**Preplanned Studies**

### Risk of Lung Cancer and Occupational Exposure to Polycyclic Aromatic Hydrocarbons Among Workers Cohorts

— Worldwide, 1969–2022

Huige Yuan; Yanhua Wang; Huawei Duan

### Summary

**What is already known about this topic?**

Lung cancer has a high mortality, resulting in a severe disease burden. Polycyclic aromatic hydrocarbons (PAHs) are definitive carcinogens to human, and occupational exposure to PAHs is associated with lung cancer.

**What is added by this report?**

We analyzed the cancer cases from cohort studies on various PAHs exposed workers in China and other countries, calculated the quantitative risk of lung cancer based on meta-analyses, and confirmed the increased risk from lung cancer in selected PAHs exposed occupations.

**What are the implications for public health practices?**

There is a clear need to prevent lung cancer on a wide range of PAHs-related occupations in China and around the world. It is crucial to establish guidelines for improving the monitoring on exposure and health promotion in related working environments.

Polycyclic aromatic hydrocarbons (PAHs), the chemical mixture characterized by two or more benzene rings, which mainly derive from the insufficient combustion of organic materials, can cause some respiratory diseases and lung cancer. Globally, lung cancer cases and deaths are increasing. In 2018, International Agency for Research on Cancer (IARC) estimated 2.09 million new cases and 1.76 million deaths, due partly to occupational exposure to PAHs (1). IARC has identified 12 occupational exposures to lung carcinogens, including aluminum production, coke, and coal gasification fumes (2). Coal tar and bitumen are also occupational carcinogens identified by IARC, containing a variety of carcinogenic PAHs in volatile compounds. Exposure industries include coal tar products, coke, gas, aluminum, steel plants, paving and construction, etc. Lung cancer caused by coke oven emissions has been listed as a national statutory occupational cancer in China and most countries (3). In China, the manufacturing industry is developing with many workers. Lung cancer caused by occupational exposure to PAHs is a serious public health problem that needs attention. The relationship between PAHs and lung cancer is inconsistent in different industries. To explore the status of lung cancer caused by PAHs, a meta-analysis of related cohorts was conducted in this study.

We conducted a systematic literature analysis in the databases of PubMed, Embase, Web of Science, China National Knowledge Infrastructure (CNKI), Wan Fang, China Science and Technology Journal Database from January 1, 1969 to March 1, 2022. Combining subject words and free words, taking PubMed as an example, the retrieval formula was “[(polycyclic aromatic hydrocarbons) OR PAHs] AND [(lung cancer) OR (lung neoplasm)] AND [(cohort OR prospective OR longitudinal OR retrospective)]”. We hand-searched references that have been included in the articles to identify relevant studies. The retrieved studies were selected through inclusion and exclusion criteria by two researchers independently. The retrieved articles were read in full and extracted key information. Concrete inclusion criteria included: (a) studies published before March 2022; (b) study type was prospective or retrospective cohort study; (c) subjects were occupational populations exposed to PAHs; and (d) number of cases, standardized incidence ratio (SIR)/standardized mortality ratio (SMR) and 95% confidence interval (CI) of lung cancer were reported in the paper. Some studies were excluded: 1) non-occupational exposure to PAHs; 2) study types other than cohort studies; 3) the required information could not be retrieved completely from the study; and 4) for repeated population studies, only the most complete articles were included. We assessed the quality of the included cohort studies by the Newcastle-Ottawa Scale (NOS). The quality assessments were completed by
two researchers independently, and the disagreement was discussed. Stata (17.0, StataCorp, LP, TX, USA) was used for statistical analysis of the research data, and the evaluation indicators were mainly standardized morbidity or mortality and 95% CI.

PAHs are one of the main risks of lung cancer, and some PAHs-related industries increased the risk of lung cancer among workers. The literature results were in Supplementary Figure S1 (available in https://weekly.chinacdc.cn/), a total of 2,843 studies were initially retrieved from 6 databases. 2,678 articles were excluded after reading the titles and abstracts, and 121 articles were excluded after reading the full text. After screening, 44 articles were identified as eligible literature for meta-analysis. The included articles and retrieved information of articles were shown in Table 1. The random-effects model and fixed-effects model were used separately to combine the results. In Table 2, we presented the results of a pooled analysis of the risk of lung cancer exposure to PAHs across industries and the results of various subgroup analyses. In the random-effects model analysis, the overall pooled relative risk (RR) (95% CI) was 1.32 (1.22–1.43) for 44 studies. Among them, a total of 2,024 lung cancer cases were observed in 11 studies on aluminum production, the pooled RR (95% CI) was 1.15 (1.05–1.26). A total of 571 lung cancer cases were observed totally in 9 studies on coke plants, the pooled RR (95% CI) was 1.82 (1.42–2.32); 1,053 lung cancer cases were collected in 8 cohort studies on iron and steel industries, the pooled RR (95% CI) was 1.39 (1.26–1.53). A total of 650 lung cancer cases were found in 7 cohort studies on asphalt tar production, the pooled RR (95% CI) was 1.28 (1.04–1.59), and 126 lung cancer cases in 6 cohort studies on carbon electrode, the pooled RR (95% CI) was 1.01 (0.77–1.33). Figure 1 showed the meta-analysis of 7 cohort studies on PAHs-related industries in China. For a total of 385 cases, the pooled RR (95% CI) was 1.75 (1.33–2.30). In addition, the three carbon black articles retrieved were not merged due to the small number of articles and the large heterogeneity. Coke production had the highest carcinogenic risk of lung cancer in different industries.

Publication bias analyses were conducted in various industry studies. There was no significant publication bias in any analyses, results were presented in Supplementary Table S1 (available in https://weekly.chinacdc.cn/) (Begg’s test all P>0.05). Among them, the Egger’s test was P<0.05 of the aluminum factory research, but its Begg’s test was P>0.05. We further conducted a sensitivity analysis, and the result was relatively stable. Sensitivity analyses were performed by serially excluding each study to determine the influence of individual studies on the overall risk of lung cancer. The results of sensitivity analysis were shown in Supplementary Figure S2 (available in https://weekly.chinacdc.cn/). We did not find that a study significantly affected the pooled effect size.

**DISCUSSION**

In this study, an excess risk of lung cancer mortality was found for aluminum production workers, and the difference was statistically significant. This was different from the existing research results. The risk of lung cancer has increased in coke, iron and steel, coal tar, asphalt PAHs-related industries, but no excess risk was found in the carbon electrode industry, which is consistent with the existing meta-analysis results (48). Results across industries in China were consistent with global findings that exposure to PAHs increases lung cancer risk. Comparing with the cancer risk from PAHs, the risk of the two cohorts in China was higher than that of pooled RR on coke production, and one study in China had the highest carcinogenic risk in all cohorts on asphalt tar industry. This may be related to higher exposure in these two industries in China.

There are more than 770 million workers in China, and more than 200 million workers are exposed to occupational hazards. There were 323,833 (95% uncertain interval 283,780–369,061) deaths and 14.1 million disability-adjusted life years (DALYs) attributable to total occupational risks in 2017, China, which accounted for 27.9% of global attributable deaths (49). A study estimated that 5.8% [interquartile range (IR), approximately 2%–11%] of China’s land area, where 30% (IR, approximately 17%–43%) of the population lives, exceeded the national ambient B(a)P(eq) standard of 10 ng/m³. The overall population attributable fraction of lung cancer caused by inhalation exposure to PAHs was 1.6% (IR, approximately 0.91%–2.6%), corresponding to an excess annual lung cancer incidence rate of 0.65×10^−5. Biomass and coke production generate about 83% of the total PAHs emission in China (50). A study on coal tar pitch factory in China showed that workers were exposed to PAHs with a maximum exposure concentration of 1.931.45 ng/m³. The lifetime risk of workers was significantly higher than the acceptable range, with workers losing up to 1,033.95 hours of life.
TABLE 1. Summary of worker cohort studies of occupational exposure to PAHs and lung cancer in China and other countries.

| Authors and year | Country | Industry exposure | Follow-up | Outcome | Cases | Population | RR* 95% CI |
|------------------|---------|-------------------|-----------|---------|-------|------------|-----------|
| Mur 1987 (4)     | France  | Aluminum          | 1950–1976 | Mortality | 37    | 6,544      | 1.14 (0.85–1.48) |
| Chu 1996 (5)     | China   | Aluminum          | 1984–1993 | Mortality | 8    | 989        | 1.22 (0.50–2.28) |
| Ronneberg 1999 (6) | Norway | Aluminum          | 1953–1993 | Incidence | 42    | 2,888      | 0.96 (0.69–1.29) |
| Romundstad 2000c (7) | Norway | Aluminum          | 1953–1996 | Incidence | 189   | 11,103     | 1.00 (0.90–1.20) |
| Moulin 2000 (8)  | France  | Aluminum          | 1968–1994 | Mortality | 19    | 2,133      | 0.63 (0.38–0.98) |
| Spinelli 2006 (9) | Canada  | Aluminum          | 1957–1999 | Mortality | 120   | 6,423      | 1.07 (0.89–1.28) |
| Gibbs 2007 (10)  | Canada  | Aluminum          | 1950–1999 | Mortality | 538   | 5,977      | 1.36 (1.25–1.48) |
| Gustavsson 1990 (15) | Sweden | Coke gasification | 1966–1986 | Incidence | 4     | 295        | 0.82 (0.22–2.11) |
| Berger and Manz 1992 (16) | Germany | Coke gasification | 1953–1989 | Mortality | 78    | 4,908      | 2.98 (2.28–3.59) |
| Reid and Buck 1956 (17) | UK     | Coke             | 1950–1954 | Mortality | 14    | 8,000      | 1.40 (0.80–2.30) |
| Wu 1988 (18)     | China   | Coke             | 1971–1982 | Mortality | 93    | 21,995     | 2.55 (2.13–3.03) |
| Swaen 1991 (19)  | Netherlands | Coke        | 1954–1984 | Mortality | 62    | 5,639      | 1.29 (0.99–1.66) |
| Costantino 1995 (20) | USA and Canada | Coke | 1951–1982 | Mortality | 255   | 5,321      | 1.95 (1.59–2.33) |
| Bye 1998 (21)    | Norway  | Coke             | 1962–1993 | Incidence | 7     | 888        | 0.82 (0.33–1.70) |
| Yu 2004 (22)     | China   | Coke             | 1988–2001 | Mortality | 16    | 5,571      | 2.77 (1.70–4.52) |
| Miller 2013 (23) | UK      | Coke             | 1972–1988 | Mortality | 42    | 3,698      | 1.51 (1.06–2.15) |
| Hansen 1991 (24) | Denmark | Iron and steel   | 1970–1980 | Mortality | 9     | 632        | 1.37 (0.63–2.60) |
| Sherson 1991 (25) | Denmark | Iron and steel   | 1967–1985 | Incidence | 166   | 6,144      | 1.30 (1.12–1.51) |
| Fan 1992 (26)    | China   | Iron and steel   | 1972–1974 | Mortality | 76    | 18,242     | 1.04 (0.82–1.31) |
| Sorahan 1994 (27) | UK     | Iron and steel   | 1946–1990 | Mortality | 551   | 10,438     | 1.46 (1.34–1.58) |
| Hao 1995 (28)    | China   | Iron and steel   | 1971–1992 | Mortality | 11    | 622        | 2.04 (1.15–3.61) |
| Moulin 2000 (29) | France  | Iron and steel   | 1946–1990 | Mortality | 54    | 4,897      | 1.19 (0.89–1.55) |
| Hoshuyama 2006 (30) | China | Iron and steel   | 1980–1993 | Mortality | 133   | 21,175     | 1.54 (1.39–1.69) |
| Westberg 2013 (31) | Sweden | Iron and steel | 1958–2004 | Incidence | 53    | 3,045      | 1.58 (1.18–2.06) |
| Miller 1986 (32) | UK      | Asphalt Tar      | 1950–1982 | Mortality | 84    | 6,064      | 0.86 (0.70–1.07) |
| Gong 1996 (33)   | China   | Asphalt Tar      | 1977–1993 | Mortality | 48    | 1,793      | 1.77 (1.30–2.35) |
| Swaen 1997 (34)  | Netherlands | Asphalt Tar | 1947–1988 | Mortality | 48    | 907        | 1.18 (0.87–1.57) |
| Boffetta 2003 (35) | European countries | Asphalt Tar | 1953–2000 | Mortality | 330   | 29,820     | 1.17 (1.04–1.30) |
| Wong and Harris 2005 (36) | USA   | Asphalt Tar      | 1979–2001 | Mortality | 34    | 2,179      | 1.34 (0.93–1.87) |
| Behrens 2009 (37) | Germany | Asphalt Tar      | 1965–2004 | Mortality | 101   | 7,919      | 1.77 (1.46–2.16) |
| Zanardi 2013 (38) | Italy   | Asphalt Tar      | 1964–2001 | Mortality | 5     | 415        | 1.00 (0.40–2.40) |
| Sorahan 2001 (39) | UK      | Carbon black     | 1951–1996 | Mortality | 61    | 1,147      | 1.73 (1.32–2.22) |
| Dell 2006 (40)   | USA     | Carbon black     | 1930–2003 | Mortality | 138   | 5,011      | 0.97 (0.82–1.15) |
| Wellmann 2006 (41) | Germany | Carbon black    | 1976–1998 | Mortality | 50    | 1,535      | 2.18 (1.61–2.87) |
| Teta 1987 (42)   | USA     | Carbon electrode | 1974–1983 | Mortality | 29    | 2,219      | 0.85 (0.57–1.21) |
| Moulin 1989 (43) | France  | Carbon electrode | 1975–1985 | Incidence | 7     | 1,302      | 0.79 (0.32–1.63) |
| Moulin 1989 (43) | France  | Carbon electrode | 1957–1984 | Mortality | 13    | 1,115      | 1.18 (0.63–2.01) |
| Gustavsson 1995 (44) | Sweden | Carbon electrode | 1969–1989 | Mortality | 2     | 901        | 1.68 (0.20–6.07) |
| Donato 2000 (45) | Italy   | Carbon electrode | 1955–1996 | Mortality | 34    | 1,006      | 0.77 (0.53–1.08) |
| Mori 2002 (46)   | Japan   | Carbon electrode | 1951–1988 | Mortality | 9     | 332        | 2.62 (1.20–4.98) |
| Merlo 2004 (47)  | Italy   | Carbon electrode | 1950–1997 | Mortality | 32    | 1,291      | 0.97 (0.67–1.37) |

Abbreviations: RR=relative risk, CI=confidence interval.

* Relative risks of lung cancer (including other respiratory cancers not specified).
expectancy (51). A biomonitoring study of carbon and coal tar processing workers in China showed that the urine PAHs surrogates of 1-hydroxynaphthalene, 2-hydroxynaphthalene, and 1-hydroxypyrene in contact group tar and asphalt were 12.20, 12.55, 7.08 and 10.62, 8.73, 3.07 μg/g creatinine, respectively, which was higher than the general range (52).

In the Healthy China Action (2019–2030), the occupational health protection action was proposed, and workers have the right to occupational health protection in accordance with the law. This study showed that workers in multiple occupations are exposed to PAHs, increasing the risk of lung cancer. Therefore, it is crucial for factories and workers to take protective measures. Specific measures include reducing the toxicity of raw materials, applying new technologies, monitoring environmental PAHs concentration, wearing protective clothing, and ventilating and detoxifying to minimize exposure to PAHs (53). Moreover, global economic integration is the main trend of today’s world economic development, along with avoiding hazard transfer, to

### TABLE 2. Summary of pooled RR (95% CI) of lung cancer and exposure to PAHs in different industries.

| Industry          | No. of cohorts | Number   | Pooled RR (95% CI)* | I² | P for heterogeneity |
|-------------------|----------------|----------|---------------------|----|---------------------|
| Aluminum          | 11             | 69,602   | 1.15 (1.05–1.26)    | 63.9% | 0.001               |
|                   |                |          | 1.23 (1.18–1.29)    |     |                     |
| Coke production   | 9              | 56,315   | 1.82 (1.42–2.32)    | 80.4% | <0.0001             |
|                   |                |          | 2.06 (1.88–2.27)    |     |                     |
| Iron and steel    | 8              | 65,195   | 1.39 (1.26–1.53)    | 52.7% | 0.039               |
|                   |                |          | 1.43 (1.36–1.51)    |     |                     |
| Asphalt tar       | 7              | 49,097   | 1.28 (1.04–1.59)    | 80.8% | <0.0001             |
|                   |                |          | 1.24 (1.15–1.34)    |     |                     |
| Carbon electrode  | 7              | 8,166    | 1.01 (0.77–1.33)    | 43.6% | 0.100               |
|                   |                |          | 0.96 (0.80–1.15)    |     |                     |
| Overall industries| 44             | 256,068  | 1.32 (1.22–1.43)    | 83.3% | <0.0001             |
|                   |                |          | 1.34 (1.31–1.38)    |     |                     |

Notes: I² Statistics for the Heterogeneity Test; Number: Total number of people included in the combined cohorts. Abbreviations: RR=relative risk, PAHs=polycyclic aromatic hydrocarbons; CI=confidence interval.

* The corresponding results are that the former is a random-effects model, and the latter is a fixed-effects model.

FIGURE 1. RR (95% CI) for lung cancer in workers in PAHs-related industries in China. Abbreviations: RR=relative risk; PAHs=polycyclic aromatic hydrocarbons.
serve a healthy China.

China is a large developing country with a booming manufacturing industry. PAHs are widely distributed, and occupational groups have a high probability of exposure to PAHs (54). The incidence of lung cancer may be related to the pollution of PAHs caused by rapid and immature industrialization. The Occupational Disease Prevention and Control Plan (2021–2025) in the 14th Five-Year Report pointed out that we should deepen prevention at the source, improve working conditions in the workplace, strictly supervise law enforcement, improve the efficiency of occupational health supervision, strengthen publicity and training, and enhance the awareness of occupational health in the whole society, etc. The Chinese government can further revise occupational health laws, monitor occupational lung cancer, and develop intelligent production. Therefore, it is necessary to control the emission of PAHs, strengthen protection, and reduce the exposure of PAHs during the rapid development.

This study was subject to some limitations. First, there were few cohort studies among Chinese workers, which needs to be conducted in related occupations from now on. Second, there was heterogeneity in the literature without considering confounding factors.

In conclusion, there is an increased risk of death from lung cancer in PAHs-related industries in China and other countries. There is a prominent need to prevent lung cancer in a wide range of occupations. It is necessary to establish guidelines to cut down the generation and emission of PAHs during the production process, to improve health promotion in the occupational population and industries.

Conflicts of Interest: No conflicts of interest reported.  
Funding: Supported by the National Natural Science Foundation of China (81971416, 82073525), Beijing Natural Science Foundation (7214279). 

doi: 10.46234/ccdcw2022.085

† Corresponding author: Huawei Duan, duanhw@niohp.chinacdc.cn.

1 National Institute for Occupational Health and Poison Control, Chinese Center for Disease Control and Prevention, Beijing, China.

Submitted: April 01, 2022; Accepted: April 26, 2022

REFERENCES

1. Bade BC, Cruz CSD. Lung cancer 2020: epidemiology, etiology, and prevention. Clin Chest Med 2020;41(1):1 – 24. http://dx.doi.org/10.1016/j.ccm.2019.10.001.
2. Mao YS, Yang D, He J, Krasna MJ. Epidemiology of lung cancer. Surg Oncol Clin N Am 2016;25(3):439 – 45. http://dx.doi.org/10.1016/j.soc.2016.02.001.
3. Loomis D, Guha N, Hall AL, Straif K. Identifying occupational carcinogens: an update from the IARC Monographs. Occup Environ Med 2018;75(8):593 – 603. http://dx.doi.org/10.1136/oemed-2017-104944.
4. Mur JM, Moulin JJ, Meyer-Bisch C, Nassin N, Coulon JP, Loulegue J. Mortality of aluminium reduction plant workers in France. Int J Epidemiol 1987;16(2):257 – 64. http://dx.doi.org/10.1093/ije/16.2.257.
5. Chu LF, Sun PL, Man Y, Wang YJ. An epidemiologic study on mortality of malignancy in electrolytic aluminum workers. Chin J Ind Hyg Occup Dis 1996;14(6):347 – 50. http://dx.doi.org/10.3760/cma.j.issn.1001-9391.1996.06.111. (In Chinese).
6. Renneberg A, Haldorsen T, Romundstad P, Andersen A. Occupational exposure and cancer incidence among workers from an aluminum smelter in western Norway. Scand J Work Environ Health 1999;25(3):207 – 14. http://dx.doi.org/10.5271/sjweh.425.
7. Romundstad P, Andersen A, Haldorsen T. Cancer incidence among workers in six Norwegian aluminum plants. Scand J Work Environ Health 2000;26(6):461 – 9. http://dx.doi.org/10.5271/sjweh.569.
8. Moulin JJ, Clavel T, Bucler B, Laffitte-Rigaud G. A mortality study among workers in a French aluminum reduction plant. Int Arch Occup Environ Health 2000;73(5):323 – 30. http://dx.doi.org/10.1007/s004200000124.
9. Spinelli JJ, Demers PA, Le ND, Friesen MD, Lorenzi MF, Fang R, et al. Cancer risk in aluminum reduction plant workers (Canada). Cancer Causes Control 2006;17(7):939 – 48. http://dx.doi.org/10.1007/s10552-006-0031-9.
10. Gibbs GW, Armstrong B, Sevigny M. Mortality and cancer experience of Quebec aluminum reduction plant workers. Part 2: mortality of three cohorts hired on or before January 1, 1951. J Occup Environ Med 2005;50(10):1105 – 23. http://dx.doi.org/10.1097/JOM.0b013e318152248a.
11. Gibbs GW, Sevigny M. Mortality and cancer experience of Quebec aluminum reduction plant workers. Part 3: monitoring the mortality of workers first employed after January 1, 1950. J Occup Environ Med 2007;49(11):1269 – 87. http://dx.doi.org/10.1097/JOM.0b013e3181593da8.
12. Björ O, Damber L, Edström C, Nilsson T. Long-term follow-up study of mortality and the incidence of cancer in a cohort of workers at a primary aluminum smelter in Sweden. Scand J Work Environ Health 2008;34(6):463 – 70. http://dx.doi.org/10.5271/sjweh.1293.
13. Armstrong BG, Gibbs G. Exposure-response relationship between lung cancer and polycyclic aromatic hydrocarbons (PAHs). Occup Environ Med 2009;66(11):740 – 6. http://dx.doi.org/10.1001/2008.043711.
14. Sim MR, Del Monaco A, Hoving JL, MacFarlane E, McKenzie D, Benke G, et al. Mortality and cancer incidence in workers in two Australian prebake aluminium smelters. Occup Environ Med 2009;66(7):464 – 70. http://dx.doi.org/10.1036/10.1136/oom.2008.040964.
15. Gustavsson P, Reuterwall C. Mortality and incidence of cancer among Swedish gas workers. Br J Ind Med 1999;47(3):169 – 74. http://dx.doi.org/10.1136/oem.1999.000342.
16. Berger J, Manz A. Cancer of the stomach and the colon-rectum among workers in a coke gas plant. Am J Ind Med 1992;22(6):825 – 34. http://dx.doi.org/10.1002/ajim.4700220605.
17. Buck C, Reid DD. Cancer in coking plant workers. Br J Ind Med 1996;53(3):265 – 9. http://dx.doi.org/10.1136/oem.13.4.265.
18. Wu WA. Occupational cancer epidemiology in the People's Republic of China. J Occup Med 1988;30(12):968 – 74. http://dx.doi.org/10.1007/s10017-0000-0000-0007.
19. Swen GM, Slanger JJ, Velovic D, Hayes RB, Scheffers T, Stumians F. Mortality of coke plant workers in The Netherlands. Br J Ind Med 1991;48(2):130 – 5. http://dx.doi.org/10.1136/oem.48.2.130.
20. Contest etino JP, Redmond CK, Bearden A. Occupational related cancer risk among coke oven workers: 30 years of follow-up. J Occup Environ Med 1995;37(5):597 – 604. http://dx.doi.org/10.1007/s00437-199505000-0009.
21. Bye T, Romundstad PR, Renneberg A, Hilt B. Health survey of former
workers in a Norwegian coke plant: Part 2 Cancer incidence and cause specific mortality. Occup Environ Med 1998;55(5):622 – 6. http://dx.doi.org/10.1136/oem.55.5.622.

22. Yu X, Sun X, Sun YL, Zheng Y, Song GX, Lu W, et al. A retrospective cohort study on the death cause of malignant neoplasm in a coke and chemical plant. J Environ Occup Med 2004;21(6):443 – 54. http://dx.doi.org/10.1097/01.jom.0000136704.06006. (In Chinese).

23. Miller BG, Doust E, Cherrie JW, Hurley JP. Lung cancer mortality and exposure to polycyclic aromatic hydrocarbons in British coke oven workers. BMC Public Health 2013;13:962. http://dx.doi.org/10.1186/1471-2458-13-962.

24. Hansen ES. Cancer mortality among Danish molders. Am J Ind Med 1991;20(3):401 – 9. http://dx.doi.org/10.1002/ajim.470200312.

25. Sherson D, Svane O, Lyngé E. Cancer incidence among foundry workers in Denmark. Arch Environ Health: Int J 1991;46(2):75 – 81. http://dx.doi.org/10.1080/00039896.1991.9937432.

26. Fan XC, Chen BY, Guan HY, Pi GZ, Li XB, Shi G, et al. Study on the relationship between metal ore dust and cancer in copper/iron mines. Ind Hyg Occup Dis 1992;18(2):71 – 4. (In Chinese).

27. Sorohan T, Faux AM, Cooke MA. Mortality among a cohort of United Kingdom steel foundry workers with special reference to cancers of the stomach and lung, 1946-90. Occup Environ Med 1994;51(5):316 – 22. http://dx.doi.org/10.1136/ocem.51.5.316.

28. Hsiao CS, Xu XH, Sun LH, Li J, Ng CY, Lin L G, et al. A cohort study of cancer deaths among foundry workers in a factory. Ind Health Occup Dis 1995;21(2):104 – 6. (In Chinese).

29. Moulin JJ, Clavel T, Roy D, Danançhe B, Marrus Q, Févotte J, et al. Risk of lung cancer in workers producing stainless steel and metal alloys. Int Arch Occup Environ Health 2000;73(3):171 – 80. http://dx.doi.org/10.1007/s004200050024.

30. Hoshuyama T, Pan GW, Tanaka C, Feng YP, Yu LF, Liu TM, et al. Mortality of iron-steel workers in Anshanl China: a retrospective cohort study. Int J Occup Environ Health 2006;12(3):193 – 202. http://dx.doi.org/10.1179/011072106X104308.

31. Westberg H, Andersson L, Bryngelsson IL, Ngo Y, Ohlsson CG. Cancer mortality and morbidity and quartz exposure in Swedish iron foundries. Int Arch Occup Environ Health 2005;78(7):583 – 92. http://dx.doi.org/10.1007/s004200400059.

32. Wang XC, Zhang F, Jia N, Zhang W, Zhang XY, Li J, et al. Analysis of PAHs exposure and occupational inner or extra-exposure for worker in carbon and coal tar process manufacturing workers. Proc Natl Acad Sci USA 2009;106(50):21063 – 7. http://dx.doi.org/10.1073/pnas.0905756106.

33. Lu CD, Sun XC, Zhang LS, Zhang F. PAHs exposure and occupational inner or extra-exposure for worker in carbon and coal tar process manufacturing workers. Proc Natl Acad Sci USA 2009;106(50):21063 – 7. http://dx.doi.org/10.1073/pnas.0905756106.

34. Moulin JJ, Faux AM, Cooke MA. Mortality among a cohort of United Kingdom steel foundry workers with special reference to cancers of the stomach and lung, 1946-90. Occup Environ Med 1994;51(5):316 – 22. http://dx.doi.org/10.1136/ocem.51.5.316.

35. Miller BG, Cowie HA, Middleton WG, Seaton A. Epidemiologic studies of Scottish oil shale workers: III. Causes of death. Am J Ind Med 1996;30(5):433 – 46. http://dx.doi.org/10.1002/ajim.4703005050.

36. Gong DT, Han XY, Gong XY, Zhang CS, Feng ZJ, et al. Epidemiological study on lung cancer in workers exposed to asphalt. Chin J Ind Med 1996;9(5):433 – 46. http://dx.doi.org/10.1119/och.2006.12.3.193.

37. Swaan GM, Slangen JMM. Mortality in a group of tar distillery workers and roofers. Int Arch Occup Environ Health 1997;70(2):133 – 7. http://dx.doi.org/10.1007/s000388900001.

38. Boffetta P, Burusten Y, Partanen T, Kromhout H, Svane O, Langård S, et al. Cancer mortality among European asphalt workers: an international epidemiological study I. Results of the analysis based on job titles. Am J Ind Med 2003;43(1):18 – 27. http://dx.doi.org/10.1002/ajim.10181.

39. Wang XC, Zhang F, Jia N, Zhang W, Zhang XY, Li J, et al. Analysis of inner or extra-exposure for worker in coal tar pitch factory. Chin J Ind Hyg Occup Dis 2013;28(1):38 – 41. http://dx.doi.org/10.13706/zhjhs.2013.001.

40. Li J, Yin P, Wang HD, Zeng XY, Zhang X, Wang L, et al. The disease burden attributable to 18 occupational risks in China: an analysis for the global burden of disease study 2017. Environ Health 2020;19(1):21. http://dx.doi.org/10.1186/s12940-020-00577-y.

41. Zhang YX, Tao S, Shen HZ, Ma JM. Inhalation exposure to ambient polycyclic aromatic hydrocarbons and respiratory and urinary tract cancers: an updated systematic review and a meta-analysis to 2014. Arch Toxicol 2014;88(8):1479 – 90. http://dx.doi.org/10.1007/s00204-014-1096-5.

42. Li J, Yin P, Wang HD, Zeng XY, Zhang X, Wang L, et al. The disease burden attributable to 18 occupational risks in China: an analysis for the global burden of disease study 2017. Environ Health 2020;19(1):21. http://dx.doi.org/10.1186/s12940-020-00577-y.

43. Chen BY, Guan HY, Pi GZ, Lu XB, Shi G, et al. Study on the relationship between metal ore dust and cancer in copper/iron mines. Ind Hyg Occup Dis 1992;18(2):71 – 4. (In Chinese).

44. Miller BG, Cowie HA, Middleton WG, Seaton A. Epidemiologic studies of Scottish oil shale workers: III. Causes of death. Am J Ind Med 1996;30(5):433 – 46. http://dx.doi.org/10.1002/ajim.4703005050.

45. Gong DT, Han XY, Gong XY, Zhang CS, Feng ZJ, et al. Epidemiological study on lung cancer in workers exposed to asphalt. Chin J Ind Med 1996;9(5):433 – 46. http://dx.doi.org/10.1119/och.2006.12.3.193.

46. Westberg H, Andersson L, Bryngelsson IL, Ngo Y, Ohlsson CG. Cancer mortality and morbidity and quartz exposure in Swedish iron foundries. Int Arch Occup Environ Health 2013;86(5):499 – 507. http://dx.doi.org/10.1007/s00420-012-0782-4.

47. Miller BG, Cowie HA, Middleton WG, Seaton A. Epidemiologic studies of Scottish oil shale workers: III. Causes of death. Am J Ind Med 1996;30(5):433 – 46. http://dx.doi.org/10.1002/ajim.4703005050.

48. Boffetta P, Burusten Y, Partanen T, Kromhout H, Svane O, Langård S, et al. Cancer mortality among European asphalt workers: an international epidemiological study I. Results of the analysis based on job titles. Am J Ind Med 2003;43(1):18 – 27. http://dx.doi.org/10.1002/ajim.10181.

49. Wang XC, Zhang F, Jia N, Zhang W, Zhang XY, Li J, et al. Analysis of inner or extra-exposure for worker in carbon and coal tar process industries. Chin J Ind Hyg Occup Dis 2017;35(4):280 – 2. http://dx.doi.org/10.3760/cma.j.issn.1001-9391.2017.04.010. (In Chinese).

50. Guan WJ, Zheng XY, Chung KF, Zhong NS. Impact of air pollution on the burden of chronic respiratory diseases in China: time for urgent action. Lancet 2016;388(10054):1939 – 51. http://dx.doi.org/10.1016/S0140-6736(16)31597-5.

51. Han J, Liang YS, Zhao B, Wang Y, Xing FT, Qin LB. Polycyclic aromatic hydrocarbon (PAHs) geographical distribution in China and their source, risk assessment analysis. Environ Pollut 2019;251:312 – 27. http://dx.doi.org/10.1016/j.envpol.2019.05.022.
SUPPLEMENTARY FIGURE S1. Flowchart of the literature search.

SUPPLEMENTARY TABLE S1. Publication bias analysis of cohorts in different industries.

| Industry          | No. of cohorts | Obs/Exp     | SMR/SIR | Egger’s test P | Begg’s test P |
|-------------------|----------------|-------------|---------|----------------|---------------|
| Aluminum          | 11             | 2,024/1,657.67 | 1.22    | 0.036          | 0.760         |
| Coke production   | 9              | 571/299.31   | 1.91    | 0.149          | 0.251         |
| Iron and steel    | 8              | 1,053/755.69 | 1.39    | 0.530          | 0.902         |
| Asphalt Tar       | 7              | 650/522.22   | 1.24    | 0.754          | 1.000         |
| Carbon electrode  | 7              | 126/135.85   | 0.93    | 0.206          | 0.230         |
| Chinese industries| 7              | 385/227      | 1.70    | 0.738          | 1.000         |

Note: Both Begg's test and Egger's test are for publication bias in the same industry cohorts. Abbreviations: Obs/Exp=observed number of cancer cases or deaths/expected number of cancer cases or deaths; SMR/SIR=standardized mortality ratio/standardized incidence ratio.
SUPPLEMENTARY FIGURE S2. Sensitivity analysis of lung cancer among different polycyclic aromatic hydrocarbons exposed occupations. (A) aluminum factory workers. (B) coke production factory workers. (C) iron and steel factory workers. (D) asphalt tar workers. (E) carbon electrode factory workers. (F) various industries workers in China.