

# LUNG CANCER ASSOCIATED WITH CARBON BLACK EXPOSURE ON BRICK WORKERS

## Evidence-Based Case Report

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### ABSTRACT

Carbon black aerosol has potential risks to human health. It has been acknowledged to cause cardiovascular and respiratory diseases in humans. International Agency for Research on Cancer (IARC) 2010 stated that carbon black classification is 2b, which is carcinogenic. This research explains a case of lung cancer due to carbon black exposure and reviews the literature of occupational cases to get the answers about the effects of carbon black exposure and the increasing risk of lung cancer for workers exposed to carbon black. The literature review was performed to answer the clinical question via electronic databases: PubMed and Google Scholar. The keywords used were 'carbon black' and 'lung cancer' and 'workers'. The inclusion criteria of this searching strategy were the workers which exposed to carbon black, meta-analysis, randomized controlled trial, systematic reviews, cohort. The exclusion criteria of this article were inaccessible articles, RCTs that have been used in the recent systematic reviews. The selected articles were then critically appraised using relevant criteria by the Oxford Center for Evidence-based Medicine. This study reviews the literature by Rota Matteo; The epidemiological evidence on the polycyclic aromatic hydrocarbon (PAH) high exposed, perspective cohort study by Delli LD, and the control case study by Marie EPt. All the researches above showed that carbon black carcinogenic potential is the same as the IARC monograph statement that the epidemiological studies of carbon black provide possible carcinogenicity (Group of 2B).

**Keywords:** carbon black, lung cancer, workers

### INTRODUCTION

Carbon black, an important aerosol in the atmosphere, is generally produced by weathering of graphitic carbon in rocks and the incomplete combustion of fossil fuels, vegetation, biofuels, and biomass. Carbon black's nature has a distinctive form, with nanometer to micrometer particle size, and layered structure. Recently, carbon black has had an enormous contribution to global climate change and is related to a persistent organic pollutant and affects human health (Wu *et al.*, 2018). Carbon black aerosol has potential risks to human health. It has been acknowledged to cause cardiovascular and respiratory diseases in humans. Carbon black potentially induces cardiovascular morbidity and mortality. Its particle size and its catastrophic effects are strongly connected. Polycyclic aromatic hydrocarbon

(PAH) carcinogenicity activity is primarily explained by the di-epoxide process, i.e. the production of intermediate PAH metabolites (diols and di-epoxides) as a result of DNA reaction and DNA adduct formation was known to be genotoxic and carcinogenic. (*International Agency for Research on Cancer (IARC) Monographs on the evaluation of Carcinogenic Risks to Human volume*, 2018). Other possible pathways include orthoquinone and the formation of reactive oxygen species, aryl-hydrocarbon, immunosuppression, and epigenetic processes (Sharma, 2010). Agency for Research on Cancer (IARC) stated that the carcinogenic effect of carbon black on human is still a controversy. Hence, it is important to research with literatures review to have the answer about carbon black exposure effects and the increasing risk of lung cancer among carbon

black exposed workers (Hancock DG, 2014).

The finding on this case explains the relationship of lung cancer with carbon black exposure through the literature review on the occupational case report.

The case description of this research was taken from a patient in A 47-year-old man who came to the hospital with complaints of breathing shortness and chest pain. The pain spread to the upper left abdomen. The patient felt pain and tight every time he breathed. Breath is felt rather tight. This complaint has been felt since approximately 3 months ago and started to get heavy in recent weeks. Coughing of blood since 6 months ago, history of completed tuberculosis treatment, diabetes, and hypertension were denied. History of the family with diabetes and hypertension was denied, smoking over 35 years, 1-2 packs/day. (index brickman: heavy). Based on the physical examination, there were signs of hypotension and uninodular firm elastic lymphatic node enlargement with 0,5 cm in diameter in the left neck. Based on the thorax examination, there were asymmetrical left and right chest, dimmed right lung percussion, and diminished vesicular breath sound. Based on the radiology examination, there were a quite massive right pleural effusion and swelling of antibrachial soft tissue with intact visualized bone and good joints. The biopsy result showed it as squamous cell carcinoma. The occupational history of this patient has been working as a brickmaker in his home industry since 20 years ago and works 8 hours per day, 6 days per week. For making much brick, he uses combustion material from charcoal which produces carbon black. He never uses personal protective equipment such as masks, boots, google glasses, and gloves. The clinical diagnosis for this patient is squamous cell carcinoma of lung cancer. Based on the 7 steps of occupational diagnosis, it was determined as lung cancer aggravated by work.

This research aims to get the answers about the effects of carbon black exposure and the increasing risk of lung cancer for workers exposed to carbon black.

## METHODS

The literature search was performed to answer the clinical question via electronic databases: PubMed and Google Scholar. The keywords used were 'carbon black' AND 'lung cancer' AND 'workers' (table 1). The inclusion criteria of this searching strategy were the workers which exposed to carbon black, meta analysis, randomized controlled trial, systematic reviews, cohort. The exclusion criteria of this article were inaccessible articles, RCTs that have been used in the recent systematic review (figure1). The searching was done on March 23<sup>th</sup> 2019.

The selected articles were then critically appraised to determine whether the article is valid, important, and applicable to the patient using relevant criteria for etiological study by the Oxford Center for Evidence-based Medicine. (*Oxford Centre for Evidence-Based Medicine (CEBM). Critical Appraisal Tools.*, 2019).

From online search results, three selected articles fit the inclusion and exclusion criteria: A systematic review; Occupational exposures to polycyclic aromatic hydrocarbons and respiratory and urinary tract cancers: an updated systematic review and a meta-analysis to 2014 (Rota *et al.*, 2014), a prospective cohort study; Cohort Study of Carbon Black Exposure and Risk of Malignant and Nonmalignant Respiratory Disease Mortality in the US Carbon Black Industry (Dell *et al.*, 2015), and case-control study; Case-Control Study of Exposure to Carbon Black in the Occupational Setting and Risk of Lung Cancer (Marie EP, 1996).

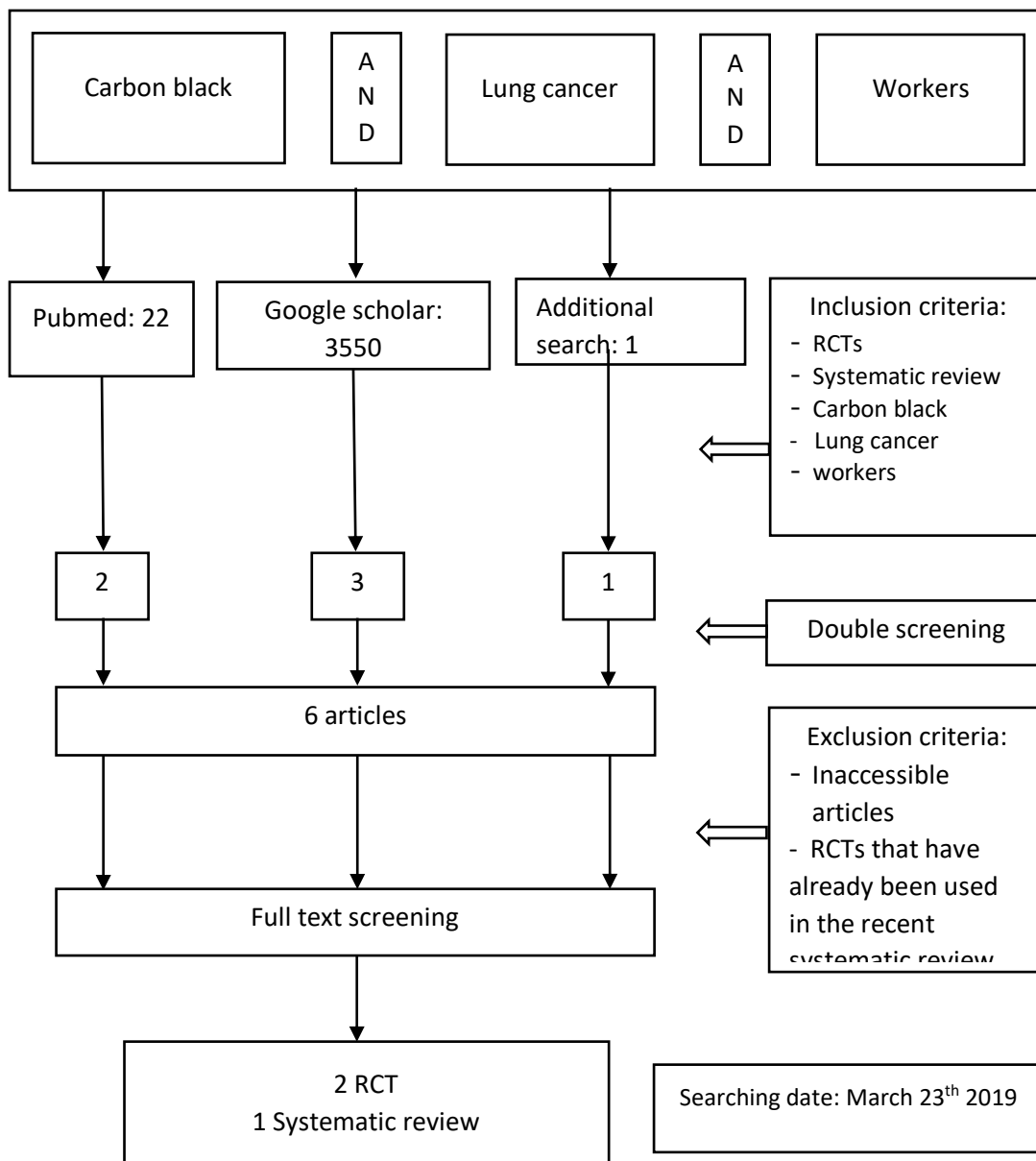


Figure 1. Literature searching chart

Table 1. Searching strategy using the database from PubMed AND Google Scholar

| Database                      | Search strategy                          | Hits | Selection |
|-------------------------------|------------------------------------------|------|-----------|
| PubMed                        | Carbon black AND Lung cancer AND workers | 22   | 2         |
| Google Scholar                | Carbon black AND Lung cancer AND workers | 3550 | 3         |
| Additional Search (reference) | Carbon black AND Lung cancer AND workers | 2    | 1         |

## RESULT

The first study Rota *et al.*, (2014) found 62 out of 474 non-specific journals identified through eligibility standard for literature searching and a complete text evaluation, 49 out of 62 articles are not included because of different occupation or peculiar cancer, control case study, investigated mortality or incident quantitative estimation, or several publications on the same cohort. Thus, there are 13 articles assessed in this review.

This systematic review assessed 13 articles that showed that polycyclic aromatic hydrocarbons (PAH) exposure among the aluminium workers was showed insignificantly related to lung cancer (including other non-specified respiratory cancers) (RR 1.08 95% CI 0.95 to 1.23). The study shows that the iron and steel factory workers were insignificantly related with lung cancer (including other non-specified respiratory cancers) (RR 1.31 95% CI 1.08 to 1.59), in three cohort studies on asphalt workers, showed insignificant results with RR for lung cancer was 1.59 (95 % CI 0.68–3.76).

**Table 2.** Critical appraisal checklist for systematic review

|          |                                                                                                                                                                |     |                                                                                                                                                                                                                                               |
|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Article  | Occupational exposures to polycyclic aromatic hydrocarbons and respiratory and urinary tract cancers: an updated systematic review and a meta-analysis to 2014 |     | Level: 1a (Systematic review of clinical trials, meta-analysis)                                                                                                                                                                               |
| Question | What question (PICO) did the systematic review address?                                                                                                        | Yes | according to the abstract and the final paragraph of the introduction the article, the PICO was<br>P: the workers in selected industries;<br>I : polycyclic hydrocarbons;<br>C: unexposed workers;<br>O:respiratory and urinary tract cancers |
| find     | Is it unlikely that important, relevant studies were missed?                                                                                                   | Yes | The search technique, including the words used, is evidence in some detail. The number of titles and abstracts checked, the number of full-text studies retrieved, the number of omitted studies and the exclusion grounds.                   |
| Appraise | Were the criteria used to select articles for inclusion appropriate?                                                                                           | Yes | Yes, they were appropriate. Inclusion criteria; cohort studies, the study of workers from selected industries characterized by PAH exposure, providing standardized mortality ratios (SMRs) and/or standardized incidence ratios              |

|            |                                                                             |         |                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------|-----------------------------------------------------------------------------|---------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|            |                                                                             |         | (SIRs) of respiratory and urinary tract neoplasms.                                                                                                                                                                                                                                                                                                                                                                                                |
| Synthesize | Were the included studies sufficiently valid for the type of question asked | Unclear | The description of how the quality of each study was assessed using predetermined quality criteria relevant to a clinical questioning method (e.g. randomization, blinding and thorough investigation) was not found in the method or result section.                                                                                                                                                                                             |
|            | Were the results similar from study to study?                               | No      | The assessment of heterogeneity between studies was focused on the chi-square test, according to the method portion. The findings of the numerous cohort studies under review were substantially heterogeneous in many cases.                                                                                                                                                                                                                     |
| Result     | What is The result of the articles?                                         |         | The forest plot shows that the exposure to polycyclic hydrocarbons <b>amid</b> aluminium workers was negligible concerning lung cancer (including other non-specified respiratory cancers) (RR 1.08 95 percent CI 0.95 to 1.23) and significant to lung cancer (including other non-specified respiratory cancers) among iron and steel smelting workers (including other non-specified respiratory cancers) (RR 1.31 95 percent CI 1.08 to 1.59) |

The second study (Dell et al., 2015) found that there was no clear association in the full-time or hourly worker community between the mortality risk of lung cancer and carbon black exposure.

Even though there is no excess lung cancer mortality in this cohort study, the lack of connection between carbon black exposure and lung cancer is persistent with the studies of the same field in the UK and Germany.

Cancer mortality in this cohort is different (RR: 2,781 CI 95% 1,923 to 4,022).

Concerning carbon black exposure estimates, this study concluded that no clear trends of increased lung cancer were found. No clear association was found between the risk of mortality from lung cancer with lagged or lugged carbon black exposure in the full cohort or the entry cohort of hourly male workers.

**Table 3.** Critical appraisal checklist for a prospective cohort study

|          |                                                                                                                                            |     |                                                                                                                                                                                                                                                                                   |
|----------|--------------------------------------------------------------------------------------------------------------------------------------------|-----|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Article  | Cohort Study of Carbon Black Exposure and Risk of Malignant and Nonmalignant Respiratory Disease Mortality in the US Carbon Black Industry |     | Level: (3) prospective cohort study                                                                                                                                                                                                                                               |
| Validity | Was the objective of the study clearly stated?                                                                                             | Yes | To know if there was a correlation between cumulative inhalable carbon black exposure and lung cancer and respiratory disease mortality among 6634 US carbon black employees.                                                                                                     |
|          | Were exposures and results measured in the same method in the patient groups?                                                              | Yes | The measurement is the same method for exposure of black carbon and the result (standardized mortality ratio) for each group of patients.                                                                                                                                         |
|          | were there clearly defined groups of patients. similar in all important ways other than exposure to the treatment or other cause?          | Yes | Employees at 18 carbon black facilities in the United States are groups of patients (of a total of 20 that were working with carbon black as of January 1, 2000)                                                                                                                  |
|          | was the investigation of the patients complete and long enough?                                                                            | Yes | Yes, the investigation of the patients is complete and long enough.<br>The analysis aimed to determine whether carbon black exposures were predictive of risk in the 15 years preceding the death of lung cancer to allow for direct comparisons of outcomes between the cohorts. |
|          | did the study have a sufficiently large sample size?                                                                                       | Yes | The sample size is 6634 subjects. It is sufficient.                                                                                                                                                                                                                               |
|          | was there a statistical adjustment for the important difference between patient groups?                                                    | Yes | Cumulative inhalable carbon black exposure was modeled as both a continuous and a categorical component. Continuous cumulative inhalable carbon black exposure was modeled in increments of 100 mg/m <sup>3</sup> .yr.                                                            |
|          |                                                                                                                                            |     | Yes                                                                                                                                                                                                                                                                               |

|                     |                                                                               |     |                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|---------------------|-------------------------------------------------------------------------------|-----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                     | is it clear that the exposure preceded the onset of the outcome?              |     | The onset of the outcome was preceded by exposure.                                                                                                                                                                                                                                                                                                                                                                                                 |
|                     | is there a dose-response gradient?                                            | Yes | It is shown in Table 4. For the entire cohort of 6634 workers, inhalable carbon black exposure influenced hazard ratios and 95 percent confidence intervals for lung cancer.                                                                                                                                                                                                                                                                       |
|                     | is the association consistent from study to study?                            | Yes | No clear association was found between the risk of mortality from lung cancer and lagging or lugging carbon black exposure in the full cohort or the entry cohort of male freelance workers. The lack of connection between carbon black exposure and lung cancer is persistent with the studies of the same field in the UK and Germany. Even though there is a huge difference in the lack of an excess of lung cancer mortality in this cohort. |
|                     | is the biological relationship plausible?                                     | Yes | Inhalation is the main route of exposure to black carbon, and the lung is considered the target organ of concern, similar to other particles.                                                                                                                                                                                                                                                                                                      |
| Clinical importance | how strong is the association between exposure and outcome, and how precise?  |     | Total patient for lung cancer : 184<br>Total patient : 6634<br>Total reference patient : 2565<br>Relative Risk for kohort: 2,781<br>CI 95% (1,923 – 4,022)                                                                                                                                                                                                                                                                                         |
| Aplicability        | were the study patient and their management similar to those in my practice ? | Yes | This patient has the same exposure, the other risk factor are similar                                                                                                                                                                                                                                                                                                                                                                              |

The result of the third study (Marie EP, 1996) is compatible with the hypothesis of the high risk of lung cancer due to black carbon exposure, yet only in the “higher” exposure group. Moreover, this study provides evidence on the risk that can occur from carbon black exposure in a wide range of occupations, compared to cohort studies

carried out in specific industries. the results from the present in-depth analyses are compatible with the hypothesis of excess risk of lung cancer with exposure to carbon black, but only in the "higher" exposure group. These findings must be interpreted cautiously, given the limited number of exposed cases in this exposure category

(n:18). The conclusion is that the evidence for carbon black's role is inadequate and contradictory. This study provides some

additional evidence for an association between exposure to carbon black and lung cancer.

**Table 4.** Critical checklist for case control study

| Article  | Case-Control Study of Exposure to Carbon Black in the Occupational Setting and Risk of Lung Cancer                                |         | Level: (3a) a case control study                                                                                                                                                                                                                                                                                                                                                                                  |
|----------|-----------------------------------------------------------------------------------------------------------------------------------|---------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Validity | are the objective of the study clearly stated?                                                                                    | Yes     | To investigate the association between carbon black exposure in the workplace and risk of lung cancer                                                                                                                                                                                                                                                                                                             |
|          | were exposures and outcomes measured in the same way in the patient groups                                                        | Yes     | The measurement is the same way for exposure of carbon black (the synthetic index of cumulative exposure to carbon black) and the outcome (estimated odds ratios)                                                                                                                                                                                                                                                 |
|          | were there clearly defined groups of patients. similar in all important ways other than exposure to the treatment or other cause? | Yes     | Male residents from the greater Montreal area aged 35-70 years were recently diagnosed with one of 19 histologically confirmed cancer types comprised the case series. The ascertainment of cases was carried out in all large hospitals in the area over 6 years                                                                                                                                                 |
|          | was the follow-up of study patients complete and long enough?                                                                     | unclear | The follow-up study is complete but it wasn't mentioned about the duration of follow up                                                                                                                                                                                                                                                                                                                           |
|          | did the study have a sufficiently large sample size?                                                                              | Yes     | The sample size is 3730 subjects. It is sufficient                                                                                                                                                                                                                                                                                                                                                                |
|          | was there a statistical adjustment for important differences between patient groups?                                              | Yes     | Exposure of carbon black was expressed in three categories, that is, unexposed, lower, and higher exposure, corresponding to the lower two-thirds and upper third of the distribution of the index of cumulative exposure described previously. This allowed for an examination of the exposure-response relationship. Adjusted regression models included linear terms for age, socioeconomic status as measured |



|                     |                                                                              |     |                                                                                                                                                                                                                                                                                                                                                                                            |
|---------------------|------------------------------------------------------------------------------|-----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                     |                                                                              |     | by self-reported income, job dirtiness, and alcohol intake, and categorical terms for ethnicity (French, Anglo, other) and respondent status (self, proxy). Asbestos and chromium compounds are recognized lung carcinogens and were incorporated as continuous variables, using the same type of synthetic index described earlier for carbon black.                                      |
|                     | is it clear that the exposure preceded the onset of the outcome?             | Yes | It is clear that exposure preceded the onset of the outcome                                                                                                                                                                                                                                                                                                                                |
|                     | is there a dose-response gradient?                                           | Yes | It is shown in TABLE 5. Odds Ratio between exposure to carbon black and Lung cancer for the main histologic Subtypes, using two control groups, Montreal, 1979-1985                                                                                                                                                                                                                        |
|                     | is the association persistent from research to research?                     | Yes | According to some research, carbon black exposure is related to non-carcinogenic diseases of the respiratory system. [Gardiner et al., 1993; Gardiner, 1995; IARC,19841, while other studies have found no such deleterious effect [Crosbie, 1986; Robertson and Ingalls, 1989; Indirect evidence pointing to carbon black as a lung carcinogen comes from studies focusing on industries. |
|                     | is the association consistent from study to study?                           | Yes | Some researchers mentioned that carbon black exposures are related to non malignant diseases of the respiratory system.                                                                                                                                                                                                                                                                    |
| Clinical importance | how strong is the association between exposure and outcome, and how precise? |     | Low Exposure :OR 1.08 CI95% 0.66 – 1.76. Higher exposure : OR 2.17 CI95% 0,95 – 4,91. The assosiation is not strong enough.                                                                                                                                                                                                                                                                |
| Applicability       | were the study patient and their management similar to those in my practice? | Yes | This patient has the same exposure, the other risk factor are similar                                                                                                                                                                                                                                                                                                                      |

## DISCUSSION

The studies above showed that the relation between carbon black and lung cancer was still not clear. A systematic review about occupational exposures to polycyclic aromatic hydrocarbons and the health effect on respiratory and urinary tract cancers showed that carbon black which is a group of polyaromatic hydrocarbon (PAH) has an insignificant related to lung cancer for aluminium workers (RR 1,08 95%CI 0,095 To 1,23), the iron and steel foundry workers (RR 1,31 95%CI 1,08 to 1,59), asphalt worker (RR 1,59 95%CI 0,68-3,76). The conclusion is there is no indication of high risk discovered in coal tar and carbon black employees.

In the study of meta-analysis, coal gasification, coke production, and carbon electrode production were observed to find the high risk of respiratory tract cancer among workers in these sectors. It revealed that there was no high risk of respiratory tract cancers in employees. The study of meta-analysis confirmed workers engaged in the manufacturing of carbon electrodes had a potential excess risk of respiratory cancer. (Rota *et al.*, 2014).

The other paper, a prospective cohort (Dell *et al.*, 2015), concluded that to estimate carbon black exposure, there were no clear trends of increased lung cancer. There was no direct connection between lagged or lugged carbon black exposure and lung cancer mortality in the full cohort or the entry cohort of hourly male workers.

The last article of case control study (Marie EP, 1996), reported that the results from the present in-depth analyses are compatible with the hypothesis of excess risk of lung cancer with exposure to carbon black, but only in the “higher” exposure group. The quality of job histories may differ depending on whether they are obtained directly from the subjects or by proxy interviews. The interviews had to be carried out for some lung cancer cases as well as for an appreciable proportion of cancer controls. Since there was little

difference (10%) in the proportions of proxies in the two groups, there was little opportunity for bias in the comparison. The inclusion of proxies may have resulted in some misclassification and have minimized the differences between groups, but not in an inflation of the risk estimates. Along with inaccurate recall of work histories and misclassification in the attribution of exposures by chemists, the use of proxy respondents is one of the factors that may have attenuated the relationships observed if there was a true association (Sorahan and Harrington, 2007).

The result from these three studies is contributed for several reasons that in the West where the three studies had been done, especially in US and UK where they have standard regulation of harmful exposure effect protection. They use standard engineering control to limit the exposure and also management early detecting management for workers' health. However, it is important to remember that each country has its medical regulation on a surveillance system that can influence the implementation, accessibility, and effectiveness of lung cancer prevention, such as the quantity examination of polyaromatic hydrocarbon (PAH) especially carbon black in the working environment and workers health by biological monitoring of carbon black exposure (Sorahan and Harrington, 2007).

The eminence of this study is a large number of research samples in a systematic review, prospective cohort study, and control cases. The study is complete with adequate quantitative data and cost-efficient data collecting by compiling cohort studies from original articles. Of course, there are weaknesses of this research, such as the heterogeneous data that reflects the varied pattern of exposure in some cohorts and the difference of period that can be a bias and confounding factor. This study did not analyze the dose–response relation between carbon black and lung cancer.

Information from the above literature study on the review of this patient

case explains that carbon black exposure causing lung cancer is still not clear. Moreover, for his patient, Other factors can contribute to lung diseases (especially lung cancer) such as smoking habits, other working process exposure, and pollutant from where he lives in.

It is important to manage carbon black exposure by medical surveillance especially in home industries in Indonesia where there is a lack of regulation, controlling and protection from exposure. Home industries like as charcoal industries, tofu industries, extraction of nutmeg oils and clove oils, food industries which are exposed by carbon black should get attention for safe and healthy workers with the hierarchy of control such as; 1) Elimination or substitution by change charcoal burning to gas which is healthier and safe. 2) If elimination and substitution can't be realized, get engineering control to enclose operations and/or provide appropriate local exhaust ventilation at machinery and at places where dust can be generated to flow away air pollutant direction and make a chimney or closed burn setting/isolating operation. 3) Administration control to lead the regulation of job procedure, health promotion to prevent the health risk for the workers, Medical surveillance to determinate the quantity of carbon black in air workplace, early detection by biomonitoring of carbon black to the workers; by examining the metabolic of hydroxypyrene (in urine) by using the high performance of liquid chromatography (HPLC) and enzyme-linked immunosorbent assay (ELISA) and periodic medical examination (Angerer J, Mannschreck C, 1997). 4) Personal protective equipment (carbon black; 1750 mg/m<sup>3</sup>) by using respirators such as respirators operated in a pressure-demand or other positive-pressure mode. For research; Advanced studies of the carbon black exposure to lung cancer in Indonesia, and the research of grading dose cumulative inhalable carbon black exposure as cancer's variable cause to human's other

organs, especially in workers (Borm and Driscoll, 2019)(McCunney RJ.et al, 2012).

## CONCLUSION

This research showed there was no strong relation between carbon black and lung cancer risk. The three types of research showed that carbon black carcinogenic potential is the same as the IARC monograph statement that the epidemiological studies of carbon black provide lack indication to the notation of carcinogenicity (Group of 2B).

## REFERENCES

- Angerer J, Mannschreck C, G. J. (1997) 'Biological monitoring and biochemical effect monitoring of exposure to polycyclic aromatic hydrocarbons', *Biological monitoring and biochemical effect monitoring of exposure to polycyclic aromatic hydrocarbons*, 70.
- Black, S. A., Pearls, B. and Spectra, R. (2010) 'Carbon black', *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, 93(October 1995), pp. 43–88.
- Borm, P. J. A. and Driscoll, K. E. (2019) 'The hazards and risks of inhaled poorly soluble particles - Where do we stand after 30 years of research?', *Particle and Fibre Toxicology*, 16(1), pp. 1–5. doi: 10.1186/s12989-019-0294-4.
- Dell, L. D. *et al.* (2015) 'Cohort Study of Carbon Black Exposure and Risk of Malignant and Nonmalignant Respiratory Disease Mortality in the US Carbon Black Industry', *Journal of Occupational and Environmental Medicine*, 57(9)984–997. doi: 10.1097/JOM.000000000000051.
- Gardiner K, et al. (2001) 'Respiratory health effects from exposure to carbon black: Results of the phase 2 and 3 cross sectional studies in the European carbon black

- manufacturing industry', *Occupational and Environmental Medicine*, 58(8),496–503. doi: 10.1136/oem.58.8.496.
- Hancock DG, et al (2014) 'Wood dust exposure and lung cancer risk: a meta-analysis', 72: 889-89. *International Agency for Research on Cancer (IARC) Monographs on the evaluation of Carcinogenic Risks to Human volume 93* (2018).
- Marie EP, et al. (1996) 'Case-Control Study of Exposure to Carbon Black in the Occupational Setting and Risk of Lung Cancer', 30;285-292.
- McCunney RJ, Muranko HJ, Long CM, Hamade AK, Valberg PA, M.P. (2012) 'Carbon Black', *Patty's Toxicology*, 429-453.
- Morfeld P, M. R. (2010) 'Bayesian bias adjustments of the lung cancer SMR in a cohort of German carbon black production workers.', *J Occup Med Toxicol*.
- Mark D,V.J (n.d.). *A new personal sampler for airborne total dust in workplaces. Ann Occup Hyg. Oxford Centre for Evidence Based Medicine (CEBM). Critical Appraisal Tools.* (2019).
- Rota, M. et al. (2014) 'Occupational exposures to polycyclic aromatic hydrocarbons and respiratory and urinary tract cancers: An updated systematic review and a meta-analysis to 2014', *Archives of Toxicology*, 88(8), pp. 1479–1490. doi: 10.1007/s00204-014-1296-5.
- Sharma, M. (2010) 'Understanding the mechanism of toxicity of carbon nanoparticles in humans in the new millennium: A systemic review', *Indian Journal of Occupational and Environmental Medicine*, 14(1), pp. 3–5. doi: 10.4103/0019-5278.64607.
- Sorahan, T. and Harrington, J. M. (2007) 'A "lugged" analysis of lung cancer risks in UK carbon black production workers, 1951-2004', *American Journal of Industrial Medicine*, 50(8), pp. 555–564. doi: 10.1002/ajim.20481.
- Van Tongeren MJA, G. K. (n.d.). *Determinants of exposure in the carbon black manufacturing industry. Appl Occup Environ Hyg.*
- Wu, J. et al. (2018) 'Distribution and health risks of aerosol black carbon in a representative city of the Qinghai-Tibet Plateau', *Environmental Science and Pollution Research*, 25(20), pp. 19403–19412. doi: 10.1007/s11356-018-2141-9.
- Sorahan, T., Faux, A.M., Cooke, M.A. (1994). Mortality among a cohort of United Kingdom steel foundry workers with special reference to cancers of the stomach and lung. *Occupational and Environmental Medicine*, 51(5), 316322. <https://doi.org/10.1136/oem.51.5.3>
- Wellmann, J., Weiland, S. K., Neiteler, G., Klein, G., & Straif, K. (2006). Cancer mortality in German carbon black workers 1976-98. *Occupational and Environmental Medicine*, 63(8), 513-521.