modelling study. *EClinicalMedicine* 2023; **56:** 101797.

12 WHO. Vaccination schedule for Meningococcal disease. 2023. https://immunizationdata.who.int/pages/schedule-by-disease/meningococcal.html?ISO_3_CODE=&TARGETPOP_GENERAL= (accessed April 28, 2023).

13 WHO. Defeating meningitis by 2030: a global road map. June 24, 2021. 2021 https://www.who.int/publications-detail-redirect/9789240026407 (accessed Feb 20, 2023).

14 Roth GA, Abate D, Abate KH, et al. Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* 2018; **392:** 1736–88.

15 James SL, Abate D, Abate KH, et al. Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* 2018; **392:** 1789–858.

16 Murray CJ, Ikuta KS, Sharara F, et al. Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. *Lancet* 2022; **399:** 629–55.

17 Vos T, Lim SS, Abbafati C, et al. Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *Lancet* 2020; **396:** 1204–22.

18 Wang H, Abbas KM, Abbasifard M, et al. Global age-sex-specific fertility, mortality, healthy life expectancy (HALE), and population estimates in 204 countries and territories, 1950–2019: a comprehensive demographic analysis for the Global Burden of Disease Study 2019. *Lancet* 2020; **396:** 1160–203.

19 Blau DM, Caneer JP, Philipsborn RP, et al. Overview and Development of the Child Health and Mortality Prevention Surveillance Determination of Cause of Death (DeCoDe) process and DeCoDe diagnosis standards. *Clin Infect Dis* 2019; **69** (suppl 4)**:** S333–41.

20 Foreman KJ, Lozano R, Lopez AD, Murray CJ. Modeling causes of death: an integrated approach using CODEm. *Popul Health Metr* 2012; **10:** 1.

21 Institute for Health Metrics and Evaluation. Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) covariates 1980–2019. 2020. https://doi.org/10.6069/CFCY-WA51. (accessed May 16, 2023).

22 WHO. Meningitis outbreak response in sub-Saharan Africa. January 8, 2014. https://www.who.int/publications-detail-redirect/WHO-HSE-PED-CED-14.5 (accessed Feb 20, 2023).

23 Institute for Health Metrics and Evaluation. Meningitis — Level 3 cause. Oct 15, 2020. http://www.healthdata.org/results/gbd_summaries/2019/meningitis-level-3-cause (accessed Jan 2, 2021).

24 Zheng P, Barber R, Sorensen RJD, Murray CJL, Aravkin AY. Trimmed constrained mixed effects models: formulations and algorithms. *J Comput Graph Stat* 2021; **30:** 544–56.

25 Fullman N, Yearwood J, Abay SM, et al. Measuring performance on the Healthcare Access and Quality Index for 195 countries and territories and selected subnational locations: a systematic analysis from the Global Burden of Disease Study 2016. *Lancet* 2018; **391:** 2236–71.

26 Wahl B, O'Brien KL, Greenbaum A, et al. Burden of *Streptococcus pneumoniae* and *Haemophilus influenzae* type b disease in children in the era of conjugate vaccines: global, regional, and national estimates for 2000–15. *Lancet Glob Health* 2018; **6:** e744–57.

27 Trotter CL, Lingani C, Fernandez K, et al. Impact of MenAfriVac in nine countries of the African meningitis belt, 2010–15: an analysis of surveillance data. *Lancet Infect Dis* 2017; **17:** 867–72.

28 Mustapha MM, Harrison LH. Vaccine prevention of meningococcal disease in Africa: major advances, remaining challenges. *Hum Vaccin Immunother* 2018; **14:** 1107–15.

29 Colombini A, Trotter C, Madrid Y, Karachaliou A, Preziosi M-P. Costs of *Neisseria meningitidis* group A disease and economic impact of vaccination in Burkina Faso. *Clin Infect Dis* 2015; **61** (suppl 5)**:** S473–82.

30 Novak RT, Ronveaux O, Bita AF, et al. Future directions for meningitis surveillance and vaccine evaluation in the meningitis belt of sub-Saharan Africa. *J Infect Dis* 2019; **220** (suppl 4)**:** S279–85.

31 LaForce FM, Djingarey M, Viviani S, Preziosi M-P. Successful African introduction of a new Group A meningococcal conjugate vaccine: future challenges and next steps. *Hum Vaccin Immunother* 2018; **14:** 1098–102.

32 Collard J-M, Issaka B, Zaneidou M, et al. Epidemiological changes in meningococcal meningitis in Niger from 2008 to 2011 and the impact of vaccination. *BMC Infect Dis* 2013; **13:** 576.

33 Alderson MR, LaForce FM, Sobanjo-Ter Meulen A, Hwang A, Preziosi M-P, Klugman KP. Eliminating meningococcal epidemics from the African meningitis belt: the case for advanced prevention and control using next-generation meningococcal conjugate vaccines. *J Infect Dis* 2019; **220** (suppl 4)**:** S274–78.

34 Løchen A, Croucher NJ, Anderson RM. Divergent serotype replacement trends and increasing diversity in pneumococcal disease in high income settings reduce the benefit of expanding vaccine valency. *Sci Rep* 2020; **10:** 18977.

35 Durdu B, Hakyemez IN, Bolukcu S, Okay G, Gultepe B, Aslan T. Mortality markers in nosocomial *Klebsiella pneumoniae* bloodstream infection. *Springerplus* 2016; **5:** 1892.

36 Chang D, Sharma L, Dela Cruz CS, Zhang D. Clinical epidemiology, risk factors, and control strategies of *Klebsiella pneumoniae* infection. *Front Microbiol* 2021; **12:** 750662.

37 Tang LM, Chen ST. *Klebsiella pneumoniae* meningitis: prognostic factors. *Scand J Infect Dis* 1994; **26:** 95–102.

38 Hallmaier-Wacker LK, Andrews A, Nsonwu O, et al. Incidence and aetiology of infant Gram-negative bacteraemia and meningitis: systematic review and meta-analysis. *Arch Dis Child* 2022; **107:** 988–94.

39 Feagins AR, Ronveaux O, Taha M-K, et al. Next generation rapid diagnostic tests for meningitis diagnosis. *J Infect* 2020; **81:** 712–18.

40 Effah CY, Sun T, Liu S, Wu Y. *Klebsiella pneumoniae*: an increasing threat to public health. *Ann Clin Microbiol Antimicrob* 2020; **19:** 1.

41 Huang N, Jia H, Zhou B, et al. Hypervirulent carbapenem-resistant *Klebsiella pneumoniae* causing highly fatal meningitis in southeastern China. *Front Public Health* 2022; **10:** 991306.

42 Doorduijn DJ, Rooijakkers SHM, van Schaik W, Bardoel BW. Complement resistance mechanisms of Klebsiella pneumoniae. *Immunobiology* 2016; **221:** 1102–09.

43 Bassetti M, Righi E, Carnelutti A, Graziano E, Russo A. Multidrug-resistant *Klebsiella pneumoniae*: challenges for treatment, prevention and infection control. *Expert Rev Anti Infect Ther* 2018; **16:** 749–61.

44 Jansen KU, Anderson AS. The role of vaccines in fighting antimicrobial resistance (antimicrobial resistance). *Hum Vaccin Immunother* 2018; **14:** 2142–49.

45 Steer PJ, Russell AB, Kochhar S, Cox P, Plumb J, Gopal Rao G. Group B streptococcal disease in the mother and newborn-A review. *Eur J Obstet Gynecol Reprod Biol* 2020; **252:** 526–33.

46 Russell NJ, Seale AC, O'Sullivan C, et al. Risk of early-onset neonatal group B streptococcal disease with maternal colonization worldwide: systematic review and meta-analyses. *Clin Infect Dis* 2017; **65** (suppl 2)**:** S152–59.

47 Le Doare K, O'Driscoll M, Turner K, et al. Intrapartum antibiotic chemoprophylaxis policies for the prevention of group B streptococcal disease worldwide: systematic review. *Clin Infect Dis* 2017; **65** (suppl 2)**:** S143–51.

48 Nanduri SA, Petit S, Smelser C, et al. Epidemiology of invasive early-onset and late-onset group B streptococcal disease in the United States, 2006 to 2015: multistate laboratory and population-based surveillance. *JAMA Pediatr* 2019; **173:** 224–33.

49 Madrid L, Seale AC, Kohli-Lynch M, et al. Infant group B streptococcal disease incidence and serotypes worldwide: systematic review and meta-analyses. *Clin Infect Dis* 2017; **65** (suppl 2)**:** S160–72.

50 Carreras-Abad C, Ramkhelawon L, Heath PT, Le Doare K. A vaccine against group B *Streptococcus*: recent advances. *Infect Drug Resist* 2020; **13:** 1263–72.

51 WHO. Group B streptococcus vaccine: full value vaccine assessment. Nov 2, 2021. https://www.who.int/publications-detail-redirect/9789240037526 (accessed Feb 28, 2023).

52 WHO. Standard operating procedures for surveillance of meningitis preparedness and response to epidemics in Africa (Annex 4). Oct 15, 2018. https://www.who.int/publications-detail-redirect/standard-operating-procedures-for-surveillance-of-meningitis-preparedness-and-response-to-epidemics-in-africa (accessed Dec 22, 2022).

53 Patel JC, Soeters HM, Diallo AO, et al. MenAfriNet: a network supporting case-based meningitis surveillance and vaccine evaluation in the meningitis belt of Africa. *J Infect Dis* 2019; **220** (suppl 4)**:** S148–54.

54 Feagins AR, Vuong J, Fernandez K, et al. The strengthening of laboratory systems in the meningitis belt to improve meningitis surveillance, 2008–2018: a partners' perspective. *J Infect Dis* 2019; **220** (suppl 4)**:** S175–81.

55 Mbaeyi SA, Lingani C, Diallo AO, et al. Improving case-based meningitis surveillance in 5 countries in the meningitis belt of sub-Saharan Africa, 2015–2017. *J Infect Dis* 2019; **220** (suppl 4)**:** S155–64.

56 WHO. Developing a new generation RDTs for Meningitis Geneva, 9 March 2018. https://www.who.int/publications/m/item/developing-a-new-generation-rdts-for-meningitis (accessed May 16, 2023).

57 Fleischer E, Aronson PL. Rapid diagnostic tests for meningitis and encephalitis-BioFire. *Pediatr Emerg Care* 2020; **36:** 397–401.

58 WHO. Global antimicrobial resistance and use surveillance system (GLASS) report: 2021. June 9, 2021. https://www.who.int/publications-detail-redirect/9789240027336 (accessed Feb 26, 2023).

59 Wright C, Blake N, Glennie L, et al. The global burden of meningitis in children: challenges with interpreting global health estimates. *Microorganisms* 2021; **9:** 377.

60 Flaxman AD, Joseph JC, Murray CJL, Riley ID, Lopez AD. Performance of InSilicoVA for assigning causes of death to verbal autopsies: multisite validation study using clinical diagnostic gold standards. *BMC Med* 2018; **16:** 56.

61 Brueggemann AB, Jansen van Rensburg MJ, Shaw D, et al. Changes in the incidence of invasive disease due to *Streptococcus pneumoniae*, *Haemophilus influenzae*, and *Neisseria meningitidis* during the COVID-19 pandemic in 26 countries and territories in the Invasive Respiratory Infection Surveillance Initiative: a prospective analysis of surveillance data. *Lancet Digit Health* 2021; **3:** e360–70.

62 Völk S, Pfirrmann M, Koedel U, et al. Decline in the number of patients with meningitis in German hospitals during the COVID-19 pandemic. *J Neurol* 2022; **269:** 3389–99.

63 Causey K, Fullman N, Sorensen RJD, et al. Estimating global and regional disruptions to routine childhood vaccine coverage during the COVID-19 pandemic in 2020: a modelling study. *Lancet* 2021; **398:** 522–34.

64 Larson HJ, Gakidou E, Murray CJL. The vaccine-hesitant moment. *N Engl J Med* 2022; **387:** 58–65.