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The relationship between exposure to particulate matter and breast cancer incidence and mortality

A meta-analysis

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Abstract

Background: Particulate matter (PM) acts as an environment pollutant and thus plays a vital role in the development of human lung cancer. Whether PM is a risk factor for breast cancer (BC) morbidity and mortality, however, is not clear. Recently, several studies have reported inconsistent results for the association between PM and BC risk. This meta-analysis examines the indefinite relationship between exposure to PM and BC morbidity and mortality.

Methods: Based on a search of Pubmed, Embase, Web of Science and Cochrane Library, the hazard ratio (HR) and 95% confidence interval (CI) were extracted and analyzed by Review Manager 5.3 and Stata14.0 to estimate the association between PM and BC morbidity and mortality. The heterogeneity for the included studies was evaluated using a Chi-square test and the I^2 statistic. Forest plot was used to illustrate the pooled HR and mean difference. A Funnel plot, Begg test, and Egger test were performed to explore the publication bias between the included studies.

All analyses were based on previous published studies, thus, no ethical approval and patient consent are required.

Results: A total of 14 of 284 publications with 1,004,128 BC cases were gathered. The analysis showed each 10 $\mu g/m^3$ of $PM_{2.5}$ (diameter $\leq$2.5 μm) was associated with 1.17 (95% CI: 1.05–1.30, P = .004) fold risk BC mortality, and each 10 $\mu g/m^3$ of PM_{10} (diameter $\leq$10 μm) was associated with 1.11 (95% CI: 1.02–1.21, P = .021) fold risk BC mortality. However, neither PM_{10} nor $PM_{2.5}$ was found to be significantly associated with BC morbidity. Publication bias was detected in studies on $PM_{2.5}$ and BC mortality.

Conclusions: Our study suggests that PM exposure may raise the mortality but not the morbidity of BC. Still, further studies may be necessary to confirm this finding.

Abbreviations: BC = breast cancer, CI = confidence intervals, ER = estrogen receptor, ER−/PR− BC = breast cancer with estrogen receptor and progesterone receptor negative, ER+/PR+ BC = breast cancer with estrogen receptor and progesterone receptor positive, HR = hazard ratio, PAH = polycyclic aromatic hydrocarbons, PM = particulate matter, PR = progesterone receptor, PRISMA = preferred reporting items for systematic reviews and meta-analyses.

Keywords: breast cancer, morbidity, mortality, particulate matter

1. Introduction

Ambient particulate matters (PM) have been classified as carcinogenic to human beings by the International Agency for Research on Cancer. Numeric studies of animal models and humans revealed that PM exposure is associated with the risk of lung cancer.[1–4] PM, especially the fine PM with a aerodynamic diameter $\leq$2.5 μm ($PM_{2.5}$), can infiltrate through the air-blood barrier and distribute to different organs and tissues. These particulates have a high specific surface area and are capable of caring a large amount of hazardous matter, like polycyclic aromatic hydrocarbons (PAH), Bisphenol A, and heavy metals. Those materials have been found to be significantly associated with

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ZZ and WTY contributed equally to this work and should be considered as co-first authors.

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the tumor formation of different organs, including the lungs (in particular the bronchi), skin, esophagus and colon, pancreas, bladder, and breast in women.[5] A case-control study suggested that PAH may be associated with specific p53 mutation and may also be related to BC through mechanisms other than p53 mutation.[6] PAH also have the capacity to bind to DNA and induce formation of adducts in breast tissues.[7] Epidemiological evidence suggests that Bisphenol A has carcinogenic effects on the human prostate cancer, and this effect is also found in animal models.[8,9] In addition, several studies have shown that heavy metals act as environmental endocrine disruptors and can induce oxidative stress that may influence the risk of BC, while the higher exposure level of some airborne metals has a relationship with an increased risk of pre-menopause and post-menopause BC.[10–12] These compounds may serve as carcinogens or as endocrine disruptors and interrelate for breast carcinogenesis. Recent study has shown that $PM_{2.5}$ possesses cytotoxicity and decreased cell viability not only in the respiratory system, but also in the immune system, cardiovascular system, and central nervous system. These heterogeneous effects of $PM_{2.5}$ may derive from the different compositions of PM.[13] Hence the PMs are also suspected as being a carcinogen for other carcinomas besides lung cancer.

Breast cancer (BC), the global leading carcinoma found in women, is also suspected to be related to PM. Toxicological study has shown that the PM of urban ambient air enhanced cell proliferation activity in the human BC cell line MCF-7 (a cell line of breast adenocarcinoma which expression estrogen receptor) in a dose-response manner.[14] MCF-7 when exposed to standard reference material 1649a (urban dust) had 41 RNA transcripts changed at least 2-fold, including the genes involved in carcinogen activation.[15] In 1 ecological study, the emission of $PM_{2.5}$ in the 19 counties of metro Atlanta and rural Georgia was found to be significantly associated with the county-specific incidence of BC.[16] However, in a cohort of 22,877 Danish females, no association was observed for BC to either $PM_{2.5}$ or PM_{10}.[17]

On the other hand, PM exposure seems to raise the risk of death; however, most of the involved studies mainly focused on the death of cardiovascular or respiratory mortality.[18–24] Few studies have investigated whether PM confers additional death on BC patients. To current date, whether PM is a risk factor for BC incidence and mortality is still not clear. To address this gap, we conducted a meta-analysis to examine the association between PM exposure and BC morbidity as well as mortality by synthesizing the results of 14 studies. In addition, various subgroup analyses of the factors that might influence these results are also presented.

2. Methods

Our work was conducted in accordance with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guideline (see PRISMA checklist).[25] No published protocol existed for this study.

2.1. Search strategy

In April 2019, a comprehensive literary search for potential studies was performed in PubMed, EMBase, Web of Science, and the Cochrane library, without any restriction for publication time. The keywords "fine particulate matter," "$PM_{2.5}$" "PM_{10}" "breast cancer" "breast carcinoma" "breast neoplasms" were variably combined as Medical Subject Headings terms. Reviews, comments, letters, or editorials without any irrelevant study data were excluded by screening the titles, abstracts, and main texts of the publications. In addition, all the included studies in our analysis were searched manually and the references list of all studies were also examined to avoid missing any relevant articles that might meet the include criteria.

2.2. Eligibility criteria

Inclusion criteria:

(1) BC incidence or BC-related mortality risk indicators (hazard ratio [HR]) and their confidence intervals (CIs) (95% CI) with $PM_{2.5}$/PM_{10}exposure were reported.
(2) The relative $PM_{2.5}$/PM_{10} exposure level of risk indicators was reported (that is, how ug/m^3 $PM_{2.5}$ leads to the current HR value, or how the ug/m^3 $PM_{2.5}$ exposure levels of the 2 groups were compared when the HR value was obtained).

Exclusion criteria:

(1) No population studies (eg, cell lines, animal studies);
(2) Non-English literature;
(3) The literature type is an abstract, letter, review, or other nonresearch article.

2.3. Data extraction

Two investigators independently extracted data from each included study and reached a consensus after discussion. Data were extracted using a collection template. The extracted data contained the following elements: author, public date, title, implement state, race, type of research (cohort research or ecological research), hazard index (HR), sample size, age, estrogen receptor (ER) status, progesterone receptor (PR) status, human epidermal growth factor receptor type 2 status, adjustment factors, study duration, follow-up time, baseline $PM_{2.5}$/PM_{10} exposure levels, and HR with a corresponding 95% CI.

2.4. Quality assessment of primary studies

The Newcastle–Ottawa quality assessment scale was used to assess the quality of each included cohort study. Only studies with a score above 6 were kept for the meta-analysis. The ecological studies were assessed using a modified Newcastle–Ottawa quality assessment scale for the cohort study, and only studies with a score above 5 were kept.

2.5. Statistical analysis

All statistical analysis was performed using Review Manager 5.3 software (Cochrane Collaboration, Copenhagen, Denmark) and Stata14.0 software (Stata Corp, College Station, TX). Heterogeneity among the included studies was evaluated by a Chi-square test and I^2 statistic. The random-effect model was used when there was significant heterogeneity (I^2 value >40% or $P<.1$) between studies; otherwise, the fixed-effect model was used. The integrated analysis was carried out based on the generic inverse variance method, and the effect size was represented by a 95% CI. Statistically significant differences were represented by P-values of <.05 and 95% CI that did not overlap. Subgroup analyses were performed for invasive BC, ER/PR status, research type, and $PM_{2.5}$ exposure levels (depending on the World Health Organization [WHO] guidelines).[26] Forest plot was used to

illustrate the pooled HR and mean difference. Funnel plot, Begg test, and Egger test were conducted to check the bias existing in the included studies and $P < .05$ representative statistic that was significant.

3. Results

3.1. Literature search

We initially retrieved 284 articles through a database search including PubMed, Embase, Web of Science, and Cochrane Library. In total, 79 articles remained after the exclusion of duplicate articles. After reviewing the study titles and abstracts, 54 articles that did not investigate the association between air pollution and BC morbidity or mortality were excluded. A full closer review of the remaining 25 articles identified 17 articles that fulfilled the inclusion criteria. In addition, we excluded 3 studies for the following reasons: estimates from 1 ecological study (Parikh et al 2016) and 1 cohort study (Ancona et al 2015) that could not be converted to units of ug/m^3. These 2 studies could not be integrated with the other studies. Another research study (Huo et al 2015) was excluded because of low study quality. A total of 14 articles were finally selected (see Fig. 1).

3.2. Study characteristics

We identified 12 cohort studies (Hu et al 2013; Reding et al 2015; To et al 2015; Hart et al 2016; Tagliabue et al 2016; Wong et al 2016; Andersen et al 2017; Andersen et al 2017; Cheng et al 2019; DuPre et al 2019; Datzmann et al 2018; Turner et al 2017) and 2 ecological studies (Hung et al 2012; Iwai et al 2005) on BC that provided estimates of the quantitative relationships between the risk of BC morbidity and mortality with PM.

Table 1 summarizes the details of the studies included in this meta-analysis. In total, there were 7 studies that provided estimates of BC morbidity. Another 7 studies provided estimates of BC mortality. Among the 7 studies contributes to an association with PM exposure and BC incidence risk, 5 studies provides both $PM_{2.5}$ and PM_{10} data, 1 study merely provided PM_{10} data, while the last single study provided $PM_{2.5}$ data only. For BC mortality, the entire 7 included studies presented $PM_{2.5}$ exposure with BC mortality and 2 together revealed an association between PM_{10} exposure and BC mortality. The population size ranged from 2021 to 344,593, and the age range of the population included all ages. Most of the results were corrected for age, race, post-menopause hormone therapy, smoking status, education, and body mass index as shown in Table 1. The qualities of the recruited studies are listed in Supplementary Tables 1, http://links.lww.com/MD/D476 and 2, http://links.lww.com/MD/D477.

3.3. PM and BC morbidity

BC incidence risk was reported in 7 cohort studies. First, we performed an overall analysis of the relationship between PM and

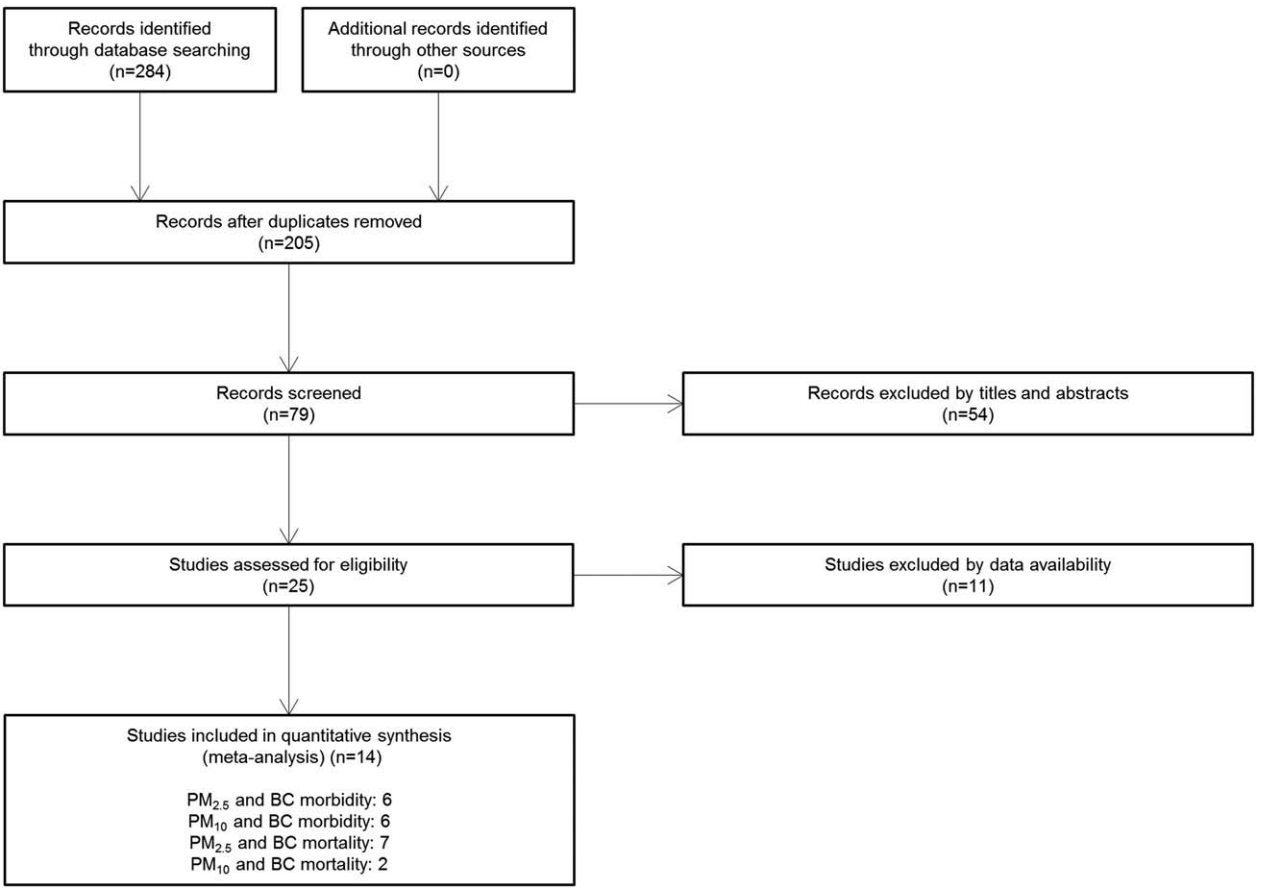

Figure 1. Flowchart for article search and selection process.

Table 1

Characteristics of included studies.

Study	Research type	Sample size	Age	Classification	Hormone receptor	Starting date	Ending date	Pollution	Exposure level (ug/m^3)	Outcome	NOS
To et al (2015)	Cohort	29,549	40–59	BC	NA	1980–1985	2013	$PM_{2.5}$	12.54 ± 2.37, IQR11.10–14.60	Morbidity	9
Reding et al (2015)	Cohort	47,591	35–74	Invasive BC	ER+/PR+ ER−/PR−	2003.08 2009.07	2013	$PM_{2.5}$ PM_{10}	10.5 (IQR: 3.6) 22.2 (IQR: 5.8)	Morbidity	8
Hart et al (2016)	Cohort	115,921	29–46	Invasive BC	ER+/PR+ ER−/PR−	1993	2011	$PM_{2.5}$ PM_{10}	NA	Morbidity	8
Andersen et al (2017a)	Cohort	22,877	52.9 ± 7.8	Invasive BC	NA	1993–1999	2013	$PM_{2.5}$ PM_{10}	19.7 ± 3.5 23.5 ± 3.9	Morbidity	8
Andersen et al (2017b)	Cohort	74,750	>65 yr	BC	NA	1985–2005	NA	$PM_{2.5}$ PM_{10}	NA	Morbidity	9
Datzmann et al (2018)	Cohort	9577	NA	BC	NA	2007	2014	PM_{10}	20.89 (15.47–26.30)	Morbidity	9
Cheng et al (2019)	Cohort	57,589	45–75	Invasive BC	ER+/PR+ ER−/PR−	1993–1996	2010	$PM_{2.5}$ PM_{10}	IQR:3.8	Morbidity	9
Hu et al (2013)	Cohort	255,128	NA	BC	NA	1999	2009	$PM_{2.5}$ PM_{10}	IQR:11.64–15.04 IQR:23.09–28.82	Mortality	6
Wong et al (2016)	Cohort	35,596	≥65	BC	NA	1998–2001	2011	$PM_{2.5}$	33.7 ± 3.2	Mortality	9
Tagliabue et al (2016)	Cohort	2021	50–69	BC	NA	2003	2009	$PM_{2.5}$	20.71–26.65	Mortality	7
Turner et al (2017)	Cohort	344,593	NA	BC	NA	1982	2004	$PM_{2.5}$	12.6 ± 2.8	Mortality	9
DuPre et al (2019)	Cohort	8936	25–55	BC	NA	1988–2008	NA	$PM_{2.5}$ PM_{10}	NHS: 13.3 ± 3.5; NHS II: 12.9 ± 3.1 NHS: 8.9 ± 4.8; NHS II: 8.4 ± 4.7	Mortality	8
Hung et al (2012)	Ecological	61 stations	NA	BC	NA	1999	2008	$PM_{2.5}$	IQR:30.39–39.48	Mortality	6
Iwai et al (2005)	Ecological	47 prefectures 13 large cities	NA	BC	NA	2000	2000	$PM_{2.5}$	20.8 ± 4.5	Mortality	6

Exposure level was presented as "mean ± standard deviation" or "median (interquartile range)" if not specifically indicated.

BC = breast cancer, ER+/PR+ = estrogen receptor and progesterone receptor both positive, ER–/PR– = estrogen receptor and progesterone receptor both negative; IQR = interquartile range, NA = not available, NHS II = Nurses' Health Study II, NHS = Nurses' Health Study, NOS = Newcastle–Ottawa scale.

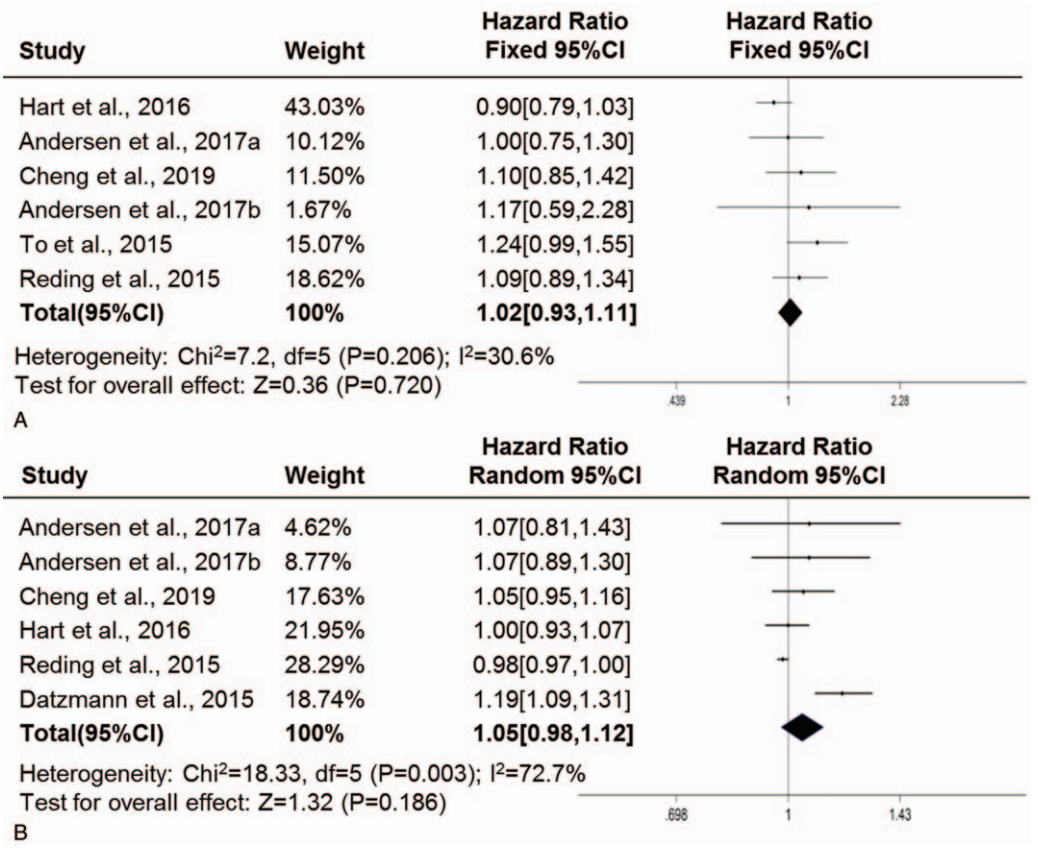

Figure 2. Forest plot for the association between $PM_{2.5}$ (A) and PM_{10} (B) and BC incidence: Overall analysis. The black diamond and its extremities indicate the pooled risk ratio center and a 95% confidential interval. BC = breast cancer, PM = particulate matter.

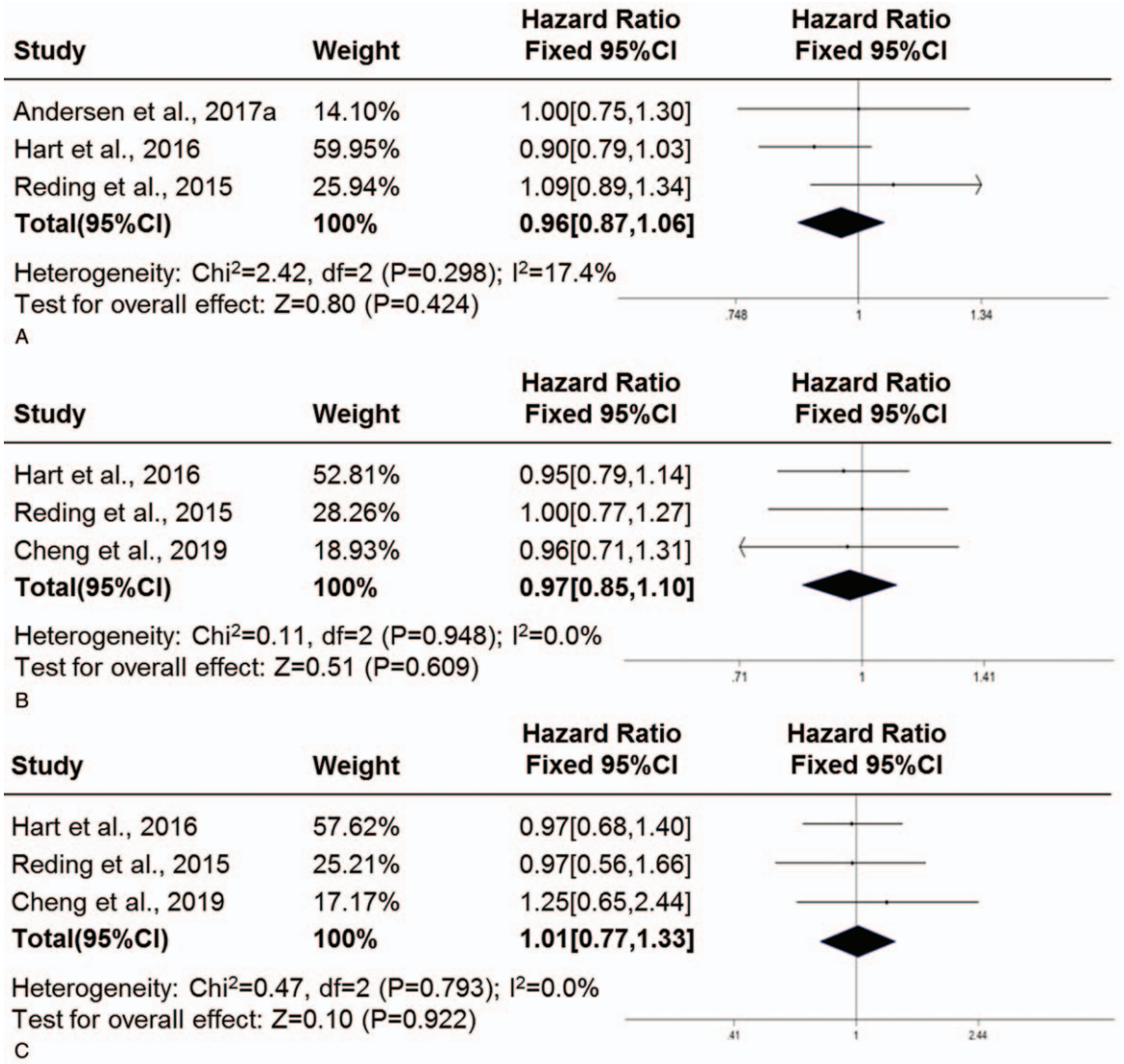

Figure 3. Forest plot for the association between $PM_{2.5}$ and BC incidence: Subgroup analysis. The results of invasive BC (A), ER+/PR+ BC (B), ER−/PR− BC (C) are shown, respectively. The black diamond and its extremities indicate the pooled risk ratio center and a 95% confidential interval. BC = breast cancer, ER = estrogen receptor, PM = particulate matter, PR = progesterone receptor.

BC incidence risk using a fixed model. No significant association was observed between $PM_{2.5}$ 1.02 (95% CI: 0.93–1.11, $P=.72$; $I^2=30.6\%$, $P=.206$) or PM_{10}1.05 (95% CI: 0.98–1.12, $P=.186$; $I^2=72.7\%$, $P=.003$) with BC incidence risk (see Fig. 2).

Second, subgroup analysis presented no significant association between PM and BC morbidity according to the ER and PR status in BC. On the 7 cohort studies, further analysis was conducted on 3 based on the status of ER/PR. We also analyzed the association between PM exposure with an incidence risk of ER+/PR+ BC, ER−/PR− BC and invasive BC, respectively. No significant relationship between PM and BC incidence risk was observed in this subgroup analysis (see Figs. 3 and 4).

3.4. PM and risk of BC mortality

From the 7 studies reporting exposure to $PM_{2.5}$ and BC mortality, 5 studies presented a positive association, 2 studies showed a risk >1, but the estimate did not reach statistical significance. According to the result of an heterogeneity test ($I^2=73.1\%$, $P=.001$), we performed an overall analysis of the association between $PM_{2.5}$ and BC death risk via random model and found that each increment of 10 ug/m^3 $PM_{2.5}$ was associated with a 1.17 (95% CI: 1.05–1.30, $P=.004$) fold risk of BC-related death.

A relationship between PM_{10} and BC mortality was reported by 2 studies. The pooled HR was assessed by a fixed model with low heterogeneity ($I^2=0.00\%$, $P=.459$). It found that each increment of 10 ug/m^3 PM_{10} was associated with a 1.11 (95% CI: 1.02–1.21, $P=.021$) fold risk of BC-related death (see Fig. 5).

We conducted an additional subgroup analysis (of $PM_{2.5}$ and BC mortality) by research type (ecological study vs cohort study) and exposure level (>15 ug/m^3 vs <15 ug/m^3). These results showed a significant positive association between $PM_{2.5}$ with BC mortality, either in the ecological studies at 1.08 (95% CI: 1.04–1.12, $P=.000$; $I^2=36.8\%$, $P=.208$) or in the cohort studies at 1.40 (95% CI: 1.06–1.86, $P=.017$; $I^2=74.2\%$, $P=.004$) (see Fig. 6). According to the WHO guidelines for the air quality of

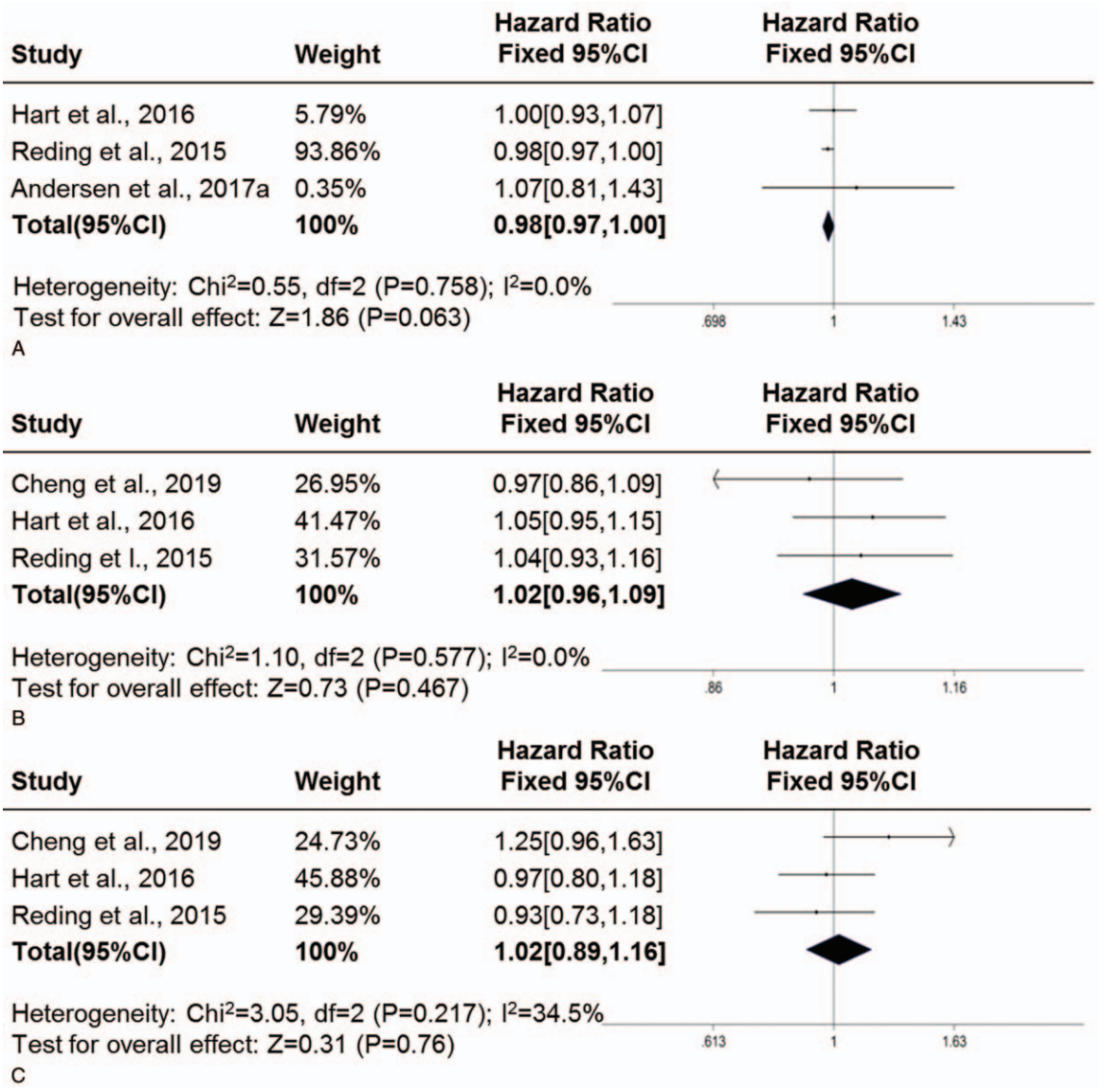

Figure 4. Forest plot for the association between PM_{10} and BC incidence: Subgroup analysis. The results of invasive BC (A), ER+/PR+ BC (B), ER−/PR− BC (C) are shown, respectively. The black diamond and its extremities indicate the pooled risk ratio center and a 95% confidential interval. BC = breast cancer, ER = estrogen receptor, PM = particulate matter, PR = progesterone receptor.

PM, we used $PM_{2.5} = 15$ ug/m^3 as a threshold and subsequently divided the exposure level data into 2 groups (>15 ug/m^3 vs <15 ug/m^3). There was a statistically significant association between $PM_{2.5}$ and BC mortality in the high exposure subgroup 1.27 (95% CI: 1.08–1.49, $P = .003$; $I^2 = 82.0\%$, $P = .000$) and a suggestive association in the low exposure subgroup 1.07 (95% CI: 0.97–1.20, $P = .190$; $I^2 = 0.0\%$, $P = .884$) (see Fig. 7).

3.5. Sensitivity analysis and estimate of publication bias

To evaluate the influence of an individual study on the pooled results, a sensitivity analysis was performed by removing each eligible study separately. Most of the primary results were not affected by this turn. Funnel plot was used to detect the potential publication bias that might affect the validity of the results. No substantial bias was found in the analysis of PM and BC morbidity. However, it is worth noting that more studies with positive results could have been published on the relationship of $PM_{2.5}$ and BC mortality (see Fig. 8).

4. Discussion

We conducted a meta-analysis and the results demonstrate that both $PM_{2.5}$ and PM_{10} are associated with a significantly increased risk of BC mortality. Furthermore, the relationship remained prospectively significant in the subgroup of high exposure level (>15 ug/m^3). However, funnel plot showed that publishing bias may exist in studies on $PM_{2.5}$ and BC mortality, suggesting that some of the potential studies with negative results may have not been published. There was no significant association between $PM_{2.5}/PM_{10}$ with BC incidence risk.

Our findings are consistent with those reported in the recent literature. For example, higher $PM_{2.5}$ exposure significantly increased death risk for BC patients living in the Varese Province

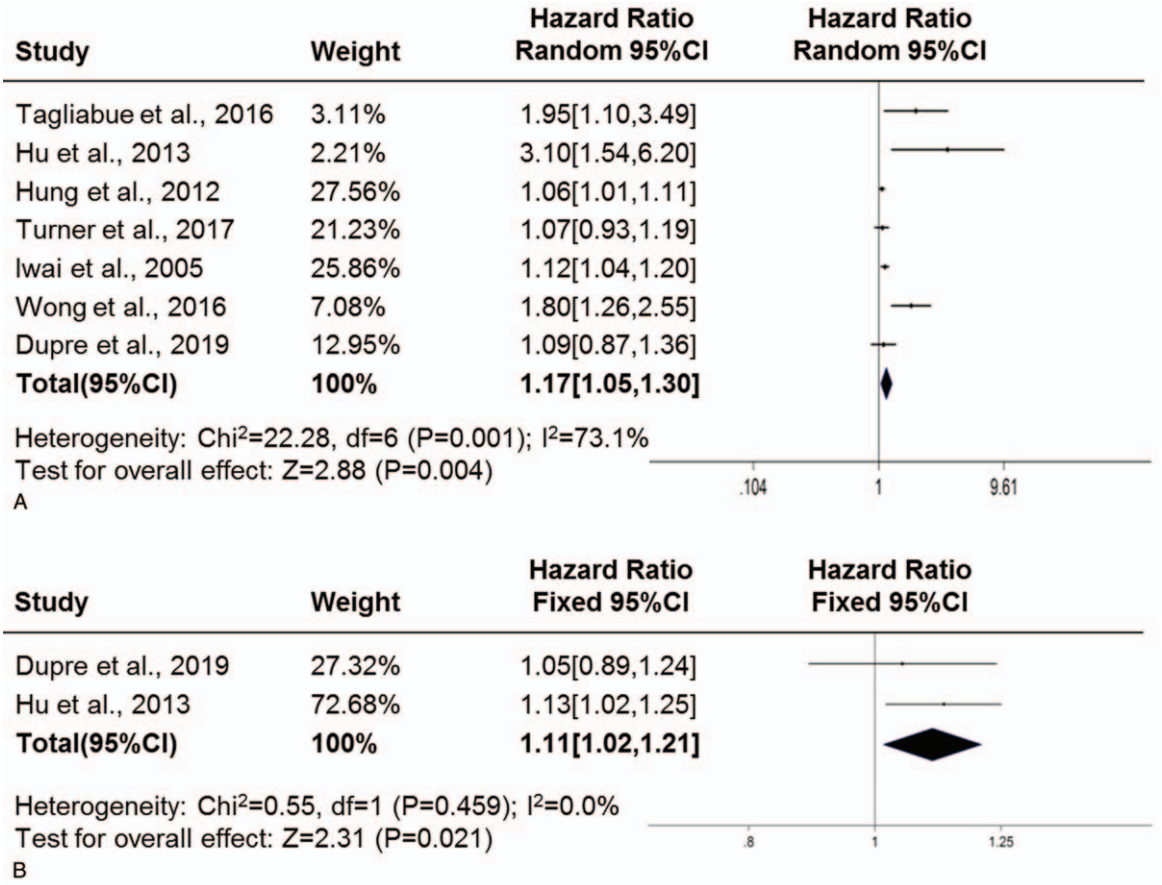

Figure 5. Forest plot for the association between $PM_{2.5}$ (A) and PM_{10} (B) and BC mortality: Overall analysis. The black diamond and its extremities indicate the pooled risk ratio center and a 95% confidential interval. BC = breast cancer, PM = particulate matter.

of Northern Italy.[27] In Hong Kong, they confirmed that $PM_{2.5}$ was associated with an elevated death risk of cancers in various organs including the mammary glands.[28] For other organ cancers, a meta-analysis conducted by Kim et al. showed an increased mortality risk with $PM_{2.5}$ exposure (lung, liver, colorectal, bladder, kidney) and PM_{10} exposure (lung, pancreas, larynx), respectively.[29] Coincidentally, several previous studies suggested that particulate air pollutants can travel to partial organs, such as the liver, kidneys, and brain.[30–32] Hence, we speculate that the adverse effects of PM on survival occur not only in lung cancers, but also in non-lung cancers, including BC.

Up to now, the mechanisms by which PM affects the survival of BC patients have not yet been fully elucidated. Fortunately, previous studies have reported some potential pathways that may explain this outcome. The first mechanism involves inflammation due to oxidative stress. Current evidence has suggested that PM acts as 1 prevalent environmental oxidative stressor, resulting in systemic inflammation and epigenetic changes.[33–37] As we all know, PM can increase the risk of mortality through interfering with the normal operation of the cardiovascular or respiratory system. Furthermore, some studies have reported that inflammation may be the hypothetical underlying mechanism promoting BC progression.[38–41] Some epidemiological studies have shown that the use of aspirin and other nonsteroidal anti-inflammatory drugs after BC diagnosis can improve survival rate, suggesting the vitality of the inflammatory process following diagnosis.[42,43] Similarly, the expression of cyclooxygenase-2 (COX-2) in breast tissue samples is associated with a worse prognosis, for as we all know, COX-2 is an inflammation marker and a target of aspirin.[44] Although there was no published research that reported the relationship between PM and BC mortality among aspirin users, this inference may be the underlying mechanism that contributed to our results.

The second hypothesis mechanism was DNA damage and PAH–DNA adducts formation. PM in ambient air possesses the ability to combine different chemicals, such as PAH. While PAH's adverse effect on human cancers was already demonstrated, some epidemiologic researches have revealed the relationship between PAH and DNA adducts in BC.[45,46] The accumulation of PAH–DNA adducts plays an critical role in the further progression of the malignant BC cells, which might increase mutations and induce genomic instability and further contribute to the cancerous phenotype of the cells. Yet, this hypothesis needs to be further investigated. Future research needs to consider exposure periods for early life time, tumor subtype, menopausal status, and cancer stage as potential related contributors to BC mortality.

Given the relationships between $PM_{2.5}$/PM_{10} with BC mortality, the studies up until now have offered little evidence to support a connection between PM and BC incidence risk.[17,47–51] Similarly, the European Study of Cohorts for air pollution effects have

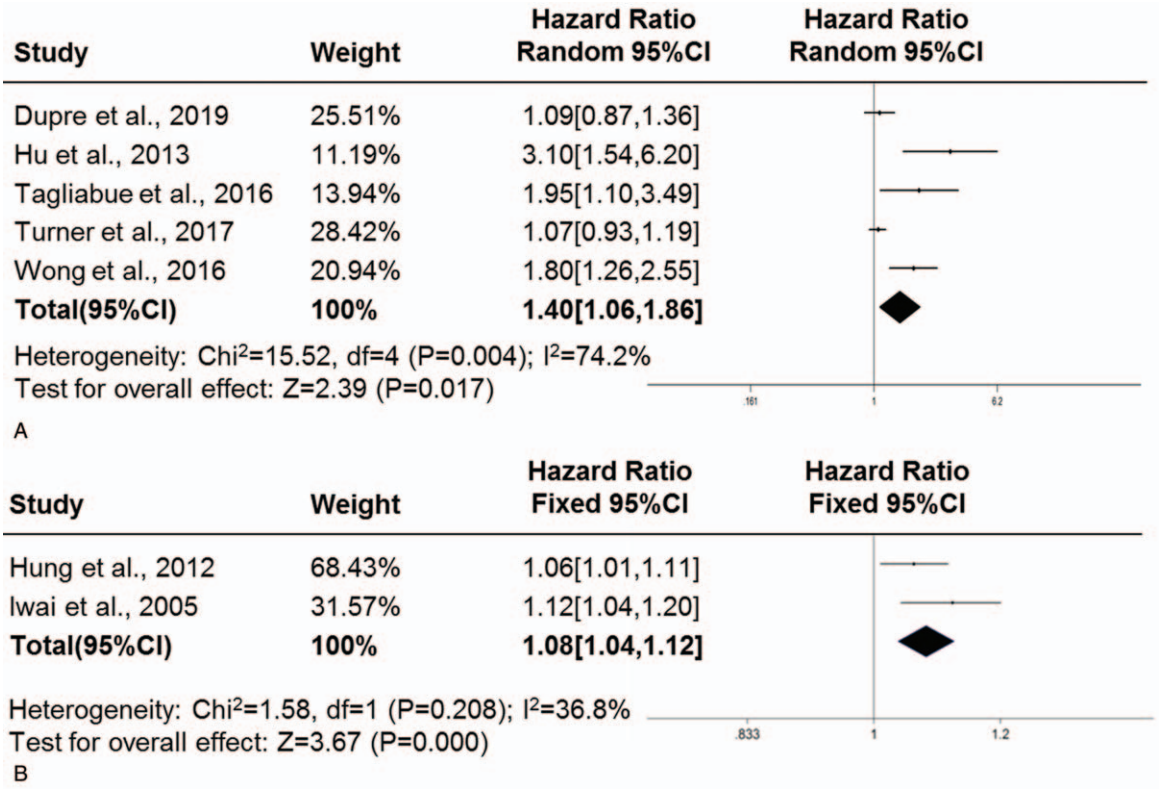

Figure 6. Forest plot for the association between $PM_{2.5}$ and BC mortality: Subgroup analysis. The results of cohort studies (A) an ecological studies (B) are shown, respectively. The black diamond and its extremities indicate the pooled risk ratio center and a 95% confidential interval. BC = breast cancer, PM = particulate matter.

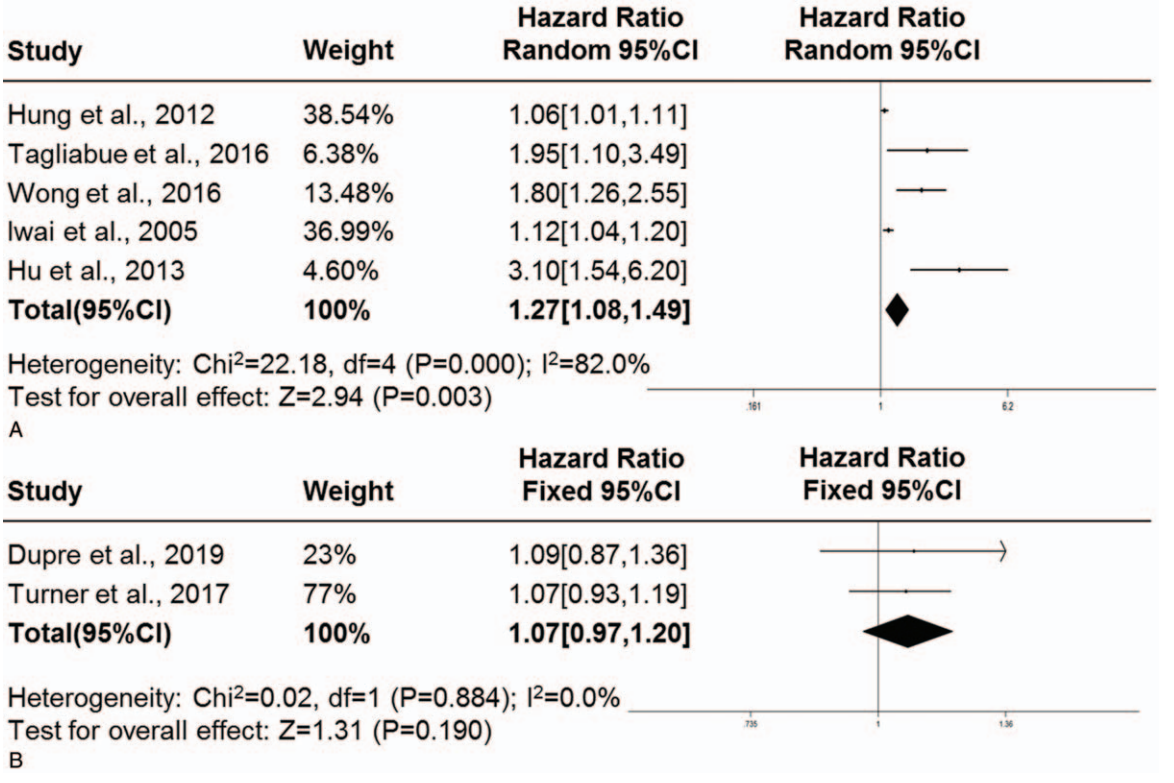

Figure 7. Forest plot for the association between $PM_{2.5}$ and BC mortality: Subgroup analysis. The results of higher exposure (A) and lower exposure (B) are shown, respectively. The black diamond and its extremities indicate the pooled risk ratio center and a 95% confidential interval. BC = breast cancer, PM = particulate matter.

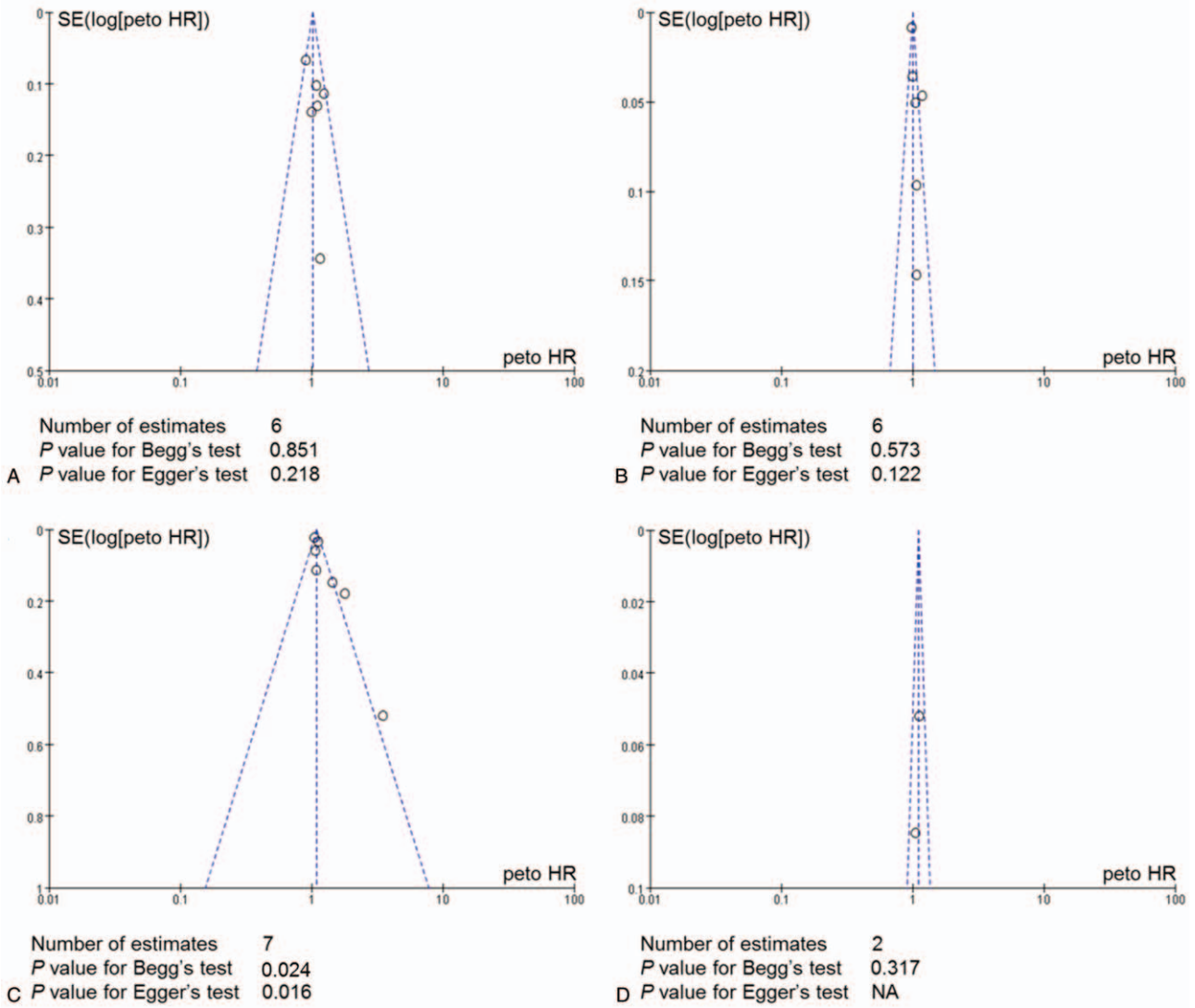

Figure 8. Funnel plot for the studies included for the association between $PM_{2.5}$ and BC morbidity (A), PM_{10} and BC morbidity (B), $PM_{2.5}$ and BC mortality (C), PM_{10} and BC mortality (D). BC = breast cancer, PM = particulate matter.

suggested a positive but nonstatistical significant, association between PM and some non-lung cancer (brain, stomach, liver, bladder, kidney) incidence risk.[52–55] Nonetheless, evaluating this association is still a challenging topic a worldwide. More study to explore the association between PM and BC is urgently needed.

A few limitations should be noted for this meta-analysis. First, there are 7 researches that have reported the relationship between $PM_{2.5}$ and BC mortality using a significant heterogeneity test ($I^2 = 73.1\%$, $P = .001$). Among these studies, 5 reported a positive association between $PM_{2.5}$ and BC mortality, while 2 showed a insignificant outcome with positive estimated HRs (HR = 1.07, HR = 1.09), respectively. Sample size, different models for statistical analysis, diverse region exposure levels, and population characteristics, and various methods for recording may explain this heterogeneity. Even so, the pooled estimates present a consistently remarkable adverse effect between $PM_{2.5}$ with BC mortality, and the results of a subgroup analysis were unchanged. Secondly, merely 2 studies reported PM_{10} with a BC mortality risk, and an overall pooled HR from these was inaccurate, not only because of an insufficient number of articles, but also because the 2 viewpoints are inconsistent. To address this issue, further research is urgently needed. Third, no published literature has reported the relationship between PM and BC mortality according to ER/PR status, so further research to address this gap is also necessary. Fourth, publishing bias was suggested in the studies on $PM_{2.5}$ and BC mortality. More studies are necessary to clarify this issue.

In conclusion, the present meta-analysis demonstrated that there is an increased mortality between PM exposure and BC patients. In particular, exposure of people at higher PM levels tends to present a greater probability of mortality compared to people's exposure at relative-lower PM levels. It is very necessary to improve the living quality and elevate health protection of females. Better methods or capturing and monitoring ambient PM exposure and applicable public health strategies are urgent and need to be established or modified in the future.

Author contributions

Q.C. proposed the conception ideas for the study. Y.X. supervised and modified the study. Z.Z. and N.Y.Z. extracted the data. Z.Z. and W.T.Y. analyzed the data. Z.Z. and W.T.Y. drafted the manuscript.

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