Cohort study of chronic obstructive pulmonary disease-specific mortality based on the CLHLS and CHARLS databases

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Abstract

Introduction: The aim of the study was to analyze the risk of all-cause mortality among middle-aged and older adults with chronic obstructive pulmonary disease (COPD) in China.
Material and methods: Data were retrieved from the Chinese Longitudinal Healthy Longevity Survey (CLHLS) and the China Health and Retirement Longitudinal Study (CHARLS). COPD-related information was extracted to establish a longitudinal cohort study. A total of 17,988 participants who met the inclusion criteria were ultimately included in the analysis.
Results: Significant differences in baseline characteristics were observed between the CLHLS and CHARLS cohorts ($p < 0.001$). Pearson correlation analysis indicated that COPD prevalence was positively associated with sex, age, educational level, marital status, multiple comorbidities, and smoking ($p < 0.05$). Kaplan–Meier survival analysis demonstrated significant differences in survival curves according to cohort, survival age, baseline COPD, newly diagnosed COPD, and total COPD ($p < 0.05$), whereas no significant difference was found between sexes ($p > 0.05$). Cox proportional hazards regression showed that female sex, older age, baseline COPD, lower educational level, marital status, and smoking were significantly associated with COPD-specific mortality ($p < 0.05$), while residence, alcohol consumption, and exercise were not significantly associated ($p > 0.05$).
Conclusion: Older age, male sex, smoking, lower educational level, and long-term widowhood are associated with a higher risk of COPD-specific mortality among middle-aged and older adults with COPD.

Key words: Chinese Longitudinal Healthy Longevity Survey, China Health and Retirement Longitudinal Study, chronic obstructive pulmonary disease, cohort study, survival analysis.

Introduction

Chronic obstructive pulmonary disease (COPD) is a common condition among middle-aged and older adults and is strongly associated with environmental air pollution, smoking, occupational exposure, aging, and genetic factors [1]. As of 2023, data from the Global Burden of Disease (GBD) database indicate that the global number of individuals living with COPD has exceeded 200 million, with approximately one-quarter of cases occurring in China – an increase of about 3 million compared with 2021 [2]. This condition not only severely impairs the

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quality of life of middle-aged and older adults but also imposes a substantial burden on both families and society through the need for elderly care. A 16-year follow-up study demonstrated that patients with COPD have significantly higher risks of all-cause and cause-specific mortality compared with individuals without COPD, and are also at increased risk of other respiratory diseases, cardiovascular diseases, and infectious diseases [3]. Furthermore, a Mendelian randomization study by Liu *et al.* revealed that COPD may increase the risk of lung cancer, particularly lung adenocarcinoma, by stimulating immune responses and tumor cell activity [4]. This may be explained by the fact that COPD further limits patients' physical activity, resulting in reduced duration and frequency of cardiopulmonary exercise, increased susceptibility to infections, and persistent inflammatory stimulation that may accelerate tumor cell proliferation or promote pathological changes in lung tissue, bronchi, and blood vessels [5, 6].

However, due to limited observation of exposure intensity to risk factors such as population aging, tobacco use, air pollution, and comorbidities, substantial gaps remain in the prevention and control of COPD and related diseases in China. The Chinese Longitudinal Healthy Longevity Survey (CLHLS) and the China Health and Retirement Longitudinal Study (CHARLS) databases provide important micro-level data sources for Chinese scholars to investigate population aging and related social, economic, and health issues. These databases are of great significance for interdisciplinary research, healthcare support, and the development of targeted aging-related policies with Chinese characteristics [7, 8]. Based on these resources, the present study integrated data from the CLHLS and CHARLS databases to analyze the risk of all-cause mortality associated with COPD. The aim was to clarify the survival status and mortality characteristics of middle-aged and older adults with COPD, thereby providing additional scientific evidence to support their rehabilitation and clinical management.

Material and methods

Data information

In December 2025, data related to COPD were extracted from the CLHLS and CHARLS databases to conduct a retrospective cohort study. As no new clinical medical records were involved, ethical approval was not required for this study.

1) CLHLS database:

- The study population included older adults aged 65–119 years and their children aged 35–65 years.
- Collected data included more than 30 biomedical indicators covering routine blood tests, routine urine tests, and plasma biochemical tests.
- The follow-up survey included community-level information on socioeconomic conditions, healthcare, elderly care services, air pollution, and other environmental factors across 23 provinces, municipalities, and autonomous regions, involving more than 860 counties or districts nationwide.
- The study data were derived from the first wave of the survey conducted in 1998 and the most recent follow-up survey conducted during 2017–2018, including a total of 15,874 participants aged ≥ 65 years.
- Website: https://opendata.pku.edu.cn/dataset.xhtml?persistentId=doi:10.18170/DVN/WBO7LK

2) CHARLS database:

- The study population included middle-aged and older adults aged 45 years and older and their families.
- The database contains information on basic demographics, health status and functioning, healthcare and insurance, family structure, and household income and expenditures.
- The survey covered 150 county-level units and 450 village-level units, involving approximately 10,000 households and 17,000 individuals.
- The data were derived from the baseline survey conducted in 2011 and the fifth wave of the survey conducted in 2020.
- Website: https://charls.pku.edu.cn/index.htm.

Methods

Variable inclusion

Information on 19,104 COPD cases and related variables from the two databases was obtained through questionnaires or follow-up records. Among them, all cases diagnosed with COPD or other diseases were clearly confirmed by medical institution examinations, including imaging examinations (such as chest CT and MRI), pulmonary function tests (including forced vital capacity [FVC], forced expiratory volume in 1 s [FEV_1], and peak expiratory flow [PEF]), inflammatory markers, blood routine tests, and pathological examinations, excluding self-reported cases. Data were screened according to the datasets, codebooks, questionnaires, coding manuals, and release statements of the two databases, and a total of 17,988 participants were ultimately included to establish a longitudinal cohort. Specifically, for the CLHLS database, 9,093 participants were initially included based on the 1998 baseline data; after excluding 200 cases with unclear or inconsistent survey year information, 79 cases with missing basic information, and 201 cases with missing disease information, 8,613

participants remained and were included in the study. For the CHARLS database, household registration forms, basic information, and health status and functioning data were merged using patient IDs from the 2011 baseline survey, resulting in an initial sample of 10,011 participants; after data cleaning and screening, 25 cases with missing demographic information such as sex and age, 153 cases aged < 45 years, and 458 cases with missing disease information including COPD were excluded, leaving 9,375 participants for inclusion in the study (Figure 1).

Observed data

Baseline variables included sex, residence, education, marital status, COPD, other common chronic diseases, smoking, alcohol consumption, and exercise. In the CLHLS cohort, the variable "education" was recorded as years of schooling (0–26 years), whereas in the CHARLS cohort it was recorded as educational attainment (from no formal education to doctoral degree). To enhance comparability, education levels were standardized according to the Chinese education system into four categories: primary school or below (0–6 years), junior to senior high school (7–12 years), secondary vocational school to junior college (13–16 years), and bachelor's degree or above (17–26 years). For the smoking variable, individuals who had ever smoked but had quit, as well as those who were currently smoking or had smoked within the past month, were classified as smokers; otherwise, they were classified as non-smokers. For alcohol consumption, individuals who had never consumed alcohol or had consumed alcohol less than once per month on average during the past year were classified as non-drinkers, while all others were classified as drinkers.

Statistical analysis

Data from the CLHLS and CHARLS databases were processed using STATA 18 and IBM SPSS Statistics 27 for data cleaning, screening, merging, coding conversion, and handling of missing values. Categorical variables were expressed as n (%) and compared using the χ^2 test, while continuous variables were presented as mean ± standard deviation (±s) and compared using the *t*-test. Pearson correlation coefficients were calculated to assess the relationships between COPD prevalence and various indicators. Based on follow-up data, Kaplan–Meier survival analysis and Cox proportional hazards regression models were performed for COPD-specific mortality. The log-rank test was used to examine survival differences between groups in the Kaplan–Meier analysis. For participants with follow-up but missing survival time, the overall mean survival time was imputed. Stratified Cox regression analyses were conducted for the CLHLS and CHARLS cohorts using the Breslow method. In the Cox models, a hazard ratio (HR) > 1 indicated an increased risk (risk factor), HR < 1 indicated a decreased risk (protective factor), and HR = 1 indicated no effect. Statistical significance was set at $p < 0.05$.

Results

Comparison of baseline characteristics between the two cohorts

In the CLHLS cohort, the proportions of males, urban residents, participants with hypertension,

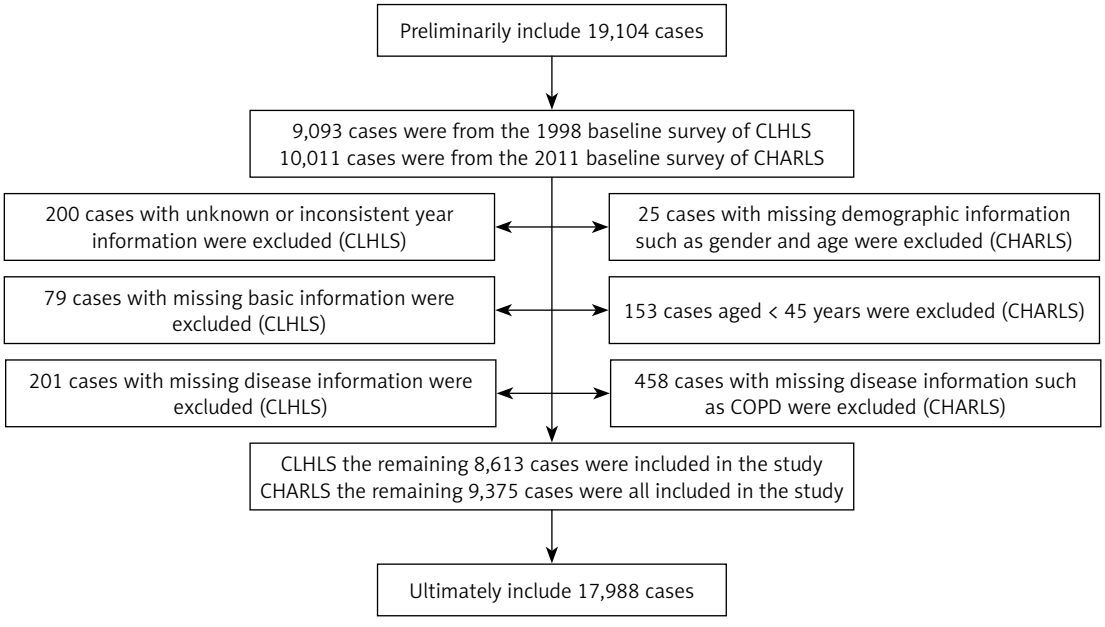


Figure 1. Flowchart of data inclusion from the CLHLS and CHARLS databases

diabetes, cancer, heart attack, digestive diseases, emotional or mental problems, arthritis or rheumatism, smoking, and exercise duration were all significantly lower than those in the CHARLS cohort, whereas age, primary school education or below, widowed status, COPD, stroke, memory-related diseases, and alcohol consumption were significantly higher than in the CHARLS cohort, with all differences reaching statistical significance ($p < 0.001$). There were no statistically significant differences in chronic disease management between the two cohorts ($p > 0.05$). The CLHLS cohort did not separately collect data on dyslipidemia, liver disease, kidney disease, or asthma; therefore, comparisons for these variables were not conducted (Table I).

Correlation analysis between COPD prevalence and various indicators

Pearson correlation analysis showed that COPD prevalence was positively associated with sex, age, educational level, marital status, hypertension, diabetes, cancer, liver disease, heart attack, stroke, kidney disease, digestive diseases, memory-related diseases, arthritis or rheumatism, asthma, and smoking ($p < 0.05$), whereas no significant associations were observed with residence, dyslipidemia, emotional or mental problems, alcohol consumption, or exercise ($p \geq 0.05$) (Table II).

COPD incidence and survival status during follow-up

In the CLHLS cohort, a total of 4,546 participants were followed from 1998 to 2018, with 4,067 lost to follow-up. In the CHARLS cohort, 2,630 participants were followed from 2011 to 2020, with 6,745 lost to follow-up. Compared with the CHARLS cohort, the CLHLS cohort had significantly higher proportions of females, deaths, survival age, newly diagnosed COPD, and total COPD, while survival time was significantly lower, with all differences reaching statistical significance ($p < 0.001$) (Table III). In addition, information on cause of death was collected from relatives of deceased participants, including medical history, admission diagnosis, primary diagnosis, and autopsy reports, to ascertain the cause of death (Table IV).

Survival analysis of COPD by different subgroups

Kaplan–Meier survival analysis was performed using COPD-specific mortality as the outcome event and survival time as the time variable. Significant differences in survival curves were observed between cohorts, age groups, baseline COPD, newly diagnosed COPD, and total COPD ($p < 0.05$), whereas no significant differences were found between sexes ($p > 0.05$) (Table V, Figures 2 A–F).

Cox proportional hazards regression analysis of COPD

Cox proportional hazards regression analysis was conducted using baseline COPD as the exposure variable, COPD-specific mortality as the outcome event, and survival time as the time variable. In Model 1, the mortality risk for females was 28% [(1–0.72) 100%] lower than that for males, each additional year of age was associated with an 8% increase in mortality risk, and participants without baseline COPD had an 87% [(1–0.13) 100%] lower risk of mortality compared with those with baseline COPD. After adjustment in Models 2 and 3, sex, age, baseline COPD, educational level, marital status, and smoking remained significantly as-

Table I. Comparison of baseline characteristics between the CLHLS and CHARLS cohorts ($\bar{x} \pm$ SD, *n* (%))

Item		CLHLS (*n* = 8613)	CHARLS (*n* = 9375)	$t/\chi^2/Z$	*P*-value
Sex	Male	3411 (39.60)	4595 (49.01)	160.950	< 0.001
	Female	5202 (60.40)	4780 (50.99)		
Age [years]		92.30 ±7.67	60.28 ±10.34	234.240	< 0.001
Residence	Urban	3176 (36.87)	3819 (40.74)	28.166	< 0.001
	Rural	5437 (63.13)	5556 (59.26)		
Education level	≤ Primary school	7905 (91.78)	6256 (66.73)	1800	< 0.001
	Middle high school	506 (5.87)	2638 (28.14)		
	Vocational associate degree	116 (1.35)	401 (4.28)		
	≥ Bachelor's degree	86 (1.00)	80 (0.85)		
Marital status	Divorced/separated	153 (1.78)	209 (2.23)	7200	< 0.001
	Never married	97 (1.13)	143 (1.53)		
	Married/living with	1397 (16.22)	7307 (77.94)		
	Widowed	6966 (80.88)	1716 (18.30)		

Table I. Cont.

Item		CLHLS (n = 8613)	CHARLS (n = 9375)	$t/\chi^2/Z$	P-value
COPD	Yes	1078 (12.52)	1017 (10.85)	406.437	< 0.001
	No	7187 (83.44)	8358 (89.15)		
	Don't know	348 (4.04)	0 (0.00)		
Hypertension	Yes	1121 (13.02)	2390 (25.49)	870.245	< 0.001
	No	7050 (81.85)	6985 (74.51)		
	Don't know	442 (5.13)	0 (0.00)		
Dyslipidemia	Yes	/	907 (9.67)	/	/
	No	/	8468 (90.33)		
Diabetes	Yes	69 (0.80)	541 (5.77)	815.663	< 0.001
	No	8095 (93.99)	8834 (94.23)		
	Don't know	449 (5.21)	0 (0.00)		
Cancer	Yes	44 (0.51)	93 (0.99)	535.585	< 0.001
	No	8100 (94.04)	9282 (99.01)		
	Don't know	469 (5.45)	0 (0.00)		
Liver disease	Yes	/	381 (4.06)	/	/
	No	/	8994 (95.94)		
Heart attack	Yes	630 (7.31)	1176 (12.54)	593.600	< 0.001
	No	7550 (87.66)	8199 (87.46)		
	Don't know	433 (5.03)	0 (0.00)		
Stroke	Yes	271 (3.15)	215 (2.29)	449.110	< 0.001
	No	7953 (92.34)	9160 (97.71)		
	Don't know	389 (4.52)	0 (0.00)		
Kidney disease	Yes	/	631 (6.73)	/	/
	No	/	8744 (93.27)		
Digestive disease	Yes	277 (3.22)	2083 (22.22)	1800	< 0.001
	No	7942 (92.21)	7292 (77.78)		
	Don't know	394 (4.57)	0 (0.00)		
Emotional/nervous/ psychiatric problems	Yes	35 (0.41)	116 (1.24)	37.238	< 0.001
	No	8578 (99.59)	9259 (98.76)		
Memory-related disease	Yes	1075 (12.48)	136 (1.45)	869.837	< 0.001
	No	7538 (87.52)	9239 (98.55)		
Arthritis/rheumatism	Yes	84 (0.98)	3189 (34.02)	3300	< 0.001
	No	8529 (99.02)	6186 (65.98)		
Asthma	Yes	/	376 (4.01)	/	/
	No	/	8999 (95.99)		
Smoking	Yes	2780 (32.28)	3803 (40.57)	132.906	< 0.001
	No	5833 (67.72)	5572 (59.43)		
Drinking	Yes	3006 (34.90)	2332 (24.87)	216.222	< 0.001
	No or < 1/month	5607 (65.10)	7043 (75.13)		
Exercise [h/day]	< 2	6324 (73.42)	6592 (70.31)	21.434	< 0.001
	≥ 2	2289 (26.58)	2783 (29.69)		
Chronic disease management	Yes	3005 (34.89)	3188 (34.01)	1.553	0.213
	No	5608 (65.11)	6187 (65.99)		

sociated with COPD-specific mortality ($p < 0.05$), whereas residence, alcohol consumption, and exercise showed no significant association ($p > 0.05$) (Table VI).

Sensitivity analysis

A global proportional hazards (PH) assumption test was performed for the core Cox model (Model 3), which indicated that the baseline COPD variable did not satisfy the PH assumption ($\chi^2 = 40.99$, $p < 0.05$). After correction using a time-varying coefficient Cox model, the main effect of baseline COPD showed an HR of 0.06 (95% CI: 0.046–0.079, $p < 0.001$), and the time-dependent effect had an HR of 1.13 (95% CI: 1.091–1.172, $p < 0.001$), indicating that the protective effect of not having baseline COPD slightly decreased over follow-up time but remained protective (main effect HR < 1). Meanwhile, the effect directions of other variables, including sex, age, and educational lev-

Table II. Correlation between COPD prevalence and various indicators (*r*)

Variable	*r*	95% CI	*P*-value
Sex	0.062	0.048–0.077	< 0.001
Age	0.015	0–0.029	0.046
Residence	–0.004	–0.019–0.011	0.595
Education level	0.015	0–0.030	0.044
Marital status	0.024	0.009–0.038	0.002
Hypertension	0.138	0.123–0.152	< 0.001
Dyslipidemia	0.011	-0.003–0.026	0.127
Diabetes	0.227	0.213–0.240	< 0.001
Cancer	0.264	0.250–0.278	< 0.001
Liver disease	0.040	0.026–0.055	< 0.001
Heart attack	0.235	0.221–0.248	< 0.001
Stroke	0.236	0.222–0.250	< 0.001
Kidney disease	0.059	0.045–0.074	< 0.001
Digestive disease	0.206	0.192–0.220	< 0.001
Emotional/nervous/psychiatric problems	0.007	–0.007–0.022	0.319
Memory-related disease	0.025	0.010–0.039	0.001
Arthritis/rheumatism	0.064	0.050–0.079	< 0.001
Asthma	0.207	0.193–0.221	< 0.001
Smoking	0.085	0.070–0.099	< 0.001
Drinking	0.015	0–0.029	0.051
Exercise	–0.007	–0.022–0.007	0.318

Table III. COPD incidence and survival status during follow-up ($\bar{x} \pm SD$, *n* (%))

Item		CLHLS (*n* = 4546)	CHARLS (*n* = 2630)1	t/χ^2	*P*-value
Sex	Male	1842 (40.52)	1312 (49.89)	59.340	< 0.001
	Female	2704 (59.48)	1318 (50.11)		
Death	Yes	3479 (76.53)	409 (15.55)	2495.448	< 0.001
	No	1067 (23.47)	2221 (84.45)		
Alive time [years]		5.96 ±2.70	8.46 ±1.54	403.919	< 0.001
Alive age [years]		96.34 ±7.19	69.02 ±9.82	316.840	< 0.001
Baseline COPD	Yes	515 (11.33)	338 (12.85)	3.690	0.055
	No	4031 (88.67)	2292 (87.15)		
Newly diagnosed COPD	Yes	607 (13.35)	207 (7.87)	49.782	< 0.001
	No	3939 (86.65)	2423 (92.13)		
Total COPD	Yes	1122 (24.68)	545 (20.72)	14.640	< 0.001
	No	3424 (75.32)	2085 (79.28)		

[1]In the CLHLS cohort, 4,067 participants were lost to follow-up, while in the CHARLS cohort, a total of 6,745 participants were lost to follow-up.

Table IV. Distribution of causes of death (*n*)

Item	CLHLS (*n* = 3479)	CHARLS (*n* = 409)	Total
COPD deaths	872	93	965
CVD deaths	258	14	272
Heart disease deaths	147	4	151
Accident deaths	228	/	228
Cancer deaths	89	11	100
Digestive disease deaths	144	/	144
Respiratory disease deaths	78	6	84
Other	1663	281	1944
Total	3479	409	3888

Table V. Survival analysis of COPD by different subgroups (*n*)

Variable		Observed events	Expected events	Median alive time [years]	Log-rank χ^2	*P*-value
Group	CLHLS	872	528.98	12	645.75	< 0.001
	CHARLS	89	432.02	/		
Sex	Male	449	425.69	15	2.38	0.123
	Female	512	535.31	15		
Alive age [years]	< 60	7	91.46	/	538.68	< 0.001
	60–79	46	275.72	/		
	80–99	635	401.32	13		
	≥ 100	270	189.50	14		
Baseline COPD	Yes	467	112.41	9	1311.94	< 0.001
	No	494	848.59	18		
Newly diagnosed COPD	Yes	494	133.73	9	1197.73	< 0.001
	No	467	827.27	20		
Total COPD	Yes	961	246.14	9	2931.57	< 0.001
	No	0	714.86	/		

el, remained consistent with the primary analysis. These results support the consistency of the main findings after accounting for the violation of the PH assumption.

Discussion

Current research status of COPD

This study revealed that the prevalence of COPD was 12.52% in individuals aged ≥ 45 years and 10.85% in those aged ≥ 65 years, and that COPD was positively associated with multiple comorbidities. The long-term presence of COPD can be associated with "airway–systemic inflammation", hypoxemia/hypercapnia, impaired pulmonary ventilation, and pulmonary hypertension, which may lead to hemodynamic disturbances and neurohumoral dysregulation and may contribute to multi-system structural and functional impairment [9, 10]. Zhang *et al.* [11] reported that approximately 42% of COPD patients had varying degrees of comorbidities, and the risk of all-cause mortality increased significantly with longer follow-up. However, other studies have indicated that all-cause mortality risk in COPD is also influenced by sociodemographic and geographic factors; for example, individuals living in rural areas have been reported to have lower all-cause mortality [12, 13]. Galiatsatos *et al.* [14] analyzed 1,800 COPD patients and found that participation and exacerbation rates in communities with better living environments were 56% and 98% higher, respectively, than in communities with poorer environments ($p < 0.01$). Lee *et al.* [15] further reported that adverse COPD events were independently associated with socioeconomic status and air pollution. These findings suggest that regional differences may substantially affect the generalizability of survey results. Therefore, by integrating follow-up data from different cohorts, this study further analyzed the risk of all-cause mortality in COPD patients.

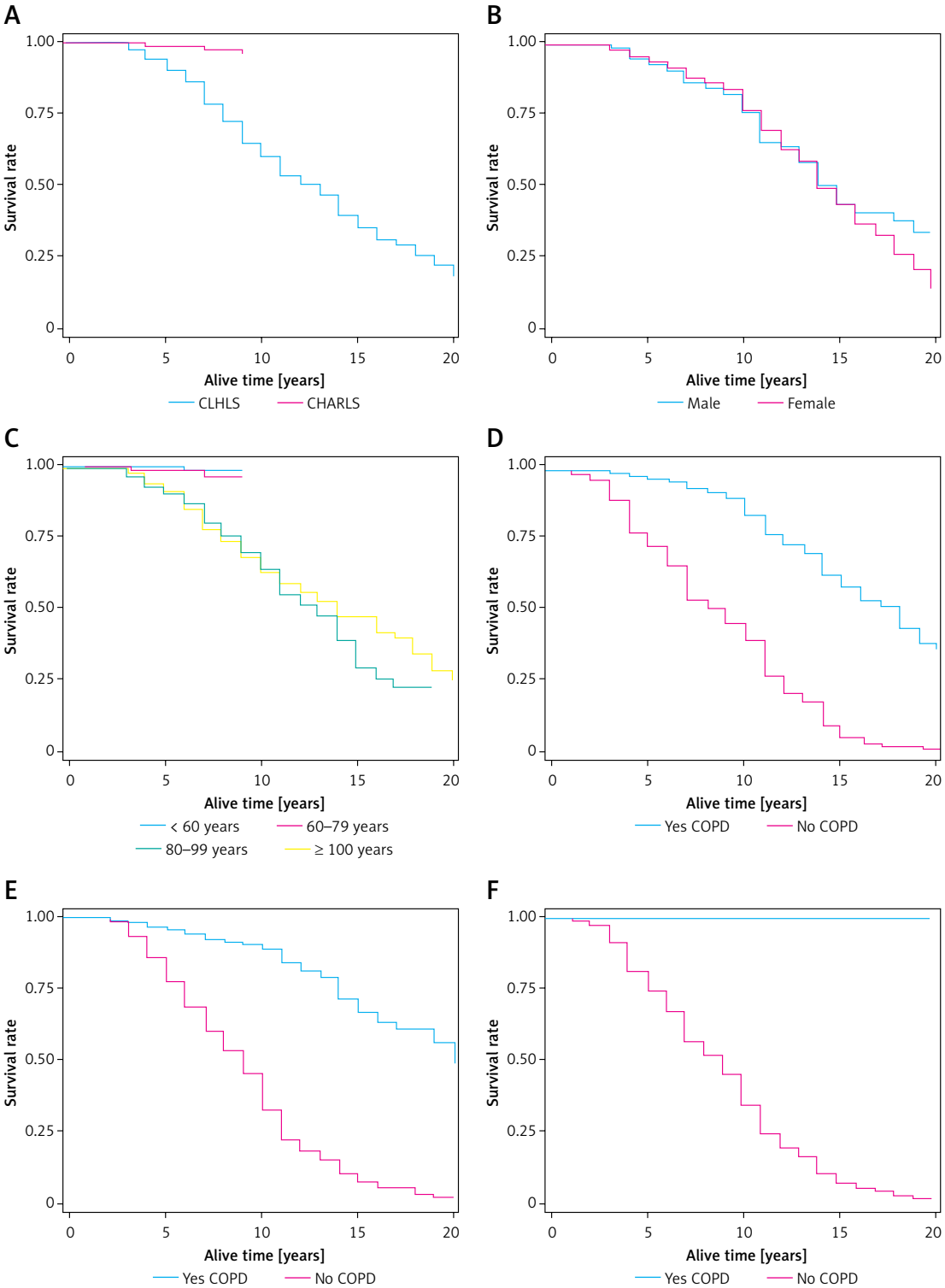


Figure 2. A – Survival curves by cohort; **B** – Survival curves by sex; **C** – Survival curves by age groups; **D** – Survival curves by baseline COPD status; **E** – Survival curves by newly diagnosed COPD; **F** – Survival curves by total COPD status

Table VI. Cox proportional hazards regression analysis of COPD [HR (95% CI)]

Variable	Model 1	Model 2	Model 3
Sex	0.72 (0.628–0.818)***	0.76 (0.648–0.892)**	0.76 (0.646–0.890)**
Baseline age	1.08 (1.071–1.082)***	1.06 (1.048–1.067)***	1.05 (1.037–1.056)***
Baseline COPD	0.13 (0.115–0.151)***	0.13 (0.117–0.153)***	0.13 (0.116–0.153)***
Residence	/	1.01 (0.878–1.165)	1.05 (0.909–1.209)
Education level	/	0.81 (0.673–0.971)*	0.81 (0.674–0.971)*
Marital status	/	1.24 (1.079–1.417)**	1.23 (1.074–1.407)**
Smoking	/	0.76 (0.646–0.883)***	0.76 (0.653–0.892)**
Drinking	/	0.99 (0.860–1.144)	1.00 (0.869–1.158)
Exercise	/	0.92 (0.797–1.070)	0.94 (0.811–1.091)
Weight	/	1	1

*Model 1 was adjusted for sex and age; Model 2 was adjusted for sex, age, residence, education, marital status, smoking, alcohol consumption, exercise, and weight; Model 3 was based on Model 2 and used stratified Cox regression by CLHLS and CHARLS cohorts. *P < 0.05, **P < 0.01, ***P < 0.001.*

Follow-up and survival analysis of COPD

During follow-up from 1998 to 2018, the CLHLS cohort exhibited a mortality rate of 76.53% (3,479/4,546), which was significantly higher than the 15.55% (409/2,630) observed in the CHARLS cohort from 2011 to 2020, and median survival time was markedly shorter than in CHARLS. This finding is consistent with the older age and greater burden of chronic disease in the CLHLS cohort [16]. Consequently, age at death/end of follow-up and baseline, newly diagnosed, and total COPD were significantly lower in the CHARLS cohort compared with CLHLS. Kaplan–Meier survival analysis for COPD-specific mortality showed that participants without baseline or newly diagnosed COPD had median survival times of 18 and 20 years, respectively. Subsequent Cox proportional hazards regression analysis showed that individuals without baseline COPD had an 87% lower risk of mortality compared with those with baseline COPD. These results indicate that absence of COPD was associated with a lower hazard of COPD-specific mortality. Moreover, survival curves differed significantly across cohorts and age groups ($p < 0.05$); although individuals under 79 years did not reach median survival, their survival rates were clearly higher than those aged 80 years and above. This suggests that particular attention should be paid to monitoring disease status and physical function in individuals aged ≥ 80 years, and that age-stratified approaches to COPD management and prevention may be warranted.

Furthermore, COPD is associated with increased mortality from cardiovascular and cerebrovascular diseases and other comorbidities [17, 18]. Even mild COPD is associated with significantly higher all-cause mortality and respiratory disease-related mortality compared with individuals without COPD, and the risk of all-cause death has been reported to increase with greater severity or frequency of clinical symptoms such as wheezing, airway obstruction, respiratory infections, and pneumonia [19, 20]. A systematic review [21] reported that, compared with mild COPD, the hazard ratios for mortality progressively increase with moderate, severe, and very severe COPD (HR = 1.32, 1.62, 2.18, and 2.94, respectively), with the highest risk observed among patients with concurrent respiratory diseases (HR = 3.64), followed by those with lung cancer (HR = 2.57). These findings indicate that, in COPD follow-up studies, particular attention should be paid to monitoring symptom onset and frequency in high-risk populations, such as individuals with impaired lung function or a history of pulmonary disease, and to encouraging self-monitoring by patients and their families, which may help inform assessment of COPD-related mortality and comorbidity risk.

Analysis of COPD-specific mortality

After adjustment in Models 1–3, female sex was associated with a slightly increased mortality risk, but remained associated with a lower hazard of COPD-specific mortality (HR = 0.76). This may be related to males having significantly higher rates of smoking and occupational exposures, and the cumulative effect of these hazards may contribute to a higher risk of COPD-related death [22, 23]. Accordingly, Zou *et al.* [24] suggested that, based on the differences in COPD risk between males and females associated with exposures such as smoking, drinking behaviors, or occupational exposures including environmental particulate matter, ozone, and high temperature, relevant departments should strengthen disease prevention and treatment measures, and further investigate sex-specific biological characteristics in COPD. Each additional year of age was associated with a 5–8% higher hazard of COPD-specific mortality, indicating that older age was associated

with higher mortality hazard. With advancing age, patients' self-care abilities decline, and economic, medical, and caregiving burdens increase [25, 26], which may contribute to the higher COPD mortality risk observed among widowed individuals compared with those with a partner (HR = 1.23). Place of residence was not significantly associated with COPD-specific mortality, suggesting that residence was not an important independent predictor of COPD-specific mortality in this analysis. Subsequent sensitivity analyses confirmed these findings.

In addition to targeted medical interventions, the management or symptom control of COPD largely depends on daily care provided by individuals and their families, as well as the level of knowledge about the disease [27]. Higher educational attainment can improve patients' quality of life across multiple domains, including diet, healthcare, physical activity, and social engagement, while also reducing disease burden and supporting psychological well-being and cognitive function [28, 29]. Furthermore, an international study [30] reported that lower educational levels are associated with an increased risk of hospitalization for COPD. Therefore, for participants with lower educational attainment, health education and disease-related knowledge dissemination should be strengthened to promote early prevention and management of COPD and other chronic conditions. In Models 2 and 3, the hazard ratio (HR) for smoking was 0.76, indicating that the group classified as nonsmokers had a 24% lower hazard of COPD-specific mortality than the reference group. It should be noted that in this study, both current and former smokers were classified as smokers. However, de la Rosa-Carrillo *et al.* [31] reported that smoking cessation has a beneficial effect in reducing the incidence of bronchiectasis and significantly improves COPD clinical symptoms. Analyses by Wang *et al*. [32] and Huang *et al.* [33] further demonstrated that smoking cessation significantly improves lung function and exercise capacity in COPD patients. These findings support the potential benefits of smoking cessation but do not establish an effect on COPD-related mortality in the present study. Nevertheless, the duration of cessation required to lower mortality risk, the extent of risk reduction, and whether risk can return to normal remain unclear. Secondly, although the study's models showed consistent findings in sensitivity analyses, a large number of patients were lost to follow-up in both the CLHLS and CHARLS cohorts (47.22% and 71.95%, respectively). High loss to follow-up may reduce the proportion of effective samples, which can affect population representativeness and reliability to a certain extent, potentially introducing selection bias. This may be related to differences in follow-up participation across factors such as geographic location, educational level, age, and comorbidity burden, but these factors were not directly evaluated in the present study. Therefore, when conducting large-scale data collection and model construction, effective follow-up strategies should be implemented according to the actual situation of different regions, such as infrastructure, community management, healthcare levels, and population demographics, in order to reduce sample attrition and enhance the generalizability of results.

In conclusion, sex, age, baseline COPD, education, marital status, and smoking were all significantly associated with COPD-specific mortality, suggesting that these factors may help identify individuals at higher risk and inform targeted risk-reduction strategies. However, this study also has the following limitations. (1) This study did not analyze participants' economic status because the CLHLS database lacks information on personal and household income, and the corresponding data in CHARLS are highly heterogeneous. Nevertheless, previous research indicates that economic status can also influence the development of COPD and related diseases. (2) The protective effect of smoking cessation on COPD-specific mortality could not be adequately evaluated. However, both the CLHLS and CHARLS databases contain relatively few participants who had quit smoking and had available data on pulmonary function changes and COPD outcomes, which makes it difficult to adequately evaluate the effects of smoking cessation. (3) The CLHLS survey covered the period from 1998 to 2018, whereas the CHARLS survey covered the period from 2011 to 2020. Differences in COPD diagnostic criteria across different periods may have affected the comparability and interpretation of the study results to some extent. (4) Different levels of COPD severity may require different prevention and management strategies; however, this study did not conduct a detailed analysis based on COPD severity. Therefore, future studies should include larger sample sizes and more objective indicators, establish proactive follow-up strategies, and further investigate these issues.

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Ethical approval

This study was carried out according to Helsinki Declaration, and approved by the Ethics Committee of Hunan Provincial People's Hospital.

Conflict of interest

The authors declare no conflict of interest.

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