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A comparative study of the disease burden of COPD attributable to PM2.5 in China, Japan, and South Korea from 1990 to 2019

Xiao-Fen Cheng[1†], Yi-Li Zhang[1], Shu-Hui Min[1], Rui-Qi Guo[1], Jin-Dan Zhang[1], Bei Li[1†*]

Abstract

Objective We hope to reveal the changing trends of chronic obstructive pulmonary disease (COPD) burden attributable to PM2.5 and its age, period, and cohort effects in China, Japan and Korea.

Design We analyzed the trend of COPD disease burden attributable to PM2.5 from 1990-2019 based on GBD2019 using JoinPoint model and analyzed the effect of age, period and cohort on COPD disease burden attributable to PM2.5 in China, Japan and Korea from 1990-2019 using age-period-cohort model.

Main outcomes and measures Outcomes included the age standardized mortality rate (ASMR), the age-standardized DALY, average annual percent change (AAPC), net drift, local drift, longitudinal age curves, period (cohort) rate ratios, age (period, cohort) bias coefficient.

Results From 1990 to 2019, the age standardized mortality rate (ASMR) and the age-standardized DALY of COPD attributable to PM2.5 in China, Japan, and South Korea showed a downward trend. Mortality of COPD attributable to PM2.5 increases slowly with age in Korea and Japan. Mortality of COPD attributable to PM2.5 in China declines after peaking in the 90-95 year age group. Mortality of COPD attributable to PM2.5 decreased significantly over time in China and Korea, while it increased slightly in Japan from 2015 to 2019. In China and Japan, mortality of COPD attributable to PM2.5 was approximately lower the later the birth, while in Korea it gradually decreased after a small increase to a peak in the 1900-1910 birth cohort.

Conclusion Most COPD disease burden attributable to PM2.5 is on the decline; COPD mortality attributable to PM2.5 both increased with age and decreased with time and cohort. Countries, especially China, should develop targeted measures to control local particulate matter exposure based on pollutant types and age groups, and reduce the burden of COPD caused by particulate matter pollution according to local conditions.

Keywords: PM2.5, COPD, JoinPoint regression model, age-period-cohort analysis, burden of disease

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Strengths and limitations of this study

There are some strengths in this study. First, this study comprehensively described and compared the mortality rate and DALY of COPD attributed to particulate matter pollution in China, Japan, and South Korea. Second, this study evaluated the long-term trend changes of COPD attributed to particulate matter pollution in the three countries. Third, This study analyzed the age effect, period effect, and cohort effect of COPD attributed to particulate matter pollution in the three countries.

There are also some limitations in this study. First, this study used GBD2019 for data analysis, and GBD2019 collected missing data by modifying and adjusting data sources and collection assessment methods, which could not eliminate data bias and affected the accuracy of the results. Second, the APC model only considered the effects of age, period and cohort without further analysis of other risk factors.

Background

Air pollution is the largest environmental cause of increased non-accidental mortality and morbidity, and a significant global health threat[1 2]. In fact, according to the State of Global Air 2020, a staggering 6.67 million people worldwide are predicted to perish from air pollution in 2019, underscoring the gravity of this global health threat[3]. Air pollution is usually quantified according to particulate pollution and ozone[4], where particulate pollution is a crucial factor in air pollution, as clinical studies have shown that particulate pollution has a greater impact on health than gaseous components[5]. Particulate matter is defined as particles with a diameter of 2.5 microns or smaller, and particulate matter pollution (PM2.5) can be divided into APM and HAP. In 2019, the disease burden due to APM is the seventh highest for all ages, with average concentrations exceeding the WHO air quality guidelines of 10μg/m3 and affecting over 90% of the world's population[3]. The situation is further compounded by increasingly alarming exposure to APM in a majority of developing countries in recent years[6]. HAP mainly refers to PM2.5 exposure from home heating or cooking through polluting fuels such as wood, coal, kerosene, etc. Despite the downward trend in overall HAP exposure, nearly 3 billion people worldwide still rely on polluting fuels for daily household living in 2019[7], and 32% of Chinese still use solid fuels for cooking or heating[8]. Cohort studies conducted across the globe consistently highlight a clear correlation between exposure to PM2.5 and mortality and disease incidence[9-11], while particulate pollution conclusively causes acute lower respiratory disease, cerebrovascular disease, ischemic heart disease, COPD, and lung cancer[12].

Over the past few decades, epidemiological studies and meta-analyses have established that both short-term and long-term exposure to particulate matter pollution are associated with COPD[13 14]. Particulate pollution is a top three risk factor for COPD-related death and disability[15]. Respirable particulate matter in the environment leads to an increase in reactive oxygen species (ROS), and mitochondria are affected by excess ROS, leading to severe mitochondrial dysfunction or activation of processes such as autophagy, mitophagy and apoptosis[16], which can induce airway inflammation, airway wall remodeling, emphysematous lesions, lung function impairment and mucus hypersecretion[17-19]. In addition, it's not just a matter of public health, as COPD also carries an economic cost[20]. The direct medical costs of COPD alone in the United States are projected to skyrocket to an alarming $800.9 billion over the next two decades[21]. Overall, COPD is a formidable health problem that warrants increased attention and concerted effort in both developed and developing countries.

It's worth noting that East Asia, for instance, has the highest number of COPD cases, deaths, and DALYs on the global stage[22]. In East Asia, China, Japan, and South Korea belong to its three largest economies, with economies exceeding one-fifth of the world's total. These three countries have similar cultural backgrounds but are at different stages of socioeconomic development, with Japan and South Korea leading China in terms of urbanization and industrialization. In 2019, China ranked first in air pollution-related deaths and second in air pollution-related DALYs[23], which shows that air pollution in China leads to a very serious disease burden, and similarly, South Korea faces a more serious air pollution problems, while Japan has a relatively better pollution situation[24]. Analyzing and comparing the disease burden of COPD due to particulate matter in the three countries will help to track the effectiveness of national prevention and control programs, prevent the disease burden of COPD due to air pollution, and develop targeted strategies for the management of particulate matter pollution and COPD prevention strategies.

However, previous studies have mainly focused on analyzing the effect of PM2.5 on COPD and its potential mechanisms in a particular country or global[25 26], and few studies have analyzed the disease burden of COPD due to APM and HAP in three countries, China, Japan, and Korea[24], while few studies have been able to further investigate the age, period, and cohort effects of PM2.5 and COPD using the age-period-cohort model (APC model)[24 26]. APC models are able to estimate the independent effects of age, period, and cohort on disease[27], helping us to understand COPD caused by PM2.5 from a historical perspective, such as disease screening modalities, treatments or interventions, and lifestyle changes[28 29]. Therefore, this study subdivided PM2.5 into HAP and APM, aiming to analyze the changes in COPD disease burden attributable to PM2.5 and its age, period, and cohort effects in China, Japan, and Korea from 1990 to 2019, and to provide feasible and targeted policy recommendations for countries and regions with high disease burden.

Methods

Data Sources

The study is based on the latest Global Burden of Disease Database (GBD2019) from the Institute for Health Metrics and Evaluation in Washington, USA. GBD2019 provides population estimates for 204 countries and territories from 1950 to 2019, and also provides data on the incidence, number of deaths, and DALYs for 369 diseases and injuries for 204 countries and territories from 1990 to 2019[30]. This study uses GBD2019 data to report the burden of COPD disease attributable to particulate matter pollution in China, Japan, Korea, and global from 1990 to 2019. A detailed description of the GBD 2019 methodology used to analyze the burden of disease was previously published[31] and can be accessed at https://vizhub.healthdata.org/gbd-results/.

COPD Definition

COPD data for this study were obtained from GBD2019.The COPD data reported in GBD2019 used the Global Initiative for Chronic Obstructive Lung Disease (GOLD) standard definition: when the ratio of maximum forced expiratory air volume to total forced expiratory volume (FEV1/FVC) in the first second of expiration after bronchodilation has a value <0.7[22]. Alternative definitions for evaluating whether a person has COPD include the pre-bronchodilator GOLD criteria, the post-bronchodilator lower limit of normal, the pre-bronchodilator lower limit of normal, and the European Respiratory Society guidelines[32].

Particulate Matter Pollution Assessment

We used HAP and APM data from GBD2019 as an indicator of particulate matter pollution. GBD defines PM2.5 as fine particles with an aerodynamic diameter of 2.5μm or less in 1 cubic meter of air when exposed to it. In this case, APM is measured by the annual average PM2.5 concentration in the air, which is estimated at a spatial resolution of 0.1° × 0.1° grid from satellite observations, chemical transport models and ground monitoring data [33]. HAP was defined as the daily average PM2.5 exposure due to the use of household solid fuels, which was obtained from measurements of PM2.5 concentrations in kitchens and living areas[33].

Statistical Analysis

JoinPoint Regression Analysis

This study describes the level of COPD disease burden due to PM2.5 from 1990 to 2019 by age-standardized mortality and DALY. We applied log-linear models of JoinPoint regression models to fit age-standardized COPD mortality (ASMR) and DALY data attributable to PM2.5. The average annual percent change (AAPC) was calculated by a log-linear model to observe the trend of death and DALY in COPD attributable to PM2.5 in China, Japan, Korea, and global.

Age-period-cohort analysis

This study further explored the age effect, period effect and cohort effect of the changing pattern of COPD mortality attributable to PM2.5 by using the APC model. The APC model is based on the Poisson distribution and can address the problem that there is a linear relationship between age, period and cohort to estimate the effect that age, period and cohort have on disease[34]. In this paper, the following indicators are estimated by the APC model: Net drift, an overall log-linear trend indicating the overall annual percentage change in disease using period and birth cohort adjustments; Local drift, a log-linear trend in the period and birth cohort for each age group, representing the annual percentage change for each age group; Longitudinal age curves, reflecting period deviation-adjusted longitudinal age-specific values, used to infer the effect of age effects on trends in gastric cancer; Period (cohort) rate ratios, which allow inference of the influence of period or cohort effects on trends in gastric cancer; Age (period, cohort) bias coefficient, reflecting the curvature within a certain age (period, cohort).

The APC model in this paper uses the APC Model Web Analysis Tool provided by the International Agency for Cancer (https://analysistools.cancer.gov/apc/). Based on the GBD2019 data and the characteristics of the APC model webpage analysis tool, this study selected COPD mortality data at 5-year intervals as an age group. Since the mortality data for COPD under 25 years of age was 0, data under 25 years of age were excluded from this study, and a total of 15 age groups were ultimately included. In terms of period division, this paper divides 1990-2019 into 6 periods according to 5 years as a time period. The formula of birth cohort is: birth cohort = period - age, and this paper calculates the value of birth cohort according to the data characteristics.

Excel 2019 software was used to organize data; JoinPoint Regression Program 4.9.0.0 software was applied to analyze the trend of COPD attributed to PM2.5; APC model web analysis tool was used to fit the APC model and use the web page itself with Wald $\chi 2$ test for parameter estimation; Origin2021 software was used for plotting. The test level for all statistical models in this paper was α=0.05 (two-sided).

Results

Descriptive analysis of COPD attributable to PM2.5 in China, Japan, Korea and global

Trends in ASMR for COPD attributable to PM2.5 in China, Japan, Korea, and global from 1990-2019 are shown in Figure 1A. The ASMRs in China, Japan, Korea, and global all showed a decreasing trend, with the highest and largest decrease in China. The global ASMR decline was second only to China, and the ASMR in Korea and Japan has remained low. The trends of age-standardized DALY changes in COPD attributable to PM2.5 in China, Japan, Korea, and global from 1990-2019 are shown in Figure 1B. From 1990 to 2019, the age-standardized DALYs for COPD attributable to PM2.5 and attributable to APM in China showed a decreasing trend but remained at the highest level compared with Japan, Korea, and global, while the DALY for age-standardized COPD attributable to HAP in China dropped below the global level in 2015. In addition, COPD caused by APM was higher than COPD caused by HAP in Japan and Korea, while COPD caused by HAP was higher than COPD caused by APM in China and global.

Temporal trends in COPD disease burden attributable to particulate matter pollution in China, Japan, Korea, and global

The ASMR and age standardized DALY AAPC of COPD attributable to particulate matter pollution in China, Japan, South Korea, and global from 1990 to 2019 are shown in Tables 1 and 2. The JoinPoint model results showed that except for the global trend of increasing ASMR in COPD attributed to APM by gender (AAPC=0.473, P<0.05), all other ASMR showed a decreasing trend (P<0.05). Except for the age standardized DALY of COPD attributed to APM among global women, which is statistically insignificant, all others are significant and show a downward trend under the 0.05 test standard (P<0.05).

Table 1 Trends in ASMR of COPD attributable to PM2.5, 1990–2019

Risk	Sex	China		Japan		Republic of Korea		Global	
		AAPC	95%CI	AAPC	95%CI	AAPC	95%CI	AAPC	95%CI
PM2.5	both	-5.862*	(-6.058, -5.666)	-1.715*	(-1.978, -1.452)	-1.831*	(-2.118, -1.543)	-3.263*	(-3.448, -3.079)
	male	-5.199*	(-5.503, -4.894)	-1.733*	(-1.916, -1.549)	-1.629*	(-2.248, -1.007)	-3.218*	(-3.446, -2.990)
	female	-6.442*	(-6.734, -6.150)	-2.008*	(-2.210, -1.805)	-2.447*	(-2.663, -2.230)	-3.397*	(-3.524, -3.269)

	both	-9.518*	(-9.678, -9.358)	-8.432*	(-8.750, -8.113)	-13.912*	(-14.287, -13.537)	-5.551*	(-5.715, -5.387)
HAP	male	-9.296*	(-9.556, -9.035)	-8.379*	(-8.635, -8.123)	-13.557*	(-13.844, -13.268)	-5.727*	(-5.919, -5.535)
	female	-9.706*	(-9.880, -9.532)	-8.584*	(-8.880, -8.286)	-14.283*	(-14.635, -13.930)	-5.395*	(-5.555, -5.235)
	both	-2.563*	(-3.061, -2.063)	-1.669*	(-1.932, -1.404)	-1.735*	(-2.030, -1.438)	0.473*	(-0.620, -0.326)
APM	male	-2.196*	(-2.477, -1.914)	-1.696*	(-1.887, -1.505)	-1.555*	(-2.186, -0.921)	-0.607*	(-0.766, -0.449)
	female	-2.903*	(-3.340, -2.465)	-1.945*	(-2.149, -1.741)	-2.332*	(-2.560, -2.105)	-0.404*	(-0.601, -0.208)

*statistically significant (P < 0.05)

Table 2 Trends in Age-standardized DALY of COPD attributable to PM2.5, 1990–2019

Risk	Sex	China		Japan		Republic of Korea		Global	
		AAPC	95%CI	AAPC	95%CI	AAPC	95%CI	AAPC	95%CI
	both	-5.821*	(-6.051, -5.590)	-1.39*	(-1.490, -1.290)	-1.239*	(-1.595, -0.882)	-3.118*	(-3.267, -2.968)
PM2.5	male	-5.427*	（-5.695, -5.157）	-1.485*	(-1.594, -1.376)	-1.200*	(-1.691, -0.707)	-3.170*	(-3.315, -3.024)
	female	-6.120*	(-6.284, -5.956)	-1.457*	(-1.554, -1.360)	-1.734*	(-1.976, -1.491)	-3.110*	(-3.244, -2.976)
	both	-9.434*	(-9.646, -9.223)	-8.209*	(-8.335, -8.082)	-13.353*	(-13.626, -13.080)	-5.296*	(-5.413, -5.178)
HAP	male	-9.372*	(-9.540, -9.204)	-8.278*	(-8.393, -8.163)	-13.232*	(-13.551, -12.913)	-5.545*	(-5.685, -5.405)
	female	-9.467*	(-9.649, -9.286)	-8.203*	(-8.343, -8.062)	-13.637*	(-13.970, -13.303)	-5.052*	(-5.185, -4.920)
	both	-2.430*	(-2.828, -2.030)	-1.340*	(-1.438, -1.241)	-1.146*	(-1.504, -0.786)	-0.342*	(-0.457, -0.227)
APM	male	-2.406*	(-2.683, -2.128)	-1.442*	(-1.550, -1.335)	-1.126*	(-1.627, -0.622)	-0.561*	(-0.666, -0.456)
	female	-2.399*	(-2.702, -2.094)	-1.393*	(-1.491, -1.294)	-1.618*	(-1.862, -1.374)	-0.097	(-0.273, 0.079)

Age-Period-Cohort Analysis of COPD Mortality Attributable to PM2.5 in China, Japan, Korea, and Worldwide, 1990-2019

Waldχ 2 test results and bias coefficients for the APC model

The results of the Wald χ 2 test of the APC model showed that COPD mortality attributable to HAP in Japan and Korea did not meet the requirements of the APC model, and their local drift values, all cohort RR, all age deviations, all period deviations, and all cohort deviations were statistically insignificant, and the remaining age, period, and cohort effects of mortality and the remaining estimated parameters were statistically significant (P<0.05), as shown in Table 3. In the subsequent analysis, we will analyze and report detailed age-period-cohort effects for items tested significant by the Wald χ 2 test.

Table 3 APC analysis of COPD mortality attributable to PM2.5 from 1990 to 2019

Item	Wald χ2of ASMR											
	China			Japan			Korea			Global		
	PM2.5	HAP	APM	PM2.5	HAP	APM	PM2.5	HAP	APM	PM2.5	HAP	APM
Net drift=0	5292.73*	8368.81*	1794.23*	73.58*	5.34*	70.00*	340.30*	9.80*	325.92*	6449.76*	10637.70*	302.04*
All local drifts=Net drift	659.44*	436.37*	705.61*	52.09*	0.46	52.22*	235.32*	1.47	233.70*	469.18*	124.43*	332.17*
All period RR=1	5336.33*	8633.93*	2151.6*1	580.53*	12.39*	561.94*	461.67*	13.33*	449.83*	6472.05*	10800.65*	360.72*
All cohort RR=1	34393.88*	61059.97*	8567.39*	1627.03*	201.65	1532.71*	2095.55*	142.41	1978.60*	24919.32*	41972.37*	996.88*
All age deviations=0	1294.81*	1191.16*	1598.51*	1451.12*	7.76	1439.57*	271.56*	0.84	269.42*	11409.16*	9304.07*	8512.42*
All period deviations=0	61.53*	560.05*	265.12*	530.04*	6.88	514.28*	129.88*	2.41	130.46*	33.99*	255.48*	42.32*
All cohort deviations=0	660.09*	436.80*	710.82*	55.31*	0.47	55.44*	242.18*	1.5	240.54*	479.55*	141.15*	333.89*

Net Drift and Local Drift

Figure 2 shows the net drift and local drift values of COPD mortality attributable to PM2.5, HAP, and APM for the three countries and global. The net drift represents the annual percentage change in the expected overall age-adjusted rate. The net drift values of COPD mortality rates attributed to PM2.5 in China, Japan, South Korea, and global from 1990 to 2019 were -7.40% (95% CI: -7.59, -7.20), -2.02% (95% CI: -2.48, -1.56), -3.78% (95% CI: -4.17, -3.39), and -3.80% (95% CI: -3.89, -3.71), respectively. The net drift of COPD mortality attributable to HAP was -10.93% (95% CI: -11.16, -10.71) and -5.86% (95% CI: -5.97, -5.76) in China and global, respectively. The net drift of COPD mortality attributable to APM was -3.92% (95% CI: -4.10, -3.74), -1.98% (95% CI: -2.43, -1.52), -3.71% (95% CI: -4.11, -3.31), and -0.95% (95% CI: -1.06, -0.85) in China, Japan, Korea, and global, respectively. The local drift illustrates the expected age-specific rates for each age group. The local drift values of COPD mortality attributable to PM2.5 and APM in Korea showed an overall increasing trend with age and all showed positive values at the age group of 95 years or older. Global local drift values for COPD mortality attributable to APM generally increased with age and started to show positive values at the age group 90-95 years. In addition, the local drift values of COPD mortality rates attributed to PM2.5, HAP, and APM in the three countries and globally are generally increasing with age, but all are below zero.

Age Effect

After correcting for period effects and birth cohort effects, COPD mortality attributable to PM2.5 increased slowly with age in Korea and Japan. Global COPD mortality attributable to PM2.5 peaks in the 85-90 year age group and then declines. The increase in COPD mortality attributable to PM2.5 in China was large until the age group 90-95 years and decreased to 434.25/100,000 (95% CI: 404.66, 466.01) after the age group 90-95 years. Global COPD mortality attributable to HAP peaked in the 80-85 year age group and then declined sharply to 32.76/100,000 (95% CI: 30.71, 34.94). COPD mortality attributable to HAP in China peaked at 78.17 per 100,000 (95% CI: 75.54, 80.89) in the 85-90 year age group and then declined continuously. COPD mortality attributable to APM increased with age in China, Japan, Korea, and globally, with COPD mortality attributable to APM in China being much higher than Japan, Korea, and globally. See Figure S1 for details.

Period Effect

In addition to the age effect on disease mortality, we found that period was highly correlated with disease mortality. Using 2000-2004 as a control group, COPD mortality attributable to PM2.5 decreased significantly over time in China, Korea, and globally, whereas it increased slightly in Japan from 2015 to 2019. COPD mortality attributable to HAP in China and globally all decreased significantly over time. COPD mortality attributable to APM in China, Korea, and globally showed a decreasing trend over time, but in Japan, the mortality rate of COPD attributable to APM has shown a decreasing trend between 1990 and 2015, dropping to the minimum value of 0.85 (95% CI: 0.80, 0.89), and rising to 0.91 (95% CI: 0.84, 0.98) from 2015 to 2019. See Figure S2 for details.

Cohort Effect

We show in Figure S3 the birth cohort effects of COPD mortality attributable to PM2.5 (a), HAP (b), and APM (c) for each country. In China, Japan, and globally, COPD mortality attributable to PM2.5 was approximately lower the later the birth, and gradually decreased in Korea after a small increase to a peak of 2.26 (95% CI: 2.13, 2.40) in the 1900-1910 birth cohort. Late birth cohorts with COPD mortality attributable to HAP were lower than early birth cohorts in both China and globally. COPD mortality attributable to APM in China and Japan gradually decreased with increasing birth year. Global COPD mortality attributable to APM fluctuated slightly during the 1990-1915 birth cohort and then declined slowly. COPD mortality attributable to APM in Korea showed an increasing trend during the 1895-1910 birth cohort and decreased after peaking in 1910.

Discussion

This study provides an update on trends in the disease burden of COPD attributable to PM2.5, HAP, and APM in the three major Asian economies of China, Japan, and Korea, as well as globally. We found a decreasing trend in ASMR and age-standardized DALY for COPD attributable to PM2.5, HAP, and APM in all regions, except for a global all-sex trend in ASMR for COPD attributable to APM. COPD attributable to particulate matter pollution shows a decreasing trend in most regions and is inextricably linked to local environmental health policies. In 2013, the World Health Organization designated PM2.5 as a carcinogen and recommended that the population-weighted APM should be less than 10μg/m3. In high-income countries, various strategies have been implemented to reduce air pollution, including switching to cleaner fuels, improving emission control technologies, and enhancing public environmental education[35,36]. Since 2013, China has implemented systematic regulations that have resulted in a 33.3% decrease in annual average PM2.5 concentrations from 2013 to 2017[37]. In contrast, the global all-sex ASMR for COPD attributable to APM is on the rise, which may be due to the increase in particulate matter pollution in countries with low socioeconomic development[26].

The results showed large regional differences in ASMR and age-standardized DALY for COPD attributable to PM2.5, HAP, and APM. The burden of COPD disease attributable to particulate matter pollution in China is much higher than the levels in Japan and Korea, and there is a gap with global levels. This difference may be related to socioeconomic development[26], where China is a developing country with further economic construction to be advanced, while Japan and South Korea are developed countries with economic development levels ahead of the world average. Low- and middle-income countries generate large amounts of pollution from large-scale energy consumption and electricity generation during industrialization[31], and more residents in these countries rely on traditional energy sources for household cooking and heating, resulting in much higher levels of particulate matter pollution exposure than in high-income countries[38]. In addition, the lack of quality public health care in low- and middle-income countries may amplify the burden of COPD attributable to PM2.5 due to economic deprivation and relatively poor population health awareness[39]. Further, countries with higher levels of development may have more stringent air quality controls[40].

Interestingly, we focused on the difference in COPD risk due to HAP and APM, with COPD due to APM being higher than COPD due to HAP in Japan and Korea, and conversely, COPD due to HAP being higher than COPD due to APM in China and globally. The reason for this opposite result may be that residents of economically developed areas use less solid fuels. It has been noted that biomass fuel exposure is a major risk factor for COPD in poor and developing countries[41]. In resource-limited environments, readily available solid fuels such as wood, charcoal, dried branches, crop residues and animal dung cakes are used as cooking fuels in less developed countries, covering more than 200 chemical and compound groups, 90% of which are in the respirable size range[42]. Exposure to biomass fuel smoke increased the odds of developing COPD by 2.3 times compared to no exposure to biomass smoke[41]. Thus, there is no doubt that biomass fuel exposure is an important risk factor for chronic lung disease in developing country populations and a potential causative agent of respiratory disease. In conclusion, policy actions in China and developing countries around the world to reduce the burden of COPD caused by PM2.5 should focus on HAP emission concentrations, while economically developed countries should pay more attention to APM control.

We analyzed the effect of age on COPD attributed to PM2.5 and showed that COPD mortality attributed to APM increased with age in China, Japan, Korea, and globally. COPD mortality attributable to HAP declined sharply after peaking in the 80-85 year age group globally and declining after peaking in the 85-90 year age group in China. Similar to our findings, several studies have shown that the burden of COPD caused by APM is heavier in the elderly population[43 44]. This may be due to the weaker immune and lung function, high likelihood of chronic diseases, higher sensitivity to chemicals, and greater susceptibility to air pollution in the elderly compared to the young[45]. Therefore, there is a need for all countries to take measures to address the health care issues arising from population aging. In addition, the decrease in COPD mortality rates attributed to HAP in the global and China during the advanced age stage may be due to the large base of early life exposure to HAP among residents in the region, and the inconvenience of movement and sudden decrease in HAP exposure after being too old, ultimately leading to a sharp decline in COPD mortality rates attributed to HAP in the advanced age group.

COPD mortality attributable to HAP decreased significantly over time in China and globally. COPD mortality attributable to APMs in China, Korea, and globally showed a decreasing trend over time, but Japan's showed a decreasing trend from 1990-2015 and a small increase from 2015-2019. Temporal effects are usually influenced by a complex set of environmental factors and historical events[46]. The Chinese government attaches great importance to the air pollution problem and has reduced PM2.5 exposure through measures such as improving stove programs and planning waste emission standards for factories[26 47]. In addition, advanced drug therapy and other interventions in China have controlled the risk factors for COPD and well prevented further COPD progression[26]. In the last decade or so, Korea has introduced laws and regulations such as the Emission Reduction Plan and Special Measures for Air Quality to address particulate matter pollution[48], and guaranteed effective treatment for COPD patients through the universal health insurance system, thereby reducing the severity of the disease and mortality[49]. Japan has seen a small increase in COPD mortality attributable to APM in recent years, which we speculate may be due to increased air pollution and increased patient mortality due to the growth in the number of cars[50]. Therefore, all governments need to continue to jointly adopt multiple regulations and measures to manage air pollution and clinical treatment techniques to promote primary and secondary prevention of COPD disease.

Late birth cohorts with COPD mortality attributable to HAP are lower than early birth cohorts in both China and globally. COPD mortality attributable to APM in China, Japan, and globally decreased gradually with increasing year of birth overall. COPD mortality attributable to APM in Korea showed an increasing trend during the birth cohort of 1895-1910 and decreased after peaking in 1910. We hypothesize that the decrease in COPD mortality attributable to particulate matter pollution in recent years is related to people's lifestyle, change in thinking, external environment, and risk factor exposure. Younger generations receive more comprehensive health education about the effects of unhealthy lifestyle and dietary habits on lung function and are thus better equipped to avoid COPD mortality-related risk factors[51 52]. In addition, economic development and environmental improvements are important reasons for the reduced risk of COPD mortality attributable to particulate matter pollution in young people[51].

There are also some limitations in this study. First, this study used GBD2019 for data analysis, and GBD2019 collected missing data by modifying and adjusting data sources and collection assessment methods, which could not eliminate data bias and affected the accuracy of the results. Second, the APC model only considered the effects of age, period and cohort without further analysis of other risk factors.

Abbreviations

PM2.5: particulate matter pollution; COPD: chronic obstructive pulmonary disease; ASMR: age-standardized mortality rate; APM: ambient particulate matter pollution; AAPC: average annual percent change; HAP: household air pollution from solid fuels; ROS: reactive oxygen species; APC model: age-period-cohort model; GBD2019: the latest Global Burden of Disease Database; GOLD: Global Initiative for Chronic Obstructive Lung Disease

Supplementary information

Additional file 1: Table S1. the disease burden for COPD attributable to PM2.5 in China, Japan, Korea, and global from 1990-2019.

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Declarations

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Ethics approval and consent to participate

All methods are carried out in accordance with the relevant guidelines and regulations (Declaration of Helsinki).

Consent for publication

Not applicable.

Availability of data and materials

Resources on the disease burden of COPD attributable to particulate matter pollution in each country, as well as national population data, are available from https://vizhub.healthdata.org/gbd-results/

Competing interests

The authors declare no conflict of interest.

Author contributions

BL and XFC conceptualized the paper. XFC did the statistical analysis and drafted the manuscript. SHM and RQG conducted the research and data collection. BL and YLZ reviewed and edited the writing. BL and JDZ re-reviewed and co-revised the manuscript from the English language perspective. All authors made significant intellectual contributions to multiple revisions of the draft. All authors have read and agreed to the published version of the manuscript.

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References

1. Lelieveld J, Evans JS, Fnais M, et al. The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature* 2015;525(7569):367-71. doi: 10.1038/nature15371

2. Landrigan PJ, Fuller R, Acosta NJR, et al. The Lancet Commission on pollution

and health. *The Lancet* 2018;391(10119):462-512. doi: 10.1016/S0140-6736(17)32345-0

3. Sang S, Chu C, Zhang T, et al. The global burden of disease attributable to ambient fine particulate matter in 204 countries and territories, 1990–2019: A systematic analysis of the Global Burden of Disease Study 2019. *Ecotoxicology and Environmental Safety* 2022;238:113588. doi: https://doi.org/10.1016/j.ecoenv.2022.113588

4. Pandey A, Brauer M, Cropper ML, et al. Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019. *The Lancet Planetary Health* 2021;5(1):e25-e38. doi: https://doi.org/10.1016/S2542-5196(20)30298-9

5. Hamanaka RB, Mutlu GM. Particulate Matter Air Pollution: Effects on the Cardiovascular System. 2018;9 doi: 10.3389/fendo.2018.00680

6. Lim C-H, Ryu J, Choi Y, et al. Understanding global PM2.5 concentrations and their drivers in recent decades (1998–2016). *Environment International* 2020;144:106011. doi: https://doi.org/10.1016/j.envint.2020.106011

7. Zhao S, Wang H, Chen H, et al. Global magnitude and long-term trend of ischemic heart disease burden attributed to household air pollution from solid fuels in 204 countries and territories, 1990–2019. *Indoor Air* 2022;32(2):e12981. doi: https://doi.org/10.1111/ina.12981

8. Yin P, Brauer M, Cohen AJ, et al. The effect of air pollution on deaths, disease burden, and life expectancy across China and its provinces, 1990–2017: an analysis for the Global Burden of Disease Study 2017. *The Lancet Planetary Health* 2020;4(9):e386-e98. doi: 10.1016/S2542-5196(20)30161-3

9. Bowe B, Xie Y, Yan Y, et al. Burden of Cause-Specific Mortality Associated With PM2.5 Air Pollution in the United States. *JAMA Network Open* 2019;2(11):e1915834-e34. doi: 10.1001/jamanetworkopen.2019.15834

10. Hayes RB, Lim C, Zhang Y, et al. PM2.5 air pollution and cause-specific cardiovascular disease mortality. *International Journal of Epidemiology* 2020;49(1):25-35. doi: 10.1093/ije/dyz114

11. Fenech S, Doherty RM, Heaviside C, et al. Meteorological drivers and mortality associated with O3 and PM2.5 air pollution episodes in the UK in 2006. *Atmospheric Environment* 2019;213:699-710. doi: https://doi.org/10.1016/j.atmosenv.2019.06.030

12. Burnett Richard T, Pope CA, Ezzati M, et al. An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure. *Environmental Health Perspectives* 2014;122(4):397-403. doi: 10.1289/ehp.1307049

13. Zhu R-X, Nie X-H, Chen Y-H, et al. Relationship Between Particulate Matter (PM2.5) and Hospitalizations and Mortality of Chronic Obstructive Pulmonary Disease Patients: A Meta-Analysis. *The American Journal of the Medical Sciences* 2020;359(6):354-64. doi: https://doi.org/10.1016/j.amjms.2020.03.016

14. Li N, Yang Z, Liao B, et al. Chronic exposure to ambient particulate matter induces gut microbial dysbiosis in a rat COPD model. *Respiratory Research* 2020;21(1):271. doi: 10.1186/s12931-020-01529-3

15. Collaborators GBDCRD. Global, regional, and national deaths, prevalence, disability-adjusted life years, and years lived with disability for chronic obstructive pulmonary disease and asthma, 1990-2015: a systematic analysis for the Global Burden of

Disease Study 2015. *The Lancet Respiratory medicine* 2017;5(9):691-706. doi: 10.1016/S2213-2600(17)30293-X [published Online First: 2017/08/22]

16. Liu X, Zhao X, Li X, et al. PM2.5 triggered apoptosis in lung epithelial cells through the mitochondrial apoptotic way mediated by a ROS-DRP1-mitochondrial fission axis. *Journal of Hazardous Materials* 2020;397:122608. doi: https://doi.org/10.1016/j.jhazmat.2020.122608

17. Chi M-C, Guo S-E, Hwang S-L, et al. Exposure to Indoor Particulate Matter Worsens the Symptoms and Acute Exacerbations in Chronic Obstructive Pulmonary Disease Patients of Southwestern Taiwan: A Pilot Study. *International Journal of Environmental Research and Public Health* 2017; 14(1).

18. Wang J, Zhu M, Wang L, et al. Amphiregulin potentiates airway inflammation and mucus hypersecretion induced by urban particulate matter via the EGFR-PI3Kα-AKT/ERK pathway. *Cellular Signalling* 2019;53:122-31. doi: https://doi.org/10.1016/j.cellsig.2018.10.002

19. Zhao J, Li M, Wang Z, et al. Role of PM2.5 in the development and progression of COPD and its mechanisms. *Respiratory Research* 2019;20(1):120. doi: 10.1186/s12931-019-1081-3

20. Feizi H, Alizadeh M, Nejadghaderi SA, et al. The burden of chronic obstructive pulmonary disease and its attributable risk factors in the Middle East and North Africa region, 1990–2019. *Respiratory Research* 2022;23(1):319. doi: 10.1186/s12931-022-02242-z

21. Zafari Z, Li S, Eakin MN, et al. Projecting Long-term Health and Economic Burden of COPD in the United States. *Chest* 2021;159(4):1400-10. doi:

457 https://doi.org/10.1016/j.chest.2020.09.255

458 22. Safiri S, Carson-Chahhoud K, Noori M, et al. Burden of chronic obstructive pulmonary
459 disease and its attributable risk factors in 204 countries and territories, 1990-2019:
460 results from the Global Burden of Disease Study 2019. *BMJ* 2022;378:e069679. doi:
461 10.1136/bmj-2021-069679

462 23. Hu W, Fang L, Zhang H, et al. Changing trends in the air pollution–related disease burden
463 from 1990 to 2019 and its predicted level in 25 years. *Environmental Science and*
464 *Pollution Research* 2023;30(1):1761-73. doi: 10.1007/s11356-022-22318-z

465 24. Du J, Yang J, Wang L, et al. A comparative study of the disease burden attributable to
466 PM2.5 in China, Japan and South Korea from 1990 to 2017. *Ecotoxicology and*
467 *Environmental Safety* 2021;209:111856. doi:
468 https://doi.org/10.1016/j.ecoenv.2020.111856

469 25. Wu X, Zhu B, Zhou J, et al. The epidemiological trends in the burden of lung cancer
470 attributable to PM2.5 exposure in China. *BMC Public Health* 2021;21(1):737. doi:
471 10.1186/s12889-021-10765-1

472 26. Wu Y, Zhang S, Zhuo B, et al. Global burden of chronic obstructive pulmonary disease
473 attributable to ambient particulate matter pollution and household air pollution from
474 solid fuels from 1990 to 2019. *Environmental Science and Pollution Research*
475 2022;29(22):32788-99. doi: 10.1007/s11356-021-17732-8

476 27. Wilkinson K, Righolt CH, Elliott LJ, et al. The impact of pertussis vaccine programme
477 changes on pertussis disease burden in Manitoba, 1992–2017—an age-period-cohort
478 analysis. *International Journal of Epidemiology* 2022;51(2):440-47. doi:

10.1093/ije/dyac001

28. He J, Ouyang F, Li L, et al. Incidence trends of major depressive disorder in China: an age-period-cohort modeling study. *Journal of Affective Disorders* 2021;288:10-16. doi: https://doi.org/10.1016/j.jad.2021.03.075

29. Li Y, Ren N, Zhang B, et al. Gastric cancer incidence trends in China and Japan from 1990 to 2019: Disentangling age–period–cohort patterns. *Cancer* 2023;129(1):98-106. doi: https://doi.org/10.1002/cncr.34511

30. 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. *The Lancet* 2020;396(10258):1160-203. doi: https://doi.org/10.1016/S0140-6736(20)30977-6

31. 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. 2020;396(10258):1204-22.

32. 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. *The Lancet* 2020;396(10258):1204-22. doi: https://doi.org/10.1016/S0140-6736(20)30925-9

33. Balakrishnan K, Dey S, Gupta T, et al. The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: the Global Burden of Disease Study 2017. *The Lancet Planetary Health* 2019;3(1):e26-e39. doi:

https://doi.org/10.1016/S2542-5196(18)30261-4

34. Liu X, Yu C, Bi Y, et al. Trends and age-period-cohort effect on incidence and mortality of prostate cancer from 1990 to 2017 in China. *Public Health* 2019;172:70-80. doi: https://doi.org/10.1016/j.puhe.2019.04.016

35. Beggs PJ, Zhang Y, Bambrick H, et al. The 2019 report of the MJA–Lancet Countdown on health and climate change: a turbulent year with mixed progress. *Medical Journal of Australia* 2019;211(11):490-91.e21. doi: https://doi.org/10.5694/mja2.50405

36. DuPont A. Improving and monitoring air quality. *Environmental Science and Pollution Research* 2018;25(15):15253-63. doi: 10.1007/s11356-018-1897-2

37. Huang J, Pan X, Guo X, et al. Health impact of China's Air Pollution Prevention and Control Action Plan: an analysis of national air quality monitoring and mortality data. *The Lancet Planetary Health* 2018;2(7):e313-e23. doi: https://doi.org/10.1016/S2542-5196(18)30141-4

38. Gordon SB, Bruce NG, Grigg J, et al. Respiratory risks from household air pollution in low and middle income countries. *The Lancet Respiratory Medicine* 2014;2(10):823-60. doi: 10.1016/S2213-2600(14)70168-7

39. Bazargani YT, Boer Ad, Leufkens HGM, et al. Essential medicines for COPD and asthma in low and middle-income countries. 2014;69(12):1149-51. doi: 10.1136/thoraxjnl-2014-205249 %J Thorax

40. Burns J, Boogaard H, Polus S, et al. Interventions to reduce ambient air pollution and their effects on health: An abridged Cochrane systematic review. *Environment International* 2020;135:105400. doi: https://doi.org/10.1016/j.envint.2019.105400

41. Tan WC. Trends in chronic obstructive pulmonary disease in the Asia-Pacific regions. *Current Opinion in Pulmonary Medicine* 2011;17(2)

42. Salvi S, Barnes PJ. Is Exposure to Biomass Smoke the Biggest Risk Factor for COPD Globally? *Chest* 2010;138(1):3-6. doi: https://doi.org/10.1378/chest.10-0645

43. Yang X, Zhang T, Zhang Y, et al. Global burden of COPD attributable to ambient PM2.5 in 204 countries and territories, 1990 to 2019: A systematic analysis for the Global Burden of Disease Study 2019. *Science of The Total Environment* 2021;796:148819. doi: https://doi.org/10.1016/j.scitotenv.2021.148819

44. Bell ML, Zanobetti A, Dominici F. Evidence on Vulnerability and Susceptibility to Health Risks Associated With Short-Term Exposure to Particulate Matter: A Systematic Review and Meta-Analysis. *American Journal of Epidemiology* 2013;178(6):865-76. doi: 10.1093/aje/kwt090

45. Fougère B, Vellas B, Billet S, et al. Air Pollution modifies the association between successful and pathological aging throughout the frailty condition. *Ageing Research Reviews* 2015;24:299-303. doi: https://doi.org/10.1016/j.arr.2015.09.004

46. Su X, Li H, Li F, et al. Trends in the Burden of COPD Attributable to Ambient PM2.5 Exposure in China 1990 – 2019: An Age-Period-Cohort Analysis. *Risk Management and Healthcare Policy* 2023;16:69-77. doi: 10.2147/RMHP.S395278

47. Wang S, Hao J. Air quality management in China: Issues, challenges, and options. *Journal of Environmental Sciences* 2012;24(1):2-13. doi: https://doi.org/10.1016/S1001-0742(11)60724-9

48. Han C, Kim S, Lim Y-H, et al. Spatial and Temporal Trends of Number of Deaths Attributable

to Ambient PM2.5 in the Korea. *J Korean Med Sci* 2018;33(30)

49. Lee EG, Rhee CKJJoTD. Epidemiology, burden, and policy of chronic obstructive pulmonary disease in South Korea: a narrative review. *2021* 2021;13(6):3888-97.

50. Okazaki Y, Ito L, Tokai A. Characterizing potential risk triggered by road traffic noise in comparison with typical air pollutants NO2 and PM2.5. *Environment Systems and Decisions* 2021;41(1):147-62. doi: 10.1007/s10669-021-09800-8

51. Guo Y, Bai J, Zhang X, et al. Secular Trends of Mortality and Years of Life Lost Due to Chronic Obstructive Pulmonary Disease in Wuhan, China from 2010 to 2019: Age-Period-Cohort Analysis. *International Journal of Environmental Research and Public Health* 2022; 19(17).

52. Liu X, Zhou M, Yu C, et al. Age-Period-Cohort Analysis of Type 2 Diabetes Mortality Attributable to Particulate Matter Pollution in China and the U.S. *Journal of Diabetes Research* 2020;2020:1243947. doi: 10.1155/2020/1243947

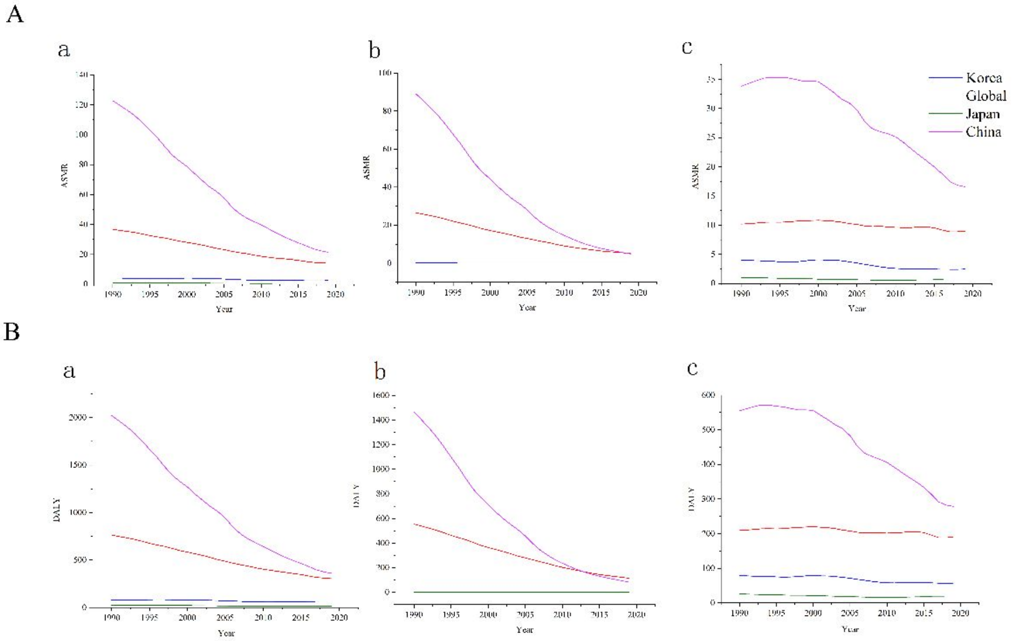

Figure 1 A. ASMR of COPD attributable to PM2.5 (a), HAP (b), and APM (c) in China, Japan, Korea, and global, 1990-2019; B. Age-standardized DALY of COPD attributable to PM2.5 (a), HAP (b), and APM (c) in China, Japan, Korea, and global, 1990-2019.

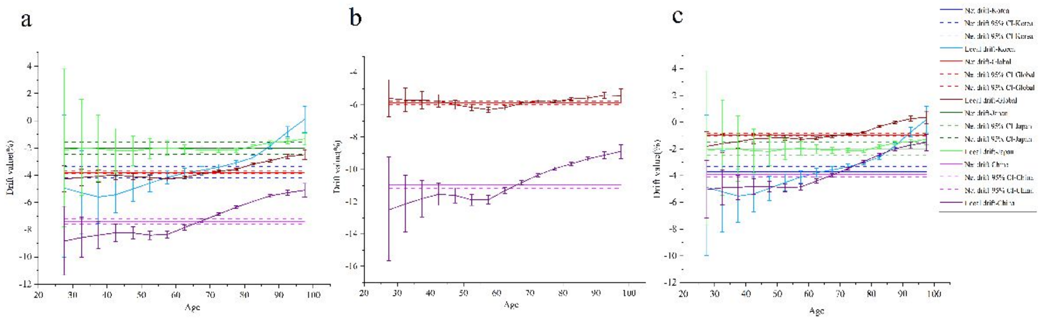

Figure 2 Net and local drift values of COPD mortality attributable to PM2.5 (a), HAP (b), and APM (c) in China, Japan, Korea, and globally, 1990-2019

Table S1 the disease burden for COPD attributable to PM2.5 in China, Japan, Korea, and global from 1990-2019

Year	ASMR												Age-standardized DALY											
	PM2.5				HAP				APM				PM2.5				HAP				APM			
	Korea	Global	Japan	China	Korea	Global	Japan	China	Korea	Global	Japan	China	Korea	Global	Japan	China	Korea	Global	Japan	China	Korea	Global	Japan	China
1990	4.16	36.70	1.04	122.84	0.13	26.51	0.02	89.03	4.03	10.19	1.02	33.82	80.74	763.13	25.89	2022.32	[illegible]	553.84	0.46	1467.51	78.37	209.29	25.44	554.81
1991	4.08	36.02	1.02	119.63	0.11	25.76	0.02	85.33	3.98	10.27	1.00	34.31	80.06	748.60	25.42	1963.96	[illegible]	538.24	0.41	1403.00	78.07	210.63	25.01	561.13
1992	4.00	35.35	1.00	116.35	0.09	25.00	0.02	81.58	3.92	10.37	0.98	34.80	78.69	733.77	24.98	1903.78	[illegible]	522.11	0.37	1337.04	77.06	212.12	24.61	567.14
1993	3.96	34.65	0.97	112.70	0.07	24.18	0.01	77.51	3.89	10.49	0.96	35.22	78.18	718.21	24.49	1837.13	[illegible]	504.65	0.33	1265.85	76.84	214.08	24.16	571.83
1994	3.91	33.67	0.93	108.15	0.06	23.16	0.01	72.84	3.85	10.52	0.92	35.34	77.99	698.95	23.81	1756.02	[illegible]	484.76	0.29	1185.04	76.88	214.57	23.52	571.42
1995	3.75	32.55	0.91	103.04	0.05	22.06	0.01	67.77	3.70	10.50	0.90	35.27	76.03	676.35	23.38	1666.39	[illegible]	462.51	0.26	1098.30	75.13	213.85	23.11	568.09
1996	3.68	31.71	0.86	98.12	0.04	21.14	0.01	62.85	3.64	10.56	0.85	35.27	75.25	658.77	22.67	1581.11	0.76	443.86	0.23	1014.79	74.48	214.66	22.44	566.22
1997	3.74	30.96	0.83	92.21	0.03	20.28	0.01	57.23	3.70	10.67	0.82	35.01	75.63	643.64	22.24	1483.46	[illegible]	426.73	0.21	922.64	74.98	216.77	22.03	561.27
1998	3.86	29.93	0.82	86.55	0.03	19.20	0.01	51.90	3.83	10.74	0.81	34.71	76.85	622.85	22.10	1394.04	[illegible]	404.81	0.19	837.69	76.29	218.13	21.91	557.35
1999	4.04	28.84	0.81	82.47	0.03	18.06	0.01	47.80	4.01	10.79	0.80	34.73	78.53	600.44	21.94	1327.49	[illegible]	381.50	0.17	771.03	78.05	219.15	21.76	557.46
2000	4.11	28.05	0.77	78.80	0.02	17.21	0.01	44.20	4.09	10.84	0.76	34.60	79.28	584.24	21.35	1269.03	[illegible]	364.08	0.16	713.21	78.86	220.16	21.19	555.82
2001	4.06	27.19	0.74	74.20	0.02	16.41	0.01	40.43	4.04	10.76	0.73	33.72	78.45	566.46	20.71	1195.57	[illegible]	347.67	0.14	653.00	78.09	218.60	20.57	541.82
2002	4.05	26.31	0.71	69.73	0.02	15.63	0.00	36.97	4.03	10.68	0.70	32.74	77.98	549.23	19.99	1130.14	[illegible]	331.96	0.12	600.92	77.67	217.23	19.87	528.90
2003	3.91	25.23	0.69	65.37	0.01	14.73	0.00	33.78	3.90	10.51	0.68	31.62	76.35	528.92	19.35	1066.54	[illegible]	314.57	0.11	552.79	76.09	214.55	19.24	514.17
2004	3.73	24.01	0.67	62.05	0.01	13.74	0.00	31.14	3.72	10.28	0.66	30.96	74.15	504.68	18.65	1011.92	[illegible]	294.57	0.10	509.50	73.93	210.39	18.55	503.17
2005	3.52	23.16	0.65	57.79	0.01	13.02	0.00	28.03	3.51	10.13	0.65	29.76	71.38	487.61	18.16	940.55	[illegible]	279.96	0.09	457.80	71.21	207.66	18.07	482.75
2006	3.29	22.11	0.63	52.00	0.01	12.23	0.00	24.20	3.28	9.88	0.63	27.76	68.19	468.19	17.48	848.84	[illegible]	264.18	0.08	396.40	68.05	203.79	17.40	451.87
2007	3.08	21.19	0.61	47.52	0.01	11.42	0.00	20.97	3.08	9.77	0.61	26.54	65.17	450.63	16.84	775.99	[illegible]	248.25	0.07	343.57	65.05	202.32	16.76	432.29
2008	2.88	20.55	0.59	44.48	0.01	10.75	0.00	18.47	2.87	9.82	0.59	26.04	62.21	437.22	16.25	723.88	[illegible]	234.12	0.07	301.67	62.10	203.29	16.18	422.72
2009	2.70	19.54	0.57	42.01	0.00	9.84	0.00	16.37	2.69	9.71	0.57	25.68	59.70	418.59	15.76	680.25	0.10	216.81	0.06	265.92	59.61	202.07	15.70	415.07
2010	2.59	18.72	0.57	39.75	0.00	9.10	0.00	14.58	2.58	9.62	0.57	25.16	58.17	404.36	15.57	641.98	0.09	202.85	0.06	236.29	58.08	201.50	15.51	405.68
2011	2.53	18.08	0.58	37.13	0.00	8.49	0.00	12.88	2.53	9.58	0.58	24.22	57.76	392.76	15.80	601.56	0.08	190.50	0.06	209.32	57.68	202.10	15.75	391.64
2012	2.54	17.47	0.60	34.35	0.00	7.90	0.00	11.24	2.54	9.58	0.60	23.10	58.66	381.08	16.31	561.56	0.07	177.78	0.05	184.46	58.59	203.51	16.26	376.85
2013	2.50	17.09	0.62	31.92	0.00	7.42	0.00	9.88	2.50	9.70	0.62	22.05	59.21	369.91	16.97	525.67	0.06	165.41	0.05	163.41	59.15	205.12	16.92	362.60

2014	2.48	16.63	0.64	29.77	0.00	6.93	0.00	8.75	2.48	9.73	0.64	21.05	59.70	358.28	17.50	494.03	0.05	153.69	0.05	145.73	59.64	205.27	17.45	348.88
2015	2.47	15.99	0.65	27.73	0.00	6.45	0.00	7.74	2.47	9.54	0.65	20.00	59.48	347.58	17.68	464.03	0.05	144.42	0.05	129.98	59.42	203.16	17.63	334.05
2016	2.42	15.27	0.65	25.87	0.00	6.08	0.00	6.99	2.42	9.19	0.65	18.84	57.94	332.41	17.59	431.92	0.05	136.37	0.05	117.36	57.89	195.89	17.55	313.98
2017	2.42	14.64	0.64	23.76	0.00	5.77	0.00	6.26	2.42	8.88	0.64	17.50	57.12	317.79	17.37	397.25	0.04	128.96	0.04	105.22	57.08	188.84	17.32	292.04
2018	2.41	14.34	0.64	22.39	0.00	5.46	0.00	5.55	2.41	8.88	0.64	16.86	56.74	310.64	17.22	375.91	0.04	121.98	0.04	93.77	56.70	188.53	17.18	282.58
2019	2.46	14.02	0.64	21.46	0.00	5.07	0.00	4.87	2.46	8.95	0.64	16.59	57.03	305.02	17.14	361.07	0.04	114.22	0.04	82.45	56.99	190.79	17.10	278.62

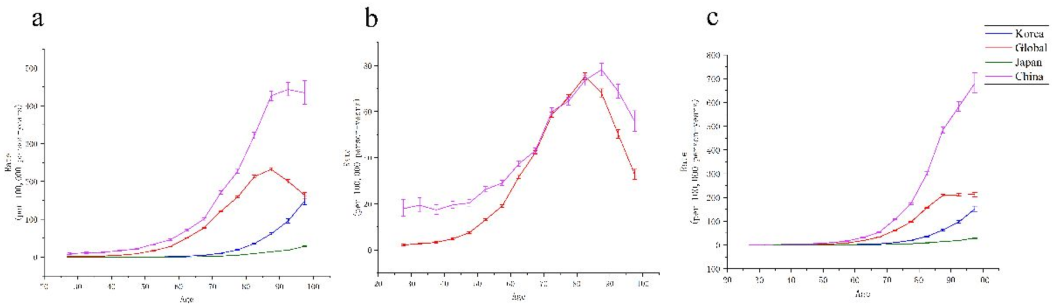

Figure S1 Age effects of COPD mortality attributable to PM2.5 (a), HAP (b), and APM (c) in China, Japan, Korea, and globally, 1990-2019

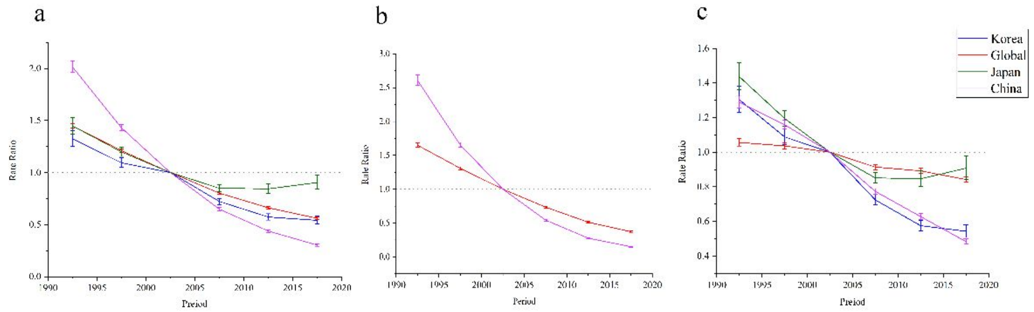

Figure S2 Period effects of COPD mortality attributable to PM2.5 (a), HAP (b), and APM (c) in China, Japan, Korea, and globally, 1990-2019

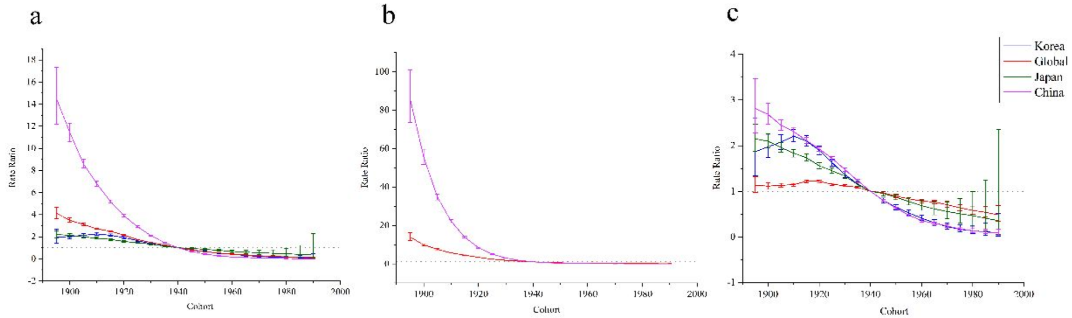

Figure S3 Cohort effects of COPD mortality attributable to PM2.5 (a), HAP (b), and APM (c) in China, Japan, Korea, and globally, 1990-2019

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Disease burden of COPD attributable to PM2.5 in China, Japan, and South Korea from 1990 to 2019: a comparative study based on Global Burden of Disease Study 2019

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Disease burden of COPD attributable to $PM_{2.5}$ in China, Japan, and South Korea from 1990 to 2019: a comparative study based on Global Burden of Disease Study 2019

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Abstract

Objective We hope to reveal the changing trends of chronic obstructive pulmonary disease (COPD) burden attributable to particulate matter pollution ($PM_{2.5}$) and its age, period, and cohort effects in China, Japan and Korea.

Design We analyzed the trend of COPD disease burden attributable to $PM_{2.5}$ from 1990-2019 based on the latest Global Burden of Disease Database (GBD 2019) using JoinPoint model and analyzed the effect of age, period and cohort on COPD burden attributable to $PM_{2.5}$ in China, Japan and Korea from 1990-2019 using age-period-cohort model (APC model).

Setting GBD data from 1990 to 2019.

Participants Data were publicly available and individuals were not involved.

Main outcomes Outcomes included the age standardized mortality rate (ASMR), the age-standardized DALY, average annual percent change (AAPC), net drift, local drift, longitudinal age curves, period (cohort) rate ratios, age (period, cohort) bias coefficient.

Results From 1990 to 2019, the age standardized mortality rate (ASMR) of COPD attributable to $PM_{2.5}$ in China (AAPC=-5.862), Japan (AAPC=-1.715), and Korea (AAPC=-1.831) showed a downward trend. The age-standardized DALY of COPD attributable to $PM_{2.5}$ in China (AAPC=-5.821), Japan (AAPC=-1.39), and Korea (AAPC=-1.239) showed a downward trend. Mortality of COPD attributable to $PM_{2.5}$ increased slowly with age in Korea and Japan. Mortality of COPD attributable to $PM_{2.5}$ in China decreased after rising (95% CI: 404.66, 466.01). Mortality of COPD attributable to $PM_{2.5}$ decreased over time in China and Korea, while it increased in Japan from 2015 to 2019. In China and Japan, mortality of COPD attributable to $PM_{2.5}$ was approximately lower the later the birth, while in Korea it decreased after an increase (95% CI: 2.13, 2.40) in the 1900-1910.

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Conclusions Most COPD burden attributable to $PM_{2.5}$ is on the decline; COPD mortality attributable to $PM_{2.5}$ both increased with age and decreased with time and cohort. Countries with high burden should develop targeted measures to control $PM_{2.5}$.

Keywords: $PM_{2.5}$, COPD, JoinPoint regression model, age-period-cohort analysis, burden of disease

Strengths and limitations of this study

1.This study comprehensively described and compared the mortality rate and DALY of COPD attributed to particulate matter pollution in China, Japan, and South Korea.

2.This study evaluated the long-term trend changes of COPD attributed to particulate matter pollution in the three countries.

3.This study analyzed the age effect, period effect, and cohort effect of COPD attributed to particulate matter pollution in the three countries.

4.One of limitations was GBD 2019 collected missing data by modifying and adjusting data sources and collection assessment methods, which could not eliminate data bias and affected the accuracy of the results.

5.Another limitation was this study used GBD 2019 data, and the $PM_{2.5}$ exposure classification was limited by the data, which only included ambient particulate matter and household air pollution.

6.The third limitation was the APC model only considered the effects of age, period and cohort without further analysis of other risk factors.

Background

Air pollution is the largest environmental cause of increased non-accidental mortality and morbidity, and a significant global health threat[1, 2]. In fact, according to the State of Global Air 2020, a staggering 6.67 million people worldwide are predicted to die from air pollution in 2019, underscoring the gravity of this global health threat[3]. Air pollution is usually quantified according to particulate pollution and ozone[4], where particulate pollution is a crucial factor in air pollution, as clinical studies have demonstrated that particulate pollution has a greater impact on health than gaseous components[5]. $PM_{2.5}$ is defined as particles with a diameter of 2.5 microns or smaller, and it can be divided into ambient particulate matter pollution (APM) and household air pollution from solid fuels (HAP). In 2019, the disease burden due to APM is the seventh highest for all ages, with average concentrations exceeding the World Health Organization (WHO) air quality guidelines of 10μg/m3 and affecting over 90% of the world's population[3]. The situation is further compounded by increasingly alarming exposure to APM in a majority of developing countries in recent years[6]. HAP mainly refers to $PM_{2.5}$ exposure from home heating or cooking through polluting fuels such as wood, coal, kerosene, etc. Despite the downward trend in overall HAP exposure, nearly 3 billion people worldwide still rely on polluting fuels for daily household living in 2019[7], and 32% of Chinese still use solid fuels for cooking or heating[8]. Cohort studies conducted worldwide consistently highlight a clear correlation between exposure to $PM_{2.5}$ and mortality and disease incidence[9-11], while particulate pollution conclusively causes acute lower respiratory disease, cerebrovascular disease, ischemic heart disease, COPD, and lung cancer[12].

Over the past few decades, epidemiological studies and meta-analyses have established that both short-term and long-term exposure to particulate matter pollution are associated with COPD[13-15]. Particulate pollution is a top three risk factor for COPD-related death and disability[16]. Respirable particulate matter in the environment leads to an increase in reactive oxygen species (ROS). Excess ROS affects mitochondria, resulting in severe mitochondrial dysfunction. This, in turn, activates processes such as autophagy, mitophagy and apoptosis[17], which can induce airway inflammation, airway wall remodeling, emphysematous lesions, lung function impairment and mucus hypersecretion[18-20]. In addition, it's not just a matter of public health, as COPD also carries an economic cost[21]. The direct medical costs of COPD alone in the United States are projected to skyrocket to an alarming $800.9 billion over the next two decades[22]. Overall, COPD is a formidable health problem that warrants increased attention and concerted effort in both developed and developing countries.

It's worth noting that East Asia, for instance, has the highest number of COPD cases, deaths, and DALYs on the global stage[23]. In East Asia, China, Japan, and South Korea belong to its three largest economies, with economies exceeding one-fifth of the world's total. These three countries have similar cultural backgrounds but are at different stages of socioeconomic development, with Japan and South Korea are ahead of China in terms of urbanization and industrialization. In 2019, China ranked first in air pollution-related deaths and second in air pollution-related DALYs[24], which shows that air pollution in China leads to a very serious disease burden, and similarly, South Korea faces a more serious air pollution problems, while Japan has a relatively better pollution situation[25]. Analyzing and comparing the disease burden of COPD due to particulate matter in the three countries will help in tracking the effectiveness of national prevention and control programs. It will also help in preventing the disease burden of COPD due to air pollution and developing targeted strategies for managing particulate matter pollution and COPD prevention.

However, previous studies have mainly focused on analyzing the effect of $PM_{2.5}$ on COPD and its potential mechanisms in a particular country or global[26, 27], and few studies have analyzed the disease burden of COPD due to APM and HAP in three countries, China, Japan, and Korea[25], while few studies have been able to further investigate the age, period, and cohort effects of $PM_{2.5}$ and COPD using the APC model[25, 27]. APC models are able to estimate the independent effects of age, period, and cohort on disease[28], helping us to understand COPD caused by $PM_{2.5}$ from a historical perspective, such as disease screening modalities, treatments or interventions, and lifestyle changes[29, 30]. Therefore, this study subdivided $PM_{2.5}$ into HAP and APM, aiming to analyze the changes in COPD disease burden attributable to $PM_{2.5}$ and its age, period, and cohort effects in China, Japan, and Korea from 1990 to 2019, and to provide feasible and targeted policy recommendations for countries and regions with high disease burden.

Methods

Data Sources

The study is based on GBD 2019 from the Institute for Health Metrics and Evaluation in

Washington, USA. GBD 2019 provides population estimates for 204 countries and territories from 1950 to 2019, and also provides data on the incidence, number of deaths, and DALYs for 369 diseases and injuries for 204 countries and territories from 1990 to 2019[31]. The GBD updates and adds new data and methodological enhancements to the estimation of the entire time series after each change to adjust for bias[32]. This study uses GBD 2019 data to report the burden of COPD disease attributable to particulate matter pollution in China, Japan, Korea, and global from 1990 to 2019. A detailed description of the GBD 2019 methodology used to analyze the burden of disease was previously published[33] and GBD 2019 can be accessed at https://vizhub.healthdata.org/gbd-results/.

COPD Definition

COPD data for this study were obtained from GBD 2019.The COPD data reported in GBD 2019 used the Global Initiative for Chronic Obstructive Lung Disease (GOLD) standard definition: when the ratio of maximum forced expiratory air volume to total forced expiratory volume (FEV_1/FVC) in the first second of expiration after bronchodilation has a value <0.7[23]. Alternative definitions for evaluating whether a person has COPD include the pre-bronchodilator GOLD criteria, the post-bronchodilator lower limit of normal, the pre-bronchodilator lower limit of normal, and the European Respiratory Society guidelines[34].

Particulate Matter Pollution Assessment

We used HAP and APM data from GBD 2019 as an indicator of particulate matter pollution. GBD defines $PM_{2.5}$ as fine particles with an aerodynamic diameter of 2.5μm or less in 1 cubic meter of air when exposed to it. In this case, APM is measured by the annual average $PM_{2.5}$ concentration in the air, which is estimated at a spatial resolution of 0.1° × 0.1° grid from satellite observations, chemical transport models and ground monitoring data [35]. HAP was defined as the daily average $PM_{2.5}$ exposure due to the use of household solid fuels, which was obtained from measurements of $PM_{2.5}$ concentrations in kitchens and living areas[35].

Statistical Analysis

JoinPoint Regression Analysis

This study describes the level of COPD disease burden due to $PM_{2.5}$ from 1990 to 2019 by age-standardized mortality and DALY. We applied log-linear models of JoinPoint regression models to fit ASMR and age-standardized DALY data on COPD attributable to $PM_{2.5}$. The AAPC was calculated by a log-linear model to observe the trend of death and DALY in COPD attributable to $PM_{2.5}$ in China, Japan, Korea, and global.

Age-period-cohort analysis

This study further explored the age effect, period effect and cohort effect of the changing pattern of COPD mortality attributable to $PM_{2.5}$ by using the APC model. The APC model is based on the Poisson distribution and can address the problem that there is a linear relationship between age, period and cohort to estimate the effect that age, period and cohort have on disease[36]. In this paper, the following indicators are estimated by the APC model: Net drift, an overall log-linear trend indicating the overall annual percentage change in disease using period and birth cohort adjustments; Local drift, a log-linear trend in the period and birth cohort for each age group, representing the annual percentage change for each age group; Longitudinal age curves, reflecting period deviation-adjusted longitudinal age-specific values, used to infer the effect of age effects on trends in COPD; Period (cohort) rate ratios, which allow inference of the influence of period or cohort effects on trends in COPD; Age (period, cohort) bias coefficient, reflecting the curvature within a certain age (period, cohort).

The APC model in this paper uses the APC Model Web Analysis Tool provided by the International Agency for Cancer (https://analysistools.cancer.gov/apc/). Based on the GBD 2019 data and the characteristics of the APC model webpage analysis tool, this study selected COPD mortality data at 5-year intervals as an age group. Since the mortality data for COPD under 25 years of age was 0, data under 25 years of age were excluded from this study, and a total of 15 age groups were ultimately included. In terms of period division, this paper divides 1990-2019 into 6 periods according to 5 years as a time period. The formula of birth cohort is: birth cohort = period - age, and this paper calculates the value of birth cohort according to the data characteristics.

Excel 2019 software was used to organize data; JoinPoint Regression Program 4.9.0.0 software was applied to analyze the trend of COPD attributed to $PM_{2.5}$; APC model web analysis tool was used to fit the APC model and use the web page itself with Wald $\chi 2$ test for parameter estimation; Origin2021 software was used for plotting. The test level for all statistical models in this paper was α=0.05 (two-sided).

Patient and public involvement

None.

Results

Descriptive analysis of COPD attributable to $PM_{2.5}$ in China, Japan, Korea and global

The ASMRs in China, Japan, Korea, and global all showed a decreasing trend, with the highest and largest decrease in China (Figure 1A). From 1990 to 2019, the age-standardized DALYs for COPD attributable to $PM_{2.5}$ and attributable to APM in China showed a decreasing trend but remained at the highest level compared with Japan, Korea, and global, while the DALY for age-standardized COPD attributable to HAP in China dropped below the global level in 2015. In addition, COPD caused by APM was higher than COPD caused by HAP in Japan and Korea, while COPD caused by HAP was higher than COPD caused by APM in China and global (Figure 1B).

Temporal trends in COPD disease burden attributable to particulate matter pollution in China, Japan, Korea, and global

The ASMR and age standardized DALY AAPC of COPD attributable to particulate matter pollution in China, Japan, South Korea, and global from 1990 to 2019 are shown in Tables 1 and 2. The JoinPoint model results showed that except for the global trend of increasing ASMR in COPD attributed to APM by gender (AAPC=0.473, P<0.05), all other ASMR showed a decreasing trend (P<0.05). Except for the age standardized DALY of COPD attributed to APM among global women, which is statistically insignificant, all others are significant and show a downward trend under the 0.05 test standard (P<0.05).

Table 1 Trends in ASMR of COPD attributable to $PM_{2.5}$, 1990–2019

Risk	Sex	China		Japan		Korea		Global	
		AAPC	95%CI	AAPC	95%CI	AAPC	95%CI	AAPC	95%CI
$PM_{2.5}$	both	-5.862*	(-6.058, -5.666)	-1.715*	(-1.978, -1.452)	-1.831*	(-2.118, -1.543)	-3.263*	(-3.448, -3.079)
	male	-5.199*	(-5.503, -4.894)	-1.733*	(-1.916, -1.549)	-1.629*	(-2.248, -1.007)	-3.218*	(-3.446, -2.990)
	female	-6.442*	(-6.734, -6.150)	-2.008*	(-2.210, -1.805)	-2.447*	(-2.663, -2.230)	-3.397*	(-3.524, -3.269)
HAP	both	-9.518*	(-9.678, -9.358)	-8.432*	(-8.750, -8.113)	-13.912*	(-14.287, -13.537)	-5.551*	(-5.715, -5.387)
	male	-9.296*	(-9.556, -9.035)	-8.379*	(-8.635, -8.123)	-13.557*	(-13.844, -13.268)	-5.727*	(-5.919, -5.535)
	female	-9.706*	(-9.880, -9.532)	-8.584*	(-8.880, -8.286)	-14.283*	(-14.635, -13.930)	-5.395*	(-5.555, -5.235)
APM	both	-2.563*	(-3.061, -2.063)	-1.669*	(-1.932, -1.404)	-1.735*	(-2.030, -1.438)	0.473*	(-0.620, -0.326)
	male	-2.196*	(-2.477, -1.914)	-1.696*	(-1.887, -1.505)	-1.555*	(-2.186, -0.921)	-0.607*	(-0.766, -0.449)
	female	-2.903*	(-3.340, -2.465)	-1.945*	(-2.149, -1.741)	-2.332*	(-2.560, -2.105)	-0.404*	(-0.601, -0.208)

*statistically significant (P < 0.05)

Table 2 Trends in Age-standardized DALY of COPD attributable to $PM_{2.5}$, 1990–2019

Risk	Sex	China		Japan		Korea		Global	
		AAPC	95%CI	AAPC	95%CI	AAPC	95%CI	AAPC	95%CI
$PM_{2.5}$	both	-5.821*	(-6.051, -5.590)	-1.39*	(-1.490, -1.290)	-1.239*	(-1.595, -0.882)	-3.118*	(-3.267, -2.96[illegible])
	male	-5.427*	(-5.695, -5.157)	-1.485*	(-1.594, -1.376)	-1.200*	(-1.691, -0.707)	-3.170*	(-3.315, -3.02[illegible])
	female	-6.120*	(-6.284, -5.956)	-1.457*	(-1.554, -1.360)	-1.734*	(-1.976, -1.491)	-3.110*	(-3.244, -2.976)
HAP	both	-9.434*	(-9.646, -9.223)	-8.209*	(-8.335, -8.082)	-13.353*	(-13.626, -13.080)	-5.296*	(-5.413, -5.17[illegible])
	male	-9.372*	(-9.540, -9.204)	-8.278*	(-8.393, -8.163)	-13.232*	(-13.551, -12.913)	-5.545*	(-5.685, -5.40[illegible])
	female	-9.467*	(-9.649, -9.286)	-8.203*	(-8.343, -8.062)	-13.637*	(-13.970, -13.303)	-5.052*	(-5.185, -4.92[illegible])
APM	both	-2.430*	(-2.828, -2.030)	-1.340*	(-1.438, -1.241)	-1.146*	(-1.504, -0.786)	-0.342*	(-0.457, -0.227)
	male	-2.406*	(-2.683, -2.128)	-1.442*	(-1.550, -1.335)	-1.126*	(-1.627, -0.622)	-0.561*	(-0.666, -0.45[illegible])
	female	-2.399*	(-2.702, -2.094)	-1.393*	(-1.491, -1.294)	-1.618*	(-1.862, -1.374)	-0.097	(-0.273, 0.079)

Age-Period-Cohort Analysis of COPD Mortality Attributable to $PM_{2.5}$ in China, Japan, Korea, and Worldwide, 1990-2019

Waldχ 2 test results and bias coefficients for the APC model

The results of the Wald χ^2 test of the APC model showed that COPD mortality attributable to HAP in Japan and Korea did not meet the requirements of the APC model, and their local drift values, all cohort RR, all age deviations, all period deviations, and all cohort deviations were statistically insignificant, and the remaining age, period, and cohort effects of mortality and the remaining estimated parameters were statistically significant (P<0.05), as shown in Table 3. In the subsequent analysis, we will analyze and report detailed age-period-cohort effects for items tested significant by the Wald χ^2 test.

Table 3 APC analysis of COPD mortality attributable to $PM_{2.5}$ from 1990 to 2019

Item	Wald $\chi^2$of ASMR

	China			Japan			Korea			Global		
	$PM_{2.5}$	HAP	APM	$PM_{2.5}$	HAP	APM	$PM_{2.5}$	HAP	APM	$PM_{2.5}$	HAP	APM
Net drift=0	5292.73*	8368.81*	1794.23*	73.58*	5.34*	70.00*	340.30*	9.80*	325.92*	6449.76*	10637.70*	302.04*
All local drifts=Net drift	659.44*	436.37*	705.61*	52.09*	0.46	52.22*	235.32*	1.47	233.70*	469.18*	124.43*	332.17*
All period RR=1	5336.33*	8633.93*	2151.6*1	580.53*	12.39*	561.94*	461.67*	13.33*	449.83*	6472.05*	10800.65*	360.72*
All cohort RR=1	34393.88*	61059.97*	8567.39*	1627.03*	201.65	1532.71*	2095.55*	142.41	1978.60*	24919.32*	41972.37*	996.88*
All age deviations=0	1294.81*	1191.16*	1598.51*	1451.12*	7.76	1439.57*	271.56*	0.84	269.42*	11409.16*	9304.07*	8512.42*
All period deviations=0	61.53*	560.05*	265.12*	530.04*	6.88	514.28*	129.88*	2.41	130.46*	33.99*	255.48*	42.32*
All cohort deviations=0	660.09*	436.80*	710.82*	55.31*	0.47	55.44*	242.18*	1.5	240.54*	479.55*	141.15*	333.89*

Net Drift and Local Drift

As shown in Figure 2, the net drift values of COPD mortality rates attributed to $PM_{2.5}$ in China, Japan, South Korea, and global from 1990 to 2019 were -7.40% (95% CI: -7.59, -7.20), -2.02% (95% CI: -2.48, -1.56), -3.78% (95% CI: -4.17, -3.39), and -3.80% (95% CI: -3.89, -3.71), respectively. The net drift of COPD mortality attributable to HAP was -10.93% (95% CI: -11.16, -10.71) and -5.86% (95% CI: -5.97, -5.76) in China and global, respectively. The net drift of COPD mortality attributable to APM was -3.92% (95% CI: -4.10, -3.74), -1.98% (95% CI: -2.43, -1.52), -3.71% (95% CI: -4.11, -3.31), and -0.95% (95% CI: -1.06, -0.85) in China, Japan, Korea, and global, respectively. The local drift values of COPD mortality attributable to $PM_{2.5}$ and APM in Korea showed an overall increasing trend with age and all showed positive values at the age group of 95 years or older. Global local drift values for COPD mortality attributable to APM generally increased with age and started to show positive values at the age group 90-95 years. In addition, the local drift values of COPD mortality rates attributed to $PM_{2.5}$, HAP, and APM in the three countries and globally are generally increasing with age, but all are below zero.

Age Effect

After correcting for period effects and birth cohort effects, COPD mortality attributable to $PM_{2.5}$ increased slowly with age in Korea and Japan. Global COPD mortality attributable to $PM_{2.5}$ peaks in the 85-90 year age group and then declines. The increase in COPD mortality attributable to $PM_{2.5}$ in China was large until the age group 90-95 years and decreased to 434.25/100,000 (95% CI: 404.66, 466.01) after the age group 90-95 years. Global COPD mortality attributable to HAP peaked in the 80-85 year age group and then declined sharply to 32.76/100,000 (95% CI: 30.71, 34.94). COPD mortality attributable to HAP in China peaked at 78.17 per 100,000 (95% CI: 75.54, 80.89) in the 85-90 year age group and then declined continuously. COPD mortality attributable to APM increased with age in China, Japan, Korea, and globally. See Figure S1 for details.

Period Effect

Using 2000-2004 as a control group, COPD mortality attributable to $PM_{2.5}$ decreased significantly over time in China, Korea, and globally, whereas it increased slightly in Japan from 2015 to 2019. COPD mortality attributable to HAP in China and globally all decreased significantly over time. COPD mortality attributable to APM in China, Korea, and globally showed a decreasing trend over time, but in Japan, the mortality rate of COPD attributable to APM has shown a decreasing trend between 1990 and 2015, dropping to the minimum value of 0.85 (95% CI: 0.80, 0.89), and rising to 0.91 (95% CI: 0.84, 0.98) from 2015 to 2019. See Figure S2 for details.

Cohort Effect

In China, Japan, and globally, COPD mortality attributable to $PM_{2.5}$ was approximately lower the later the birth, and gradually decreased in Korea after a small increase to a peak of 2.26 (95% CI: 2.13, 2.40) in the 1900-1910 birth cohort. Late birth cohorts with COPD mortality attributable to HAP were lower than early birth cohorts in both China and globally. COPD mortality attributable to APM in China and Japan gradually decreased with increasing birth year. Global COPD mortality attributable to APM fluctuated slightly during the 1990-1915 birth cohort and then declined slowly. COPD mortality attributable to APM in Korea showed an increasing trend during the 1895-1910 birth cohort and decreased after peaking in 1910. Figure S3 for details.

Discussion

This study provides an update on trends in the disease burden of COPD attributable to $PM_{2.5}$, HAP, and APM in the three major Asian economies of China, Japan, and Korea, as well as globally. We found a decreasing trend in ASMR and age-standardized DALY for COPD attributable to $PM_{2.5}$, HAP, and APM in all regions, except for a global overall trend in ASMR for COPD attributable to APM among all genders. COPD attributable to particulate matter pollution shows a decreasing trend in most regions and is inextricably linked to local environmental health policies. In 2013, the World Health Organization designated $PM_{2.5}$ as a carcinogen and recommended that the population-weighted APM should be less than 10μg/m3. In high-income countries, several strategies have been implemented to reduce air pollution. These include switching to cleaner fuels, improving emission control technologies, and enhancing public environmental education[37, 38]. Since 2013, China has implemented systematic regulations that have resulted in a 33.3% decrease in annual average $PM_{2.5}$ concentrations from 2013 to 2017[39]. In contrast, the global all-sex ASMR for COPD attributable to APM is on the rise, which may be due to the increase in particulate matter pollution in countries with low socioeconomic development[27].

The results showed large regional differences in ASMR and age-standardized DALY for COPD attributable to $PM_{2.5}$, HAP, and APM. The burden of COPD disease attributable to particulate matter pollution in China is much higher than the levels in Japan and Korea, and there is a gap with global levels. This difference may be related to socioeconomic development[27], where China is a developing country with further economic construction to be advanced, while Japan and South Korea are developed countries with economic development levels ahead of the world average. Large-scale energy consumption and power generation in low- and middle-income countries generate large amounts of pollution during the industrialization process[33]. A Chinese study, noting that urbanization and industrialization have increased particulate matter emissions in Chinese cities, found that 64.2 per cent of 338 $PM_{2.5}$ samples exceeded National Standard I, 53.0 per cent of 338 PM_{10} samples exceeded National Standard II, and 70.7 per cent of urban ambient air quality exceeded National Standard III[40]. In addition, more residents in low- and middle-income countries rely on traditional energy sources for home cooking and heating, and in China, 32% of Chinese still use solid fuels for heating and cooking, resulting in much higher levels of exposure to particulate matter pollution than in high-income countries[8, 41]. At the same time, countries with higher levels of development may have more stringent air quality controls[42], and some studies have clearly indicated that Japan and South Korea have conducted air quality research in an effort to alleviate air pollution problems within their borders, leading to relatively clean air quality in Japan and South Korea compared to other Northeast Asian countries[43]. A study measuring the accessibility and quality of health care across countries by constructing an HAQ index found that high SDI countries had higher HAQ scores, with Japan scoring 94, South Korea 90, and China 78[44]. In low- and middle-income countries, the lack of high-quality public healthcare may exacerbate the burden of $PM_{2.5}$-attributable COPD due to economic deprivation and relatively poor health awareness among the population[45]. Therefore, differences in the level of health care among the three countries may also explain the differences in COPD attributable to $PM_{2.5}$ in China, Japan, and South Korea.

Interestingly, we focused on the difference in COPD risk due to HAP and APM, with COPD due to APM being higher than COPD due to HAP in Japan and Korea, and conversely, COPD due to HAP being higher than COPD due to APM in China and globally. The reason for this opposite result may be that residents of economically developed areas use less solid fuels. It has been noted that biomass fuel exposure is a major risk factor for COPD in poor and developing countries[46]. In resource-limited environments, readily available solid fuels such as wood, charcoal, dried branches, crop residues and animal dung cakes are used as cooking fuels in less developed countries, covering more than 200 chemical and compound groups, 90% of which are in the respirable size range[47]. Exposure to biomass fuel smoke increased the odds of developing COPD by 2.3 times compared to no exposure to biomass smoke[46]. Thus, there is no doubt that biomass fuel exposure is an important risk factor for chronic lung disease in developing country populations and a potential causative agent of respiratory disease. In conclusion, policy actions in China and developing countries around the world to reduce the burden of COPD caused by $PM_{2.5}$ should focus on HAP emission concentrations, while economically developed countries should pay more attention to APM control.

We analyzed the effect of age on COPD attributed to $PM_{2.5}$ and showed that COPD mortality attributed to APM increased with age in China, Japan, Korea, and globally. COPD mortality attributable to HAP declined sharply after peaking in the 80-85 year age group globally and declining after peaking in the 85-90 year age group in China. Similar to our findings, several studies have shown that the burden of COPD caused by APM is heavier in the elderly population[48, 49]. This may be due to the weaker immune and lung function, high likelihood of chronic diseases, higher sensitivity to chemicals, and greater susceptibility to air pollution in the elderly compared to the young[50]. Therefore, there is a need for all countries to take measures to address the health care issues arising from population aging. In addition, the decrease in COPD mortality rates attributed to HAP in the global and China during the advanced age stage may be due to the large base of early life exposure to HAP among residents in the region, and the inconvenience of movement and sudden decrease in HAP exposure after being too old, ultimately leading to a sharp decline in COPD mortality rates attributed to HAP in the advanced age group.

COPD mortality attributable to HAP decreased significantly over time in China and globally. COPD mortality attributable to APMs in China, Korea, and globally showed a decreasing trend over time, but Japan's showed a decreasing trend from 1990-2015 and a small increase from 2015-2019. Temporal effects are usually influenced by a complex set of environmental factors and historical events[51]. The Chinese government attaches great importance to the air pollution problem and has reduced $PM_{2.5}$ exposure through measures such as improving stove programs and planning waste emission standards for factories[27, 52]. In addition, advanced drug therapy and other interventions in China have controlled the risk factors for COPD and well prevented further COPD progression[27]. In the last decade or so, Korea has introduced laws and regulations such as the Emission Reduction Plan and Special Measures for Air Quality to address particulate matter pollution[53], and guaranteed effective treatment for COPD patients through the universal health insurance system, thereby reducing the severity of the disease and mortality[54]. Japan has seen a small increase in COPD mortality attributable to APM in recent years, which we speculate may be due to increased air pollution and increased patient mortality due to the growth in the number of cars[55]. Therefore, all governments need to continue to jointly adopt multiple regulations and measures to manage air pollution and clinical treatment techniques to promote primary and secondary prevention of COPD disease.

In both China and globally, COPD mortality attributable to HAP is lower in late birth cohorts compared to early birth cohorts. COPD mortality attributable to APM in China, Japan, and globally decreased gradually with increasing year of birth overall. COPD mortality attributable to APM in Korea showed an increasing trend during the birth cohort of 1895-1910 and decreased after peaking in 1910. We hypothesize that the decrease in COPD mortality attributable to particulate matter pollution in recent years is related to people's lifestyle, change in thinking, external environment, and risk factor exposure. Younger generations receive more comprehensive health education about the effects of unhealthy lifestyle and dietary habits on lung function and are thus better equipped to avoid COPD mortality-related risk factors[56, 57]. In addition, economic development and environmental improvements are important reasons for the reduced risk of COPD mortality attributable to particulate matter pollution in young people[56].

There are also some limitations in this study. First, this study used GBD 2019 for data analysis, and GBD 2019 collected missing data by modifying and adjusting data sources and collection assessment methods, which could not eliminate data bias and affected the accuracy of the results. Second, this study used GBD 2019 data, and the $PM_{2.5}$ exposure classification was limited by the data, which only included ambient particulate matter and household air pollution. Third, the APC model only considered the effects of age, period and cohort without further analysis of other risk factors.

Conclusion

We observed an upward trend in ASMR and age-standardized DALY for COPD attributed to $PM_{2.5}$, HAP, and APM in all regions, except for those globally attributed to APM. There were large regional differences in ASMR and age-standardized DALYs for COPD attributable to $PM_{2.5}$, HAP, and APM, with China having the highest burden of COPD disease. The risk of COPD due to HAP and APM differed, with COPD due to APM being higher than COPD due to HAP in Japan and Korea, and COPD due to HAP being higher than COPD due to APM in China and globally. Overall, COPD mortality attributable to $PM_{2.5}$ both increased with age and decreased with time and cohort. Based on the above findings, we call on countries with high disease burden to refer to the public health policies of Japan and Korea and take targeted, site-specific policy measures to reduce the disease burden of COPD caused by $PM_{2.5}$ according to pollutant types and age groups.

Abbreviations

AAPC: average annual percent change; APC model: age-period-cohort model; APM: ambient particulate matter pollution; ASMR: age-standardized mortality rate; COPD: chronic obstructive pulmonary disease; GBD 2019: the latest Global Burden of Disease Database; GOLD: Global Initiative for Chronic Obstructive Lung Disease; HAP: household air pollution from solid fuels; $PM_{2.5}$: particulate matter pollution; ROS: reactive oxygen species

Supplementary information

Additional file 1: Table S1. the disease burden for COPD attributable to $PM_{2.5}$ in China, Japan, Korea, and global from 1990-2019.

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Declarations

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Ethics approval and consent to participate

The GBD data are de-identified and publicly available. Therefore, the study is exempted from institutional ethical board review. All methods are carried out in accordance with the relevant guidelines and regulations (Declaration of Helsinki).

Consent for publication

Not applicable.

Availability of data and materials

Resources on the disease burden of COPD attributable to particulate matter pollution in each country, as well as national population data, are available from https://vizhub.healthdata.org/gbd-results/

Competing interests

The authors declare no conflict of interest.

Author contributions

BL and XFC conceptualized the paper. XFC did the statistical analysis and drafted the manuscript. SHM and RQG conducted the research and data collection. BL and YLZ reviewed and edited the writing. BL and JDZ re-reviewed and co-revised the manuscript from the English language perspective. All authors made significant intellectual contributions to multiple revisions of the draft. All authors have read and agreed to the published version of the manuscript.

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References

1. Lelieveld J, Evans JS, Fnais M et al: **The contribution of outdoor air pollution sources to premature mortality on a global scale**. *Nature* 2015, **525**(7569):367-371.
2. Landrigan PJ, Fuller R, Acosta NJR et al: **The Lancet Commission on pollution and health**. *The Lancet* 2018, **391**(10119):462-512.
3. Sang S, Chu C, Zhang T et al: **The global burden of disease attributable to ambient fine particulate matter in 204 countries and territories, 1990–2019: A systematic analysis of the Global Burden of Disease Study 2019**. *Ecotoxicology and Environmental Safety* 2022, **238**:113588.
4. Pandey A, Brauer M, Cropper ML et al: **Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019**. *The Lancet Planetary Health* 2021, **5**(1):e25-e38.
5. Hamanaka RB, Mutlu GM: **Particulate Matter Air Pollution: Effects on the Cardiovascular System**. 2018, **9**.
6. Lim C-H, Ryu J, Choi Y et al: **Understanding global PM2.5 concentrations and their drivers in recent decades (1998–2016)**. *Environment International* 2020, **144**:106011.
7. Zhao S, Wang H, Chen H et al: **Global magnitude and long-term trend of ischemic heart disease burden attributed to household air pollution from solid fuels in 204 countries and territories, 1990–2019**. *Indoor Air* 2022, **32**(2):e12981.
8. Yin P, Brauer M, Cohen AJ et al: **The effect of air pollution on deaths, disease burden, and life expectancy across China and its provinces, 1990–2017: an analysis for the Global Burden of Disease Study 2017**. *The Lancet Planetary Health* 2020, **4**(9):e386-e398.
9. Bowe B, Xie Y, Yan Y et al: **Burden of Cause-Specific Mortality Associated With PM2.5 Air Pollution in the United States**. *JAMA Network Open* 2019, **2**(11):e1915834-e1915834.
10. Hayes RB, Lim C, Zhang Y et al: **PM2.5 air pollution and cause-specific cardiovascular disease mortality**. *International Journal of Epidemiology* 2020, **49**(1):25-

35.

11. Fenech S, Doherty RM, Heaviside C et al: **Meteorological drivers and mortality associated with O3 and PM2.5 air pollution episodes in the UK in 2006**. *Atmospheric Environment* 2019, **213**:699-710.

12. Burnett Richard T, Pope CA, Ezzati M et al: **An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure**. *Environmental Health Perspectives* 2014, **122**(4):397-403.

13. Zhu R-X, Nie X-H, Chen Y-H et al: **Relationship Between Particulate Matter (PM2.5) and Hospitalizations and Mortality of Chronic Obstructive Pulmonary Disease Patients: A Meta-Analysis**. *The American Journal of the Medical Sciences* 2020, **359**(6):354-364.

14. Li N, Yang Z, Liao B et al: **Chronic exposure to ambient particulate matter induces gut microbial dysbiosis in a rat COPD model**. *Respiratory Research* 2020, **21**(1):271.

15. Pini L, Giordani J, Gardini G et al: **Emergency department admission and hospitalization for COPD exacerbation and particulate matter short-term exposure in Brescia, a highly polluted town in northern Italy**. 2021, **179**:106334.

16. Collaborators GBDCRD: **Global, regional, and national deaths, prevalence, disability-adjusted life years, and years lived with disability for chronic obstructive pulmonary disease and asthma, 1990-2015: a systematic analysis for the Global Burden of Disease Study 2015**. *The Lancet Respiratory medicine* 2017, **5**(9):691-706.

17. Liu X, Zhao X, Li X et al: **PM2.5 triggered apoptosis in lung epithelial cells through the mitochondrial apoptotic way mediated by a ROS-DRP1-mitochondrial fission axis**. *Journal of Hazardous Materials* 2020, **397**:122608.

18. Chi M-C, Guo S-E, Hwang S-L et al: **Exposure to Indoor Particulate Matter Worsens the Symptoms and Acute Exacerbations in Chronic Obstructive Pulmonary Disease Patients of Southwestern Taiwan: A Pilot Study**. In: *International Journal of Environmental Research and Public Health.* vol. 14; 2017.

19. Wang J, Zhu M, Wang L et al: **Amphiregulin potentiates airway inflammation and mucus hypersecretion induced by urban particulate matter via the EGFR-PI3Kα-AKT/ERK pathway**. *Cellular Signalling* 2019, **53**:122-131.

20. Zhao J, Li M, Wang Z et al: **Role of PM2.5 in the development and progression of COPD and its mechanisms**. *Respiratory Research* 2019, **20**(1):120.

21. Feizi H, Alizadeh M, Nejadghaderi SA et al: **The burden of chronic obstructive pulmonary disease and its attributable risk factors in the Middle East and North Africa region, 1990–2019**. *Respiratory Research* 2022, **23**(1):319.

22. Zafari Z, Li S, Eakin MN et al: **Projecting Long-term Health and Economic Burden of COPD in the United States**. *Chest* 2021, **159**(4):1400-1410.

23. Safiri S, Carson-Chahhoud K, Noori M et al: **Burden of chronic obstructive pulmonary disease and its attributable risk factors in 204 countries and territories, 1990-2019: results from the Global Burden of Disease Study 2019**. *BMJ* 2022, **378**:e069679.

24. Hu W, Fang L, Zhang H et al: **Changing trends in the air pollution–related disease burden from 1990 to 2019 and its predicted level in 25 years**. *Environmental Science*

and Pollution Research 2023, **30**(1):1761-1773.

25. Du J, Yang J, Wang L et al: **A comparative study of the disease burden attributable to PM2.5 in China, Japan and South Korea from 1990 to 2017**. *Ecotoxicology and Environmental Safety* 2021, **209**:111856.

26. Wu X, Zhu B, Zhou J et al: **The epidemiological trends in the burden of lung cancer attributable to PM2.5 exposure in China**. *BMC Public Health* 2021, **21**(1):737.

27. Wu Y, Zhang S, Zhuo B et al: **Global burden of chronic obstructive pulmonary disease attributable to ambient particulate matter pollution and household air pollution from solid fuels from 1990 to 2019**. *Environmental Science and Pollution Research* 2022, **29**(22):32788-32799.

28. Wilkinson K, Righolt CH, Elliott LJ et al: **The impact of pertussis vaccine programme changes on pertussis disease burden in Manitoba, 1992–2017—an age-period-cohort analysis**. *International Journal of Epidemiology* 2022, **51**(2):440-447.

29. He J, Ouyang F, Li L et al: **Incidence trends of major depressive disorder in China: an age-period-cohort modeling study**. *Journal of Affective Disorders* 2021, **288**:10-16.

30. Li Y, Ren N, Zhang B et al: **Gastric cancer incidence trends in China and Japan from 1990 to 2019: Disentangling age–period–cohort patterns**. *Cancer* 2023, **129**(1):98-106.

31. 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**. *The Lancet* 2020, **396**(10258):1160-1203.

32. Liu S, Wang B, Fan S et al: **Global burden of musculoskeletal disorders and attributable factors in 204 countries and territories: a secondary analysis of the Global Burden of Disease 2019 study**. 2022, **12**(6):e062183.

33. 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**. 2020, **396**(10258):1204-1222.

34. 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**. *The Lancet* 2020, **396**(10258):1204-1222.

35. Balakrishnan K, Dey S, Gupta T et al: **The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: the Global Burden of Disease Study 2017**. *The Lancet Planetary Health* 2019, **3**(1):e26-e39.

36. Liu X, Yu C, Bi Y et al: **Trends and age-period-cohort effect on incidence and mortality of prostate cancer from 1990 to 2017 in China**. *Public Health* 2019, **172**:70-80.

37. Beggs PJ, Zhang Y, Bambrick H et al: **The 2019 report of the MJA–Lancet Countdown on health and climate change: a turbulent year with mixed progress**. *Medical Journal of Australia* 2019, **211**(11):490-491.e421.

38. DuPont A: **Improving and monitoring air quality**. *Environmental Science and Pollution Research* 2018, **25**(15):15253-15263.

39. Huang J, Pan X, Guo X et al: **Health impact of China's Air Pollution Prevention and Control Action Plan: an analysis of national air quality monitoring and mortality data**. *The Lancet Planetary Health* 2018, **2**(7):e313-e323.

40. Wu Y, Zhang N, Shi Y et al: **PAH Pollution in Particulate Matter and Risk in**

Chinese Cities. 2023:1-15.

41. Gordon SB, Bruce NG, Grigg J et al: **Respiratory risks from household air pollution in low and middle income countries**. *The Lancet Respiratory Medicine* 2014, **2**(10):823-860.
42. Burns J, Boogaard H, Polus S et al: **Interventions to reduce ambient air pollution and their effects on health: An abridged Cochrane systematic review**. *Environment International* 2020, **135**:105400.
43. Ha Y, Kim J, Lee S et al: **Spatiotemporal differences on the real-time physicochemical characteristics of PM2. 5 particles in four Northeast Asian countries during Winter and Summer 2020–2021**. 2023, **283**:106581.
44. 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**. 2018, **391**(10136):2236-2271.
45. Bazargani YT, Boer Ad, Leufkens HGM et al: **Essential medicines for COPD and asthma in low and middle-income countries**. 2014, **69**(12):1149-1151.
46. Tan WC: **Trends in chronic obstructive pulmonary disease in the Asia-Pacific regions**. *Current Opinion in Pulmonary Medicine* 2011, **17**(2).
47. Salvi S, Barnes PJ: **Is Exposure to Biomass Smoke the Biggest Risk Factor for COPD Globally?** *Chest* 2010, **138**(1):3-6.
48. Yang X, Zhang T, Zhang Y et al: **Global burden of COPD attributable to ambient PM2.5 in 204 countries and territories, 1990 to 2019: A systematic analysis for the Global Burden of Disease Study 2019**. *Science of The Total Environment* 2021, **796**:148819.
49. Bell ML, Zanobetti A, Dominici F: **Evidence on Vulnerability and Susceptibility to Health Risks Associated With Short-Term Exposure to Particulate Matter: A Systematic Review and Meta-Analysis**. *American Journal of Epidemiology* 2013, **178**(6):865-876.
50. Fougère B, Vellas B, Billet S et al: **Air Pollution modifies the association between successful and pathological aging throughout the frailty condition**. *Ageing Research Reviews* 2015, **24**:299-303.
51. Su X, Li H, Li F et al: **Trends in the Burden of COPD Attributable to Ambient PM2.5 Exposure in China 1990–2019: An Age-Period-Cohort Analysis**. *Risk Management and Healthcare Policy* 2023, **16**:69-77.
52. Wang S, Hao J: **Air quality management in China: Issues, challenges, and options**. *Journal of Environmental Sciences* 2012, **24**(1):2-13.
53. Han C, Kim S, Lim Y-H et al: **Spatial and Temporal Trends of Number of Deaths Attributable to Ambient PM2.5 in the Korea**. *J Korean Med Sci* 2018, **33**(30).
54. Lee EG, Rhee CKJJoTD: **Epidemiology, burden, and policy of chronic obstructive pulmonary disease in South Korea: a narrative review**. *2021* 2021, **13**(6):3888-3897.
55. Okazaki Y, Ito L, Tokai A: **Characterizing potential risk triggered by road traffic noise in comparison with typical air pollutants NO2 and PM2.5**. *Environment Systems and Decisions* 2021, **41**(1):147-162.
56. Guo Y, Bai J, Zhang X et al: **Secular Trends of Mortality and Years of Life Lost Due**

to Chronic Obstructive Pulmonary Disease in Wuhan, China from 2010 to 2019: Age-Period-Cohort Analysis. In: *International Journal of Environmental Research and Public Health.* vol. 19; 2022.

57. Liu X, Zhou M, Yu C et al: **Age-Period-Cohort Analysis of Type 2 Diabetes Mortality Attributable to Particulate Matter Pollution in China and the U.S**. *Journal of Diabetes Research* 2020, **2020**:1243947.

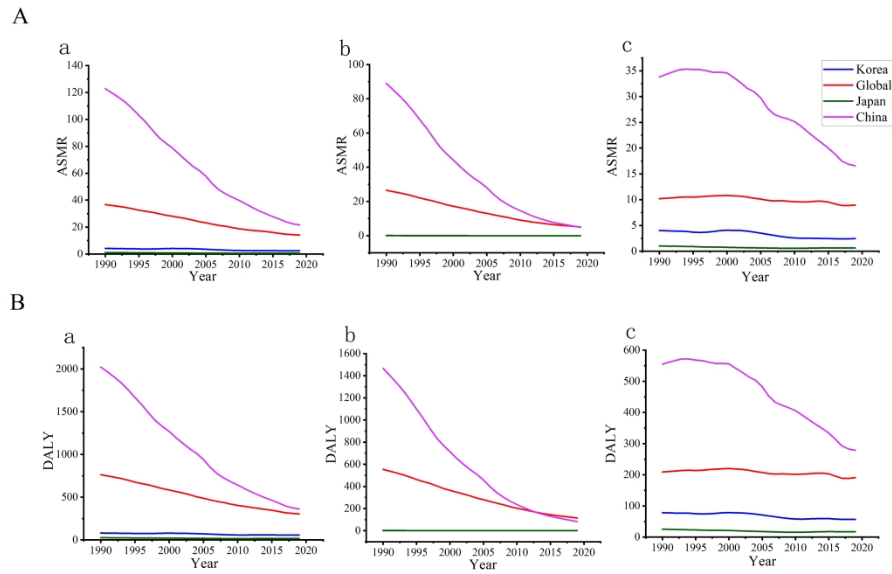

Figure 1 A. ASMR of COPD attributable to PM2.5 (a), HAP (b), and APM (c) in China, Japan, Korea, and global, 1990-2019; B. Age-standardized DALY of COPD attributable to PM2.5 (a), HAP (b), and APM (c) in China, Japan, Korea, and global, 1990-2019.

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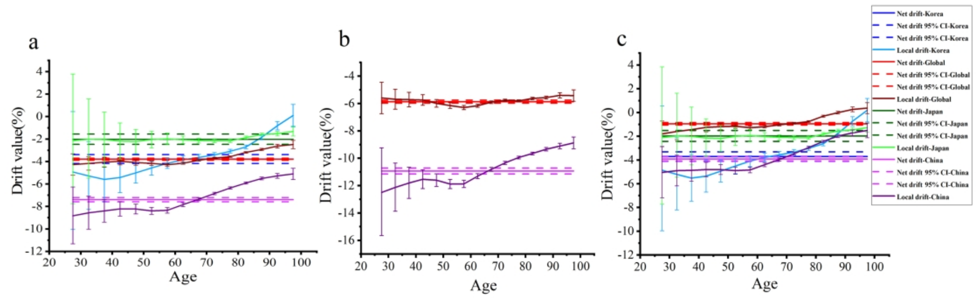

Figure 2 Net and local drift values of COPD mortality attributable to PM2.5 (a), HAP (b), and APM (c) in China, Japan, Korea, and globally, 1990-2019

272x89mm (300 x 300 DPI)

Table S1 the disease burden for COPD attributable to PM2.5 in China, Japan, Korea, and global from 1990-2019

Year	ASMR												age-standardized DALY										
	PM2.5				HAP				APM				PM2.5				HAP				APM		
	Korea	Global	Japan	China	Korea	Global	Japan	China	Korea	Global	Japan	China	Korea	Global	Japan	China	Korea	Global	Japan	China	Korea	Global	Japan
1990	4.16	36.70	1.04	122.84	0.13	26.51	0.02	89.03	4.03	10.19	1.02	33.82	80.74	763.13	25.89	2022.32	2.37	553.84	0.46	1467.51	78.37	209.29	25.44
1991	4.08	36.02	1.02	119.63	0.11	25.76	0.02	85.33	3.98	10.27	1.00	34.31	80.06	748.60	25.42	1963.96	2.00	538.24	0.41	1403.00	78.07	210.63	25.01
1992	4.00	35.35	1.00	116.35	0.09	25.00	0.02	81.58	3.92	10.37	0.98	34.80	78.69	733.77	24.98	1903.78	1.64	522.11	0.37	1337.04	77.06	212.12	24.61
1993	3.96	34.65	0.97	112.70	0.07	24.18	0.01	77.51	3.89	10.49	0.96	35.22	78.18	718.21	24.49	1837.13	1.35	504.65	0.33	1265.85	76.84	214.08	24.16
1994	3.91	33.67	0.93	108.15	0.06	23.16	0.01	72.84	3.85	10.52	0.92	35.34	77.99	698.95	23.81	1756.02	1.11	484.76	0.29	1185.04	76.88	214.57	23.52
1995	3.75	32.55	0.91	103.04	0.05	22.06	0.01	67.77	3.70	10.50	0.90	35.27	76.03	676.35	23.38	1666.39	0.91	462.51	0.26	1098.30	75.13	213.85	23.11
1996	3.68	31.71	0.86	98.12	0.04	21.14	0.01	62.85	3.64	10.56	0.85	35.27	75.25	658.77	22.67	1581.11	0.76	443.86	0.23	1014.79	74.48	214.66	22.44
1997	3.74	30.96	0.83	92.21	0.03	20.28	0.01	57.23	3.70	10.67	0.82	35.01	75.63	643.64	22.24	1483.46	0.65	426.73	0.21	922.64	74.98	216.77	22.03
1998	3.86	29.93	0.82	86.55	0.03	19.20	0.01	51.90	3.83	10.74	0.81	34.71	76.85	622.85	22.10	1394.04	0.56	404.81	0.19	837.69	76.29	218.13	21.91
1999	4.04	28.84	0.81	82.47	0.03	18.06	0.01	47.80	4.01	10.79	0.80	34.73	78.53	600.44	21.94	1327.49	0.49	381.50	0.17	771.03	78.05	219.15	21.76
2000	4.11	28.05	0.77	78.80	0.02	17.21	0.01	44.20	4.09	10.84	0.76	34.60	79.28	584.24	21.35	1269.03	0.42	364.08	0.16	713.21	78.86	220.16	21.19
2001	4.06	27.19	0.74	74.20	0.02	16.41	0.01	40.43	4.04	10.76	0.73	33.72	78.45	566.46	20.71	1195.57	0.36	347.67	0.14	653.00	78.09	218.60	20.57
2002	4.05	26.31	0.71	69.73	0.02	15.63	0.00	36.97	4.03	10.68	0.70	32.74	77.98	549.23	19.99	1130.14	0.30	331.96	0.12	600.92	77.67	217.23	19.87
2003	3.91	25.23	0.69	65.37	0.01	14.73	0.00	33.78	3.90	10.51	0.68	31.62	76.35	528.92	19.35	1066.54	0.25	314.57	0.11	552.79	76.09	214.55	19.24
2004	3.73	24.01	0.67	62.05	0.01	13.74	0.00	31.14	3.72	10.28	0.66	30.96	74.15	504.68	18.65	1011.92	0.21	294.57	0.10	509.50	73.93	210.39	18.55
2005	3.52	23.16	0.65	57.79	0.01	13.02	0.00	28.03	3.51	10.13	0.65	29.76	71.38	487.61	18.16	940.55	0.18	279.96	0.09	457.80	71.21	207.66	18.07
2006	3.29	22.11	0.63	52.00	0.01	12.23	0.00	24.20	3.28	9.88	0.63	27.76	68.19	468.19	17.48	848.84	0.15	264.18	0.08	396.40	68.05	203.79	17.40
2007	3.08	21.19	0.61	47.52	0.01	11.42	0.00	20.97	3.08	9.77	0.61	26.54	65.17	450.63	16.84	775.99	0.13	248.25	0.07	343.57	65.05	202.32	16.76
2008	2.88	20.55	0.59	44.48	0.01	10.75	0.00	18.47	2.87	9.82	0.59	26.04	62.21	437.22	16.25	723.88	0.11	234.12	0.07	301.67	62.10	203.29	16.18
2009	2.70	19.54	0.57	42.01	0.00	9.84	0.00	16.37	2.69	9.71	0.57	25.68	59.70	418.59	15.76	680.25	0.10	216.81	0.06	265.92	59.61	202.07	15.70
2010	2.59	18.72	0.57	39.75	0.00	9.10	0.00	14.58	2.58	9.62	0.57	25.16	58.17	404.36	15.57	641.98	0.09	202.85	0.06	236.29	58.08	201.50	15.51
2011	2.53	18.08	0.58	37.13	0.00	8.49	0.00	12.88	2.53	9.58	0.58	24.22	57.76	392.76	15.80	601.56	0.08	190.50	0.06	209.32	57.68	202.10	15.75
2012	2.54	17.47	0.60	34.35	0.00	7.90	0.00	11.24	2.54	9.58	0.60	23.10	58.66	381.08	16.31	561.56	0.07	177.78	0.05	184.46	58.59	203.51	16.26
2013	2.50	17.09	0.62	31.92	0.00	7.42	0.00	9.88	2.50	9.70	0.62	22.05	59.21	369.91	16.97	525.67	0.06	165.41	0.05	163.41	59.15	205.12	16.92

2014	2.48	16.63	0.64	29.77	0.00	6.93	0.00	8.75	2.48	9.73	0.64	21.05	59.70	358.28	17.50	494.03	0.06	153.69	0.05	145.73	59.64	205.27	17.45
2015	2.47	15.99	0.65	27.73	0.00	6.45	0.00	7.74	2.47	9.54	0.65	20.00	59.48	347.58	17.68	464.03	0.05	144.42	0.05	129.98	59.42	203.16	17.63
2016	2.42	15.27	0.65	25.87	0.00	6.08	0.00	6.99	2.42	9.19	0.65	18.84	57.94	332.41	17.59	431.92	0.05	136.37	0.05	117.36	57.89	195.89	17.55
2017	2.42	14.64	0.64	23.76	0.00	5.77	0.00	6.26	2.42	8.88	0.64	17.50	57.12	317.79	17.37	397.25	0.04	128.96	0.04	105.22	57.08	188.84	17.32
2018	2.41	14.34	0.64	22.39	0.00	5.46	0.00	5.55	2.41	8.88	0.64	16.86	56.74	310.64	17.22	375.91	0.04	121.98	0.04	93.77	56.70	188.53	17.18
2019	2.46	14.02	0.64	21.46	0.00	5.07	0.00	4.87	2.46	8.95	0.64	16.59	57.03	305.02	17.14	361.07	0.04	114.22	0.04	82.45	56.99	190.79	17.10

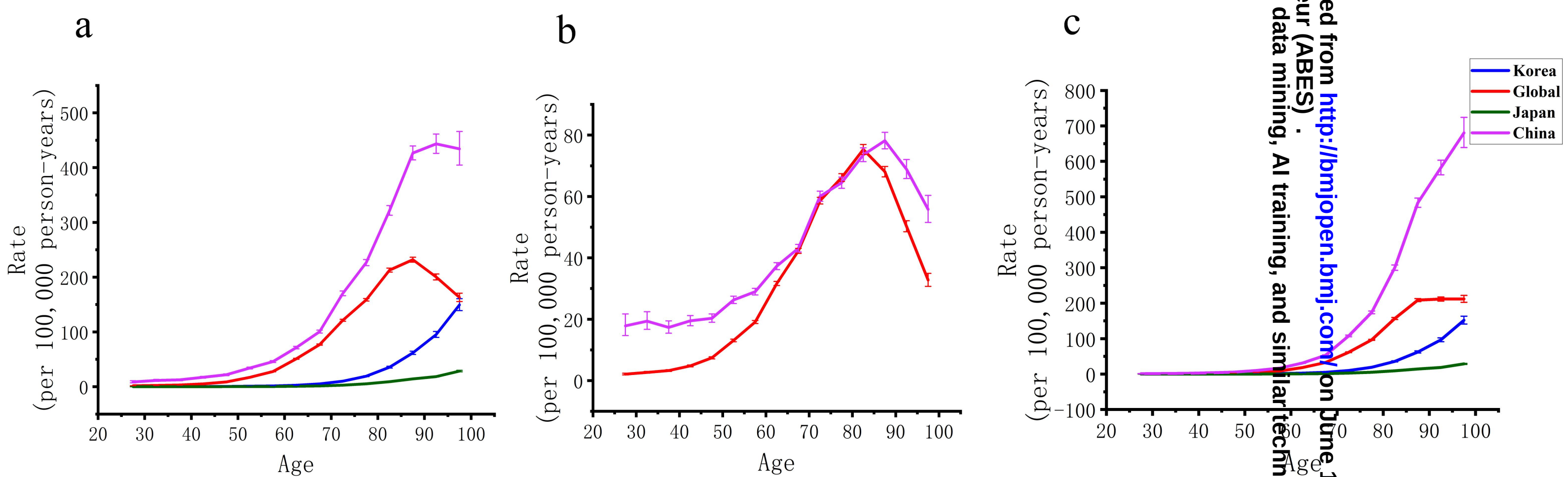

Figure S1 Age effects of COPD mortality attributable to PM2.5 (a), HAP (b), and APM (c) in China, Japan, Korea, and globally, 1990-2019

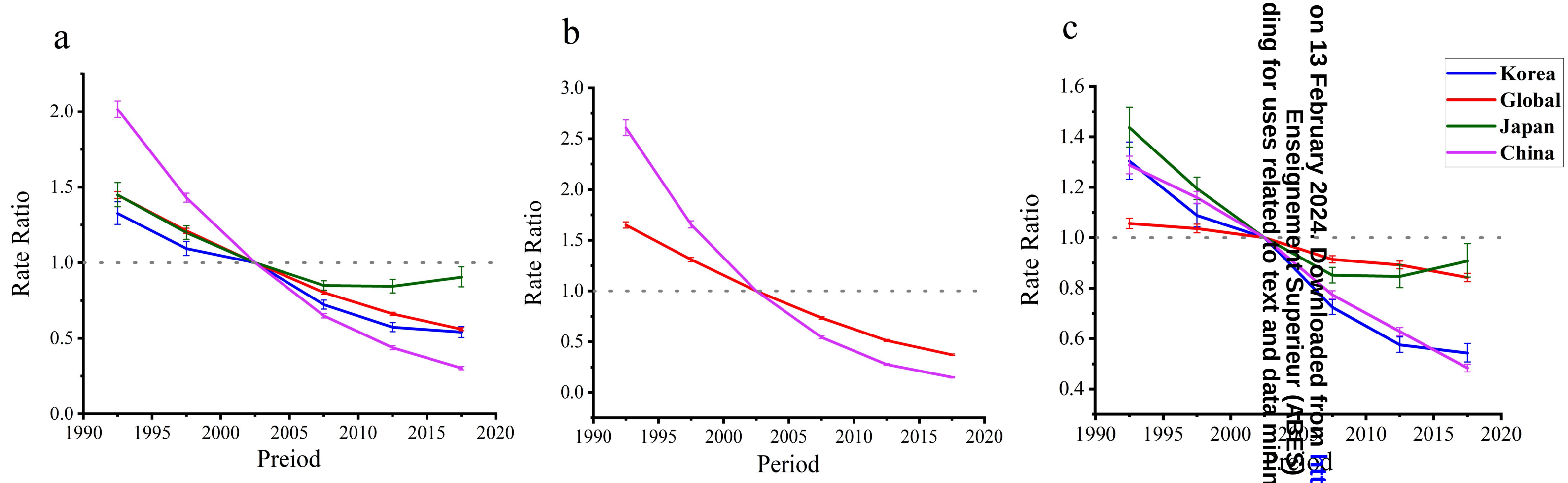

Figure S2 Period effects of COPD mortality attributable to PM2.5 (a), HAP (b), and APM (c) in China, Japan, Korea, and globally, 1990-2019

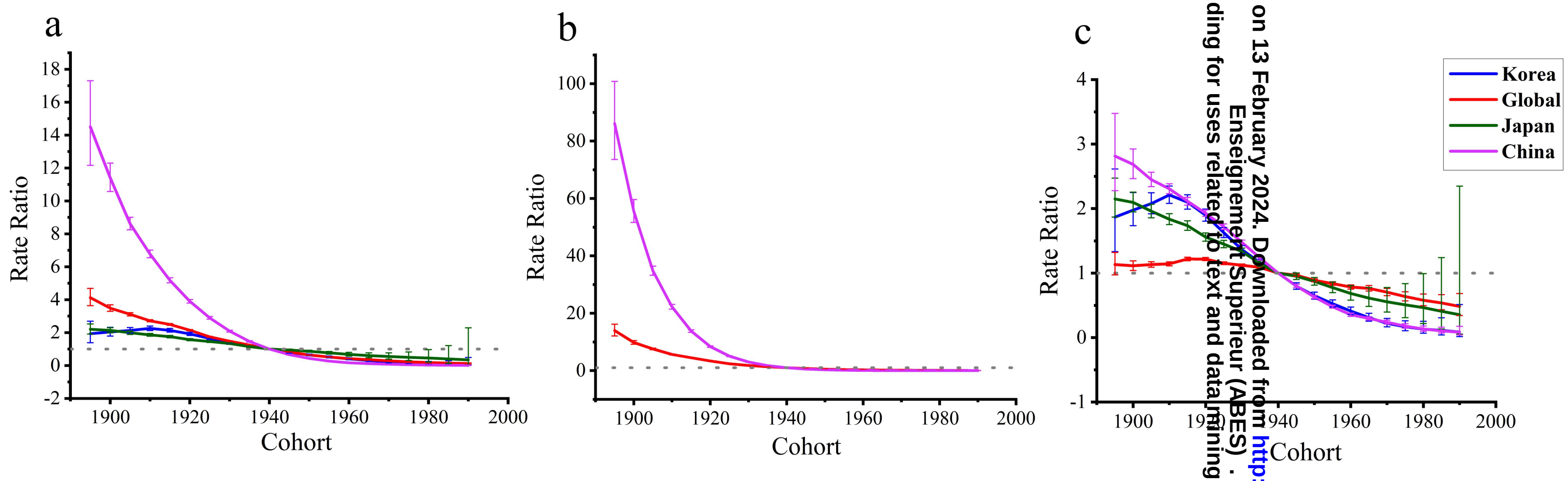

Figure S3 Cohort effects of COPD mortality attributable to PM2.5 (a), HAP (b), and APM (c) in China, Japan, Korea, and globally, 1990-2019

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Line
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Ln1-Ln4
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Ln7-Ln32
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Ln52-Ln104
Objectives	3	State specific objectives, including any prespecified hypotheses	Ln104-Ln108
Methods			
Study design	4	Present key elements of study design early in the paper	Ln116-Ln118
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Ln111-Ln120
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	Ln172
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Ln121-Ln136
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Ln111-Ln120
Bias	9	Describe any efforts to address potential sources of bias	Ln114-Ln116
Study size	10	Explain how the study size was arrived at	Ln111-Ln120
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Ln121-Ln136
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Ln138-Ln170
		(*b*) Describe any methods used to examine subgroups and interactions	
		(*c*) Explain how missing data were addressed	
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Ln172
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Ln174-Ln182
		(b) Indicate number of participants with missing data for each variable of interest	

Outcome data	15*	Report numbers of outcome events or summary measures	Ln183-Ln250
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Ln174-Ln250
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Ln183-Ln250
Discussion			
Key results	18	Summarise key results with reference to study objectives	Ln362-Ln369
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Ln354-Ln360
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Ln252-Ln353
Generalisability	21	Discuss the generalisability (external validity) of the study results	Ln369-Ln372
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Ln387-Ln392

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.