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Proximity to coke works and hospital admissions for respiratory and cardiovascular disease in England and Wales

P Aylin, A Bottle, J Wakefield, L Jarup, P Elliott

Abstract

***Background*—The incidence of hospital admissions for respiratory and cardiovascular diseases in areas close to operating coke works in England and Wales was investigated.**

***Methods*—A small area study using distance from source as a proxy for exposure was undertaken in subjects aged 65 or over and children under 5 years within 7.5 km of four coke works (1991 estimated populations 87 760 and 43 932, respectively). The main outcome measures were emergency hospital admissions in 1992/3–1994/5 with a primary diagnosis of coronary heart disease (ICD 410–414), stroke (ICD 431–438), all respiratory diseases (ICD 460–519), chronic obstructive pulmonary disease (ICD 491–492), and asthma (ICD 493) in those aged 65 or over, and all respiratory and asthma admissions in children under 5 years of age.**

***Results*—At age 65 or over the combined estimate of relative risk with proximity to coke works (per km) ranged from 0.99 (95% CI 0.90 to 1.09) for chronic obstructive pulmonary disease to 1.03 (95% CI 0.94 to 1.13) for asthma. For children under 5 years the combined estimate of risk was 1.08 (95% CI 0.98 to 1.20) for all respiratory disease and 1.07 (95% CI 0.98 to 1.18) for asthma. There was evidence of significant heterogeneity in risk estimates between coke work groups, especially in children under 5 years ($p<0.001$ and $p=0.004$ for respiratory disease and asthma, respectively). For the Teesside coke works in North East England the relative risk with proximity (per km) was 1.09 (95% CI 1.06 to 1.12) for respiratory disease and 1.09 (95% CI 1.04 to 1.15) for asthma.**

***Conclusions*—No evidence overall was found for an association between hospital admissions and living near operational coke works in England and Wales. Trends of a higher risk of hospital admission for respiratory disease and asthma among children with proximity to the Teesside plant require further investigation.**

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Acute rises in the levels of air pollution are associated with acute ill health and excess mortality,[1–3] especially from cardiorespiratory diseases. Recent attention has focused on particulate pollution,[4 5] although other pollutants including sulphur dioxide[6] and ozone[7] are also implicated. Much less is known about the effects of chronic exposure to air pollution on health,[8–10] including possible effects in people living close to industrial sources.[11–13] Coke works are an important local source of particulate and sulphurous pollution and complex mixtures of pollutants.[14] Sulphur dioxide, oxides of nitrogen, and particulates (as black smoke and soot) are continually released from the main stack. The majority of particulates are released on an intermittent basis (typical frequency of the order of half hourly) during discharge and quenching of coke. Other organic pollutants such as benzene and polyaromatic hydrocarbons are released from fugitive sources.[15]

Three recent studies have examined the health of residents near coke works in the UK. Bhopal *et al*[16] found increased rates of symptom reporting for respiratory and ear, nose and throat complaints among residents (especially children) living near Monkton coke works, and increased all cause mortality among children, but not adults. Dolk *et al*[17] found a small excess in mortality within 2 km of coke works and a decline in mortality with distance from coke works, but could not exclude residual socioeconomic confounding as an explanation. The third study found no evidence of an increased risk of perinatal and infant mortality and low birth weight among infants born to mothers living near coke works.[18]

This study investigates the incidence of hospital admissions for respiratory and cardiovascular diseases in areas close to operating coke works in England and Wales. There is evidence to suggest that hospital use is a reasonable proxy for morbidity for some conditions such as respiratory disease.[19] The focus is on potentially vulnerable groups—people aged 65 or over who may have limited respiratory reserve, and children under 5 years.[20]

Methods

Nine coke works still operational in England and Wales in 1995 were eligible for study (there were none in Scotland). They fell into six groups of sites, based on proximity between adjacent coke works (table 1, fig 1). Hospital Episode Statistics and the Patient Episode Database for Wales for the years 1992/3 to 1994/5, held by the UK Small Area Health Statistics Unit, provided numbers of emer-

Table 1 Operating coke works in England and Wales in 1995, and 1991 population estimates within 7.5 km at ages ≥65 and 0–4 years

Area	*Operating coke works*	*1991 population*	
		≥65 years	*0–4 years*
England			
Royston	Monkton coking works	23976	11362
Scunthorpe	Appleby coke ovens	13985	6569
Teesside	South Bank coke ovens	31541	17107
Wales			
Newport	Llanwern works	18258	8894
Pontypridd *	Cwm coking works	14965	7795
Port Talbot *	Morfa coking works	9638	3598
	Grange coking plant		

*Excluded from the study because of incomplete data on hospital admissions (see text).

gency hospital admissions (irrespective of whether they came via A&E or GP referral) among people whose census enumeration districts of residence had population weighted centroids within 7.5 km of the nearest coke works. Since an admission may comprise several episodes as patients are transferred from one consultant to another within the same trust, the first episode was used to identify an admission. Patients may be included more than once if they are discharged and later readmitted either to the same or to a different trust. Population estimates for 1991 (by 5 year age group, sex, and quintile of the Carstairs deprivation score[21]) were obtained for each enumeration district (ED) using figures from the "estimating with confidence" project.[22] Enumeration districts contain, on average, about 400 people. Diseases examined at age 65 years or over were coronary heart disease (ICD 410–414), stroke (ICD 431–438), all respiratory diseases (ICD 460–519), chronic obstructive pulmonary disease (ICD 491–492), and asthma (ICD 493). All respiratory diseases and asthma were examined in children under 5 years. The primary diagnosis was used in all cases.

Two hospitals serving residents near Pontypridd and Port Talbot coke works failed to record a primary diagnosis or used the ICD 9th revision code 799 (other ill defined and unknown causes of morbidity and mortality) in 25% and 36% of their emergency admissions, respectively,[23] while figures for the remaining hospitals varied between 1% and 11%. These two groups (three coke works) were therefore excluded, leaving six coke works in four groups for study (table 1). Fewer than 1% of cases within 7.5 km of coke works in England were omitted because of missing data for method of admission, age, sex, postcode, and primary diagnosis. For Newport, 3.3% had missing or invalid fields.

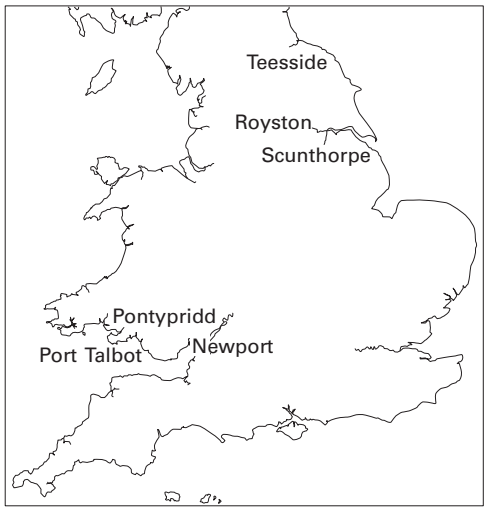

Figure 1 Location of six groups of operating coke works operational in England and Wales in 1995.

Ideally the exposure model would be based on direct measurement or modelling using, for example, stack height, operating conditions, wind direction, and other meteorological factors, but these data were not available for all of the sites. In the absence of such modelling we used a distance-decline model based on concentric areas around the coke works.[24] Using the relevant administrative region as the reference population, expected numbers of admissions, by specific cause, were calculated for each enumeration district within 7.5 km of a coke works. An indirectly standardised admission ratio (relative risk (RR) estimate) by age, sex, and Carstairs quintile was calculated from the ratio of observed to expected numbers of cases around each coke work group based on location of the population centroids of the underlying EDs for seven distance bands around each group with outer radii of 1, 2, 3, 4.6, 5.7, 6.7, and 7.5 km. Stone's conditional test[25] for decline in risk with distance was performed, with significance levels based on 999 simulations.

The specification of the form of the relation between risk of admission and distance from coke works is of particular importance. Several choices are available including linear, step, or inverse square and these were explored using the method of Diggle *et al*.[26] In view of problems such as model convergence with the more complicated forms, the linear model was preferred and Poisson regression, with distance included as a continuous variable, was used to provide an estimate of the risk of admission associated with proximity to coke works.

To adjust for possible "provider effects"—that is, the variation between hospitals in admission rates due to factors such as differences in hospital admissions policy and clinical coding—"hospital" was included as an additional categorical covariate in the Poisson regression analyses. Whereas the number of cases going to each hospital is known, the population who are "at risk" of admission to each hospital is not and must be estimated. To this end, the fraction of each ward's total emergency admissions going to each local hospital (including an artificial "other" provider, created to capture remaining admissions) was calculated. Populations in each ED within the ward were then multiplied by this set of fractions and the regression proceeded as before. This tended to improve the fit of the model and reduce overdispersion.

Estimates of association with proximity to each coke works were then combined in a Bayesian hierarchical (random effects) model using the BUGS software[27] in order to find an overall estimate of association.

Table 2 Numbers and rates of emergency hospital admissions in 1992/3–1994/5 within 7.5 km at ages ⩾65 and 0–4 years

	Age ⩾65 years				Age 0–4 years			
	Respiratory disease		CHD/stroke		Respiratory disease		Asthma	
Area	No	Crude rate per 1000/year	No	Crude rate per 1000/year	No	Crude rate per 1000/year	No	Crude rate per 1000/year
Royston	2555	36	2717	38	1549	45	374	11
Scunthorpe	1295	31	1984	47	1066	54	229	12
Teesside	2664	28	3178	34	3048	59	804	16
Newport	848	15	1275	23	845	32	252	9

CHD = coronary heart disease.

Results

In 1991 an estimated 87 760 people aged 65 or over and 43 932 children under 5 years of age lived within 7.5 km of the four coke work groups included in the study (table 1).

Table 2 shows numbers of admissions and crude rates per 1000 population per year at ages 65 or over, and for children under 5 years. At the age of 65 or over there were a total of 7362 emergency admissions for respiratory disease within 7.5 km with crude rates ranging from 15 to 36 per 1000 population per year and 9154 admissions for coronary heart disease and stroke with rates ranging from 23 to 47 per 1000 population per year. In children under 5 years of age there were 6508 respiratory disease admissions within 7.5 km with crude rates ranging from 32 to 59 per 1000 population per year and 1659 admissions for asthma with rates ranging from 9 to 16 per 1000 population per year.

For people aged 65 or over no consistent patterns emerged (fig 2). With deprivation and provider adjustment there was a significantly lower risk with proximity (per km) to Royston for all respiratory disease (RR 0.95, 95% CI 0.93 to 0.98), a borderline significantly lower risk near Royston for stroke (RR 0.96, 95% CI 0.93 to 1.00) and Newport for coronary heart disease (RR 0.94, 95% CI 0.89 to 1.00), and a borderline significantly higher risk for coronary heart disease near Teesside (RR 1.04, 95% CI 1.00 to 1.08). None of the other regression estimates was significant and none of the overall estimates for coke works combined showed a significant association in either direction (fig 2).

Results for children under 5 years are given in fig 2 and presented in table 3. The table shows RR estimates for seven distance bands around the coke works, as well as the results of Stone's conditional test and the Poisson regression analyses. Overall the Bayesian random effects model, including adjustment for deprivation and provider, indicated a combined RR estimate (per km proximity) of 1.08 (95% CI 0.98 to 1.20) for all respiratory disease and 1.07 (95% CI 0.98 to 1.18) for asthma. Using the method of moments,[28] there was evidence of significant heterogeneity between the regression estimates for the four coke work groups ($p<0.001$ for respiratory disease and $p=0.004$ for asthma with provider adjustment).

For the Teesside coke works the Stone's test indicated a significantly higher risk with proximity to the coke works for all respiratory disease ($p=0.001$) and for asthma ($p=0.024$),

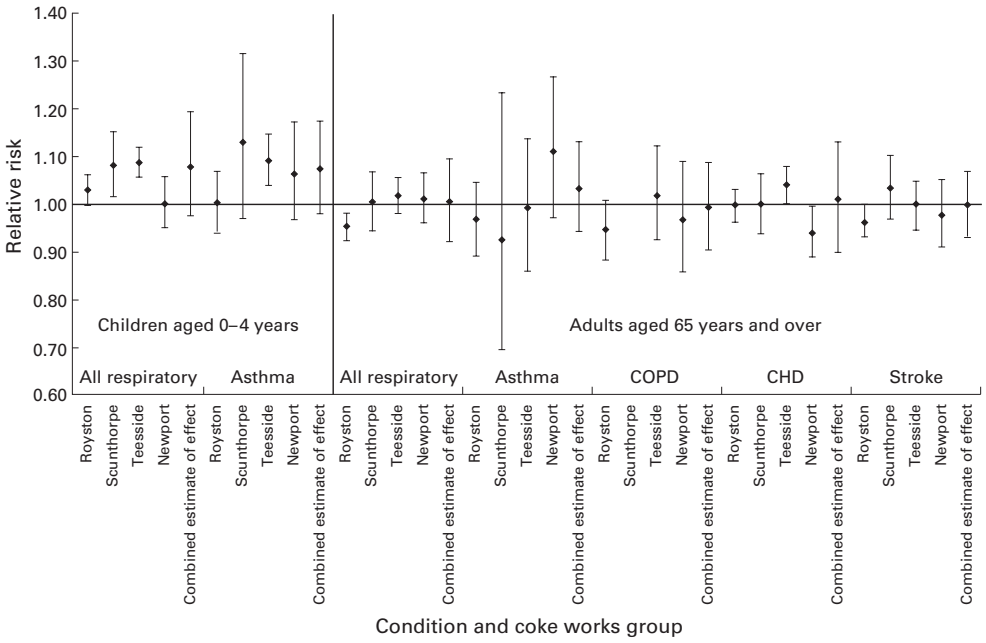

Figure 2 Relative risk per 1 km increase in proximity to nearest coke works for children under 5 and persons aged 65 years or over, adjusted for age, sex, deprivation quintile, and provider, including combined Bayesian hierarchical model estimates of effect.

Table 3 Relative risk†, Stone's conditional p value, Poisson regression estimate, unadjusted and adjusted for provider, and combined estimate of association for four coke work groups, 1992/3 to 1994/5, ages 0–4 years

		Relative risk (observed cases)							*Relative risk†/km from Poisson regression*			
		Distance band (km)							*No provider adjustment*		*Adjusted for provider*	
Condition	*Group*	*0.5–<1*	*1–<2*	*2–<3*	*3–<4.6*	*4.6–<5.7*	*5.7–<6.7*	*6.7–<7.5*	*p value (Stone's test)*	*RR*	*95% CI*	*RR*	*95% CI*
All respiratory	Royston	1.51 (28)	1.06 (52)	1.64 (157)	1.16 (346)	1.13 (348)	1.06 (243)	1.31 (375)	0.085	1.03	0.98 to 1.07	1.03	1.00 to 1.06
	Scunthorpe	(0)	1.45 (114)	1.67 (305)	1.45 (494)	1.39 (91)	1.48 (21)	1.07 (41)	0.254	1.08	1.02 to 1.15	1.08	1.02 to 1.15
	Teesside	2.28 (98)	2.10 (289)	1.62 (438)	1.56 (1096)	1.39 (600)	1.20 (289)	1.15 (238)	0.001	1.13	1.09 to 1.17	1.09	1.06 to 1.12
	Newport	(0)	0.71 (101)	0.96 (121)	0.73 (185)	0.94 (198)	0.77 (131)	0.91 (109)	0.766	1.00	0.94 to 1.06	1.00	0.95 to 1.06
										Combined estimate*		1.08	0.98 to 1.20
Asthma	Royston	1.59 (7)	1.24 (14)	1.94 (42)	0.76 (51)	1.26 (88)	1.22 (66)	1.61 (106)	0.198	0.99	0.90 to 1.09	1.00	0.94 to 1.07
	Scunthorpe	(0)	0.83 (15)	1.63 (68)	1.47 (115)	1.58 (25)	0.86 (3)	0.33 (3)	0.238	1.13	0.97 to 1.32	1.13	0.97 to 1.32
	Teesside	2.57 (30)	2.21 (83)	1.34 (99)	1.62 (311)	1.35 (160)	0.83 (54)	1.19 (67)	0.024	1.12	1.05 to 1.20	1.09	1.04 to 1.15
	Newport	(0)	1.15 (36)	1.69 (46)	0.96 (52)	1.28 (58)	0.97 (35)	0.97 (25)	0.284	1.06	0.94 to 1.20	1.06	0.97 to 1.17
										Combined estimate*		1.07	0.98 to 1.18

*From Bayesian hierarchical model. †Adjusted for age, sex, and deprivation quintile.

with an apparent gradation in risk from 2.28 (based on 98 cases) at 0.5–<1 km to 1.15 (238 cases) at 6.7–7.5 km for respiratory disease, and from 2.57 (30 cases) to 1.19 (67), respectively, for asthma. Relative risks (per km proximity) from the Poisson regression analysis were 1.13 (95% CI 1.09 to 1.17) and 1.09 (95% CI 1.06 to 1.12) for respiratory disease without and with provider adjustment, respectively, and 1.12 (95% CI 1.05 to 1.20) and 1.09 (95% CI 1.04 to 1.15), respectively, for asthma. Immediately surrounding the Teesside coke works the population is deprived, such that 83% of those living within 2 km are within the most deprived Carstairs quintile. When both deprivation and provider were removed from the regression model, the estimate for all respiratory admissions in children under 5 years became 1.16. None of the other Stone's tests was significant. Although estimated RR (per km) for respiratory disease near Scunthorpe was 1.08 (95% CI 1.02 to 1.15) both with and without provider adjustment, in contrast with Teesside, the RR within each of the seven distance bands did not show a clear gradient of declining risk with distance. Relative risks for all respiratory disease near Newport were below 1 for all distance bands.

Discussion

The main question under study was whether proximity to coke works emissions was associated with an increased risk of hospital admissions for cardiorespiratory disease. The point estimates (all non-significant) from the combined Bayesian random effects model (per km proximity to coke works) were between 1% lower risk (chronic obstructive pulmonary disease) and 3% greater risk (asthma) at ages 65 or over, and 7–8% greater risk for respiratory disease and asthma in children under 5 years of age. These results, particularly for older people, offer little or no support overall to the thesis that proximity to an important source of particulate and sulphurous pollution had a measurable impact on health.

There was, however, evidence of significant heterogeneity between the regression estimates for individual coke work groups among children. In particular, a significant trend of higher risk with proximity to the Teesside site was apparent both for all respiratory disease and asthma in children under 5 years.

There has been longstanding concern over the perceived high levels of ill health in the Teesside area.[29] A study of the health of residents near the industrial, petrochemical, and steel complex at Teesside, including the coke works, showed no clear evidence of any health effect except perhaps for lung cancer in women and a suggestion of a gradient in adults and children for self-reporting of more than 12 asthma attacks in the previous year.[30 31] The petrochemical plant was also included in a national study of lymphohaematopoietic cancers near industrial complexes containing major oil refineries in Great Britain, but the results were largely negative.[32] A study near the Monkton coke works in South Tyneside, North East England (which is now closed and

therefore not included in the present study) also found significant excess reporting of respiratory and related problems among children living near the plant.[16]

Teesside is part of a much larger industrial complex which may itself be responsible for the strong trends observed in hospital admissions for respiratory illness among young children. There is also the possibility that we have incompletely adjusted for socioeconomic deprivation and provider effects. On the other hand, if the excess risk in deprived areas near the source reflects the increased exposure, then there is a danger of overadjustment (leading to conservative estimates of risk). In our view, further analysis of health statistics for children in the Teesside area, including better exposure estimates to account for pollution sources other than coke works, is indicated in order to help disentangle these possible effects.

A number of limitations need to be recognised. Firstly, while the health data were obtained from individual records located at the level of postcode (10–100 m resolution), the exposure data and data analysis were carried out at ecological (small area) level so that resulting risk estimates may not be directly applicable to individuals.[33] Secondly, no allowance was made for migration, both into and out of the study area, and mobility through the study area as part of day to day activities. Data from linked census records in England and Wales (longitudinal study) have suggested that 67% of the population moved less than 2 km over a 10 year period,[17] while residents near the Monkton coke works had been living at the same address for an average of 15 or more years.[16] A recent paper examining health in Teesside suggested that migration is not a major issue.[30] While migration could bias estimates of association in either direction, the most likely effect is toward the null (no association). Thirdly, the study used a simple radial dispersion-decline model to describe exposure to pollutants from the source, leading to possible misclassification of areas with respect to exposure and hence possible underestimation of any health effect. Previous studies, however, based on dispersion modelling[16] and measurement around coke works,[34] have indicated that the highest pollution concentrations are found within 2 km of coke works which gives some validation to this simple model. An attempt to construct a community profile of exposure to industrial air pollution using air quality reports, dispersion modelling, and questionnaire data in Teesside also suggested that proximity of residence was a reasonable surrogate for complex community exposure.[35] Fourthly, when calculating indirectly standardised admission ratios, using the administrative region as a standard population, expected numbers of admissions in socioeconomically deprived residents close to the coke works may be underestimated (tending to overestimate the relative risk). This is because on some sites there may be greater deprivation within each quintile in the inner rings than in the standard population. However, in our regression analyses, which were based on rates within 7.5 km, this is less of an issue.

The health data were derived from Hospital Episode Statistics and the Patient Episode Database for Wales which record all National Health Service hospital inpatient activity in England and Wales. Several factors that influence hospital admission are independent of disease prevalence and severity. General practitioner referral rates,[36] supply of hospital beds,[37] variations in admission policies and hospital access (which tends to be less for less privileged groups[38]), and distance from hospital[39] are all important. The quality of hospital data is an important consideration.[40 41] Two groups (three coke works) were excluded from the analysis because of the poor quality of local hospital episode data which included failure to record a primary diagnosis or use of vague diagnoses, but we were unable to determine the accuracy of diagnostic coding for any group. Numbers and rates for Newport were also low compared with other coke work groups, suggesting the possibility of incomplete coverage. To the extent that such factors may vary between areas in the vicinity of coke works, an unknown degree of bias may have been introduced into the analyses. Some episodes are likely to be repeat admissions in the same subjects. The regression analysis for Teesside and Scunthorpe in children under 5 was repeated using individuals as the unit of analysis by linking admissions using date of birth, sex, and postcode. Although relative risks were slightly decreased, they remained significant.

In summary, we found no significant evidence overall for a health effect associated with living near to operational coke works in England and Wales. Trends of higher risk of respiratory hospital admission among children with proximity to the Teesside plant require further investigation. This should include improved definition of exposed areas through modelling of emissions both from the coke works and other major industrial sources in the area.

PA, PE, and LJ were involved in the conception and management of the project. PA and AB were involved in the development of the project with JW overseeing the statistics. PA and AB prepared the first draft of this paper and LJ, JW and PE contributed to the final submitted version. PA is the guarantor.

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