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Spatial variation in the risk of hospitalization with childhood pneumonia and empyema in the North of England

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SUMMARY

The aim of this study was to investigate spatial variation in risk of hospitalization in childhood pneumonia and empyema in the North of England and associated risk factors. Data on childhood (0–14 years) hospital admissions with a diagnosis pneumonia or empyema were linked to postcode districts. Bayesian conditional autoregressive models were used to evaluate spatial variation and the relevance of specific spatial covariates in an area-based study using postcode as the areal unit. There was a sixfold variation in the risk of hospitalization due to pneumonia across the study region. Variation in risk was associated with material deprivation, Child Well-being Index (CWI) health domain score, number of children requiring local authority support, and distance to hospital. No significant spatial variation in risk for empyema was found.

Key words: Deprivation, paediatrics, pleural empyema, pneumonia epidemiology.

INTRODUCTION

Pneumonia is the leading cause of childhood mortality in children aged <5 years, with more than 2 million deaths a year occurring worldwide [1]. Although the greatest burden of disease occurs in developing and newly industrialized countries (151 million of an estimated total of 156 million cases) it remains a serious cause of child morbidity and mortality in the developed world [2]. Empyema (thoracis) is the presence of infection within the pleural membranes that overlie the lungs and most often arises as a complication of pneumonia in the underlying lung. Incidence has increased over the last 20 years, with a sharp rise reported across Western Europe, North America, the Far East and Australia [3–6]. In the UK hospital admissions increased from <10 per million in 1998 to 37 per million in 2005 [7]. Despite these changes, the epidemiology of empyema in children remains poorly understood.

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Spatial analytical techniques have proved useful in understanding the epidemiology of infectious disease, for example identifying novel risk factors or identifying areas of increased risk which may benefit from targeted public health intervention [8]. Several studies have reported significant spatial variation in pneumonia previously [9–11]. However, published data on spatial variation in empyema in children is more limited, with only one published study which found no evidence of spatial clustering of cases between 1988 and 1994 in Ohio, USA [12].

A link between socioeconomic deprivation and risk of pneumonia in children has been previously reported in a number of individual-level studies [13–15]. The incidence rate of admissions for pneumonia was almost 30% higher in the most deprived areas compared to the most affluent in children aged 0–4 years in one UK study (incidence rate ratio 1·29, 95% confidence interval 1·18–1·41] [14]. In the North East of England children were more likely to have severe pneumonia if they were from families with higher rates of material deprivation [15]. The results of spatial studies have been more complex [10, 16]. In the North East of England differences in admission rates for childhood pneumonia were seen between counties and similarly in Crighton *et al.*'s Canadian study differences were seen between counties in hospitalizations for pneumonia and influenza [10, 15]. These differences were associated with counties with low scores for educational attainment and higher rates of Aboriginal population. Charland *et al.* observed higher rates of clinic attendance with influenza and pneumonia in areas of greatest material deprivation but could not establish a linear relationship between the two and found no link with social deprivation [16]. The influence on socioeconomic deprivation on empyema is less certain. It has been associated with increasing severity in pneumonia but a specific link to empyema has not been reported. Given the close relationship of both conditions, it could be hypothesized that similar associations may exist.

The objectives of this study were to determine whether spatial variation in the risk of hospitalization with childhood pneumonia and empyema was present in the North East of England and quantify the relationship between any variation and levels of socioeconomic deprivation, healthcare-related factors, environmental exposure and population demographic factors such as ethnicity.

METHODS

Ethical approval

The handling and use of Hospital Episode Statistics (HES) data was in accordance with the requirements of The Information Centre for Health and Social Care [17]. The UK Enhanced Surveillance of Paediatric Pneumococcal Empyema (UK-ESPE) study received a favourable opinion from the Sunderland Regional Ethics Committee which included permission to use residential postcode data.

Study population

The study area contains both large urban areas running down the south east coast, as well as hilly, sparsely populated rural areas to the north and west. The location of the in-patient units presented in Figure 1 represent a good approximation for the population density within the region. The region has above average UK levels of social deprivation and unemployment.

The spatial unit used was a postcode district. Due to constraints of data availability, two distinct study areas in the North of England were used. For pneumonia, this was the North East Strategic Health Authority (NE SHA) area, comprising 116 postcode districts. For empyema, the referral area of the centre with responsibility for managing the condition in the North East (Freeman Hospital, Newcastle-upon-Tyne) was used. This included both the whole of the NE SHA and additional districts to the south and west, a total of 150 postcode districts. The total child population of the pneumonia study area was 462 900, with the larger empyema study area comprising 532 661 children. Across the pneumonia study area, the average child population of a district was 3991 children aged 0–14 years. Across the empyema study area, the average child population of a district was 3548 children aged 0–14 years. Both areas had the same district population range (47-11406). All boundaries and population estimates were derived from the 2001 UK Census [18]. There were no instances where cases were excluded due to changes in postcode over the study period. Covariate data were matched to postcode districts by use of the GeoConvert online tool [19].

Pneumonia data

Data on childhood hospitalizations in the NE SHA area from May 1997 to April 2007 with a diagnosis

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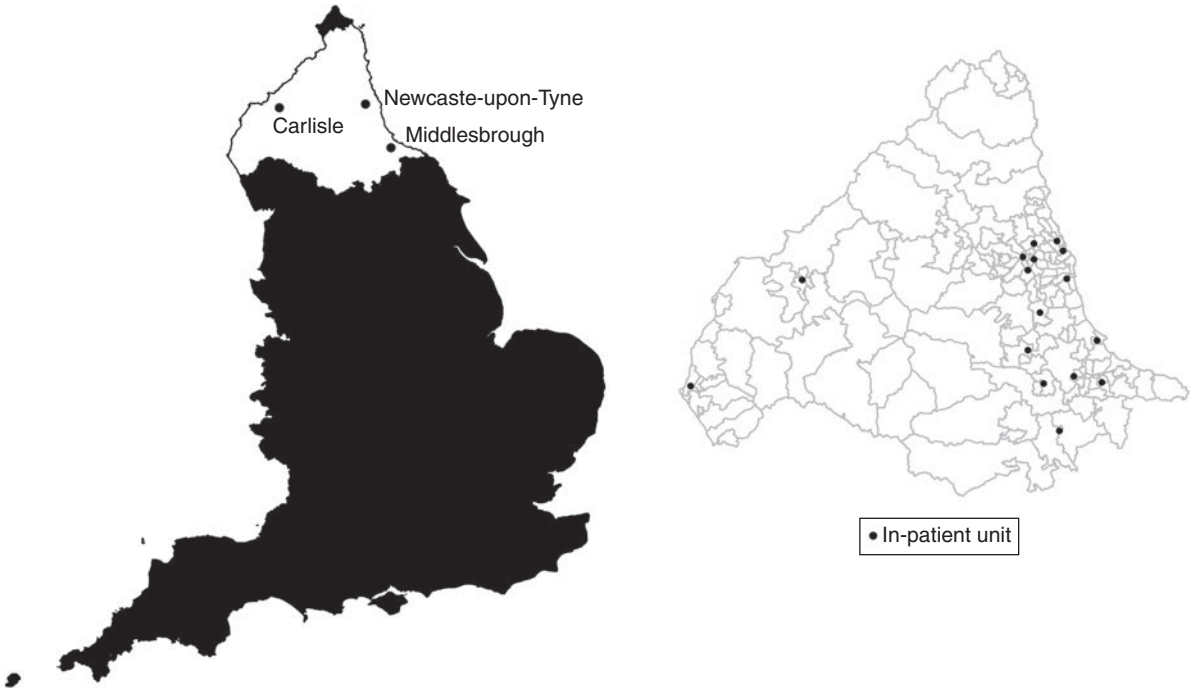

Fig. 1. Study area with postcode districts and in-patient units indicated.

of bacterial or lobar pneumonia [International Classification of Disease – 10 (ICD-10) codes J13, J14 and J150–9, J181] for children aged <15 years were extracted from the HES database.

The HES is a data collection system that records each individual episode of care for every patient admitted to NHS hospitals in England. Data were obtained from The Information Centre for Health and Social Care [17]. Fourteen diagnostic fields are available for each individual record and each diagnosis is coded according to the ICD-10 system. The period the 1 April 1997 to 30 March 2007 was used. April 1997 was chosen as the data collection start to avoid the change in coding classification from ICD-9 to ICD-10 that took place in 1995 and 1996 which may have led to problems of differential ascertainment.

All data with each disease code were counted and all those with the same HES identification number were amalgamated to convert from episodes to hospital admissions. Duplicate entries were removed and re-admissions were excluded if they occurred within a month of the initial admission. Each HES entry contains details of residence, through which all hospitalizations over the time period were linked to postcode districts. Residential data were missing or unusable in 15/3889 (0·4%) hospitalizations and were therefore excluded.

Empyema data

Empyema case data were obtained for cases of childhood empyema managed at the tertiary referral centre (Freeman Hospital, Newcastle-upon-Tyne) between 1995 and 2010. There were no other management centres in the study area and there were no changes in referral practices over the time period. As empyema exists on a spectrum of disease from uncomplicated parapneumonic effusion to frank empyema, only children requiring invasive management (pleural drainage or decortication) were included to ensure constancy of case definition. The collection of empyema data was part of a wider study of paediatric empyema, the UK-ESPE. All cases included had valid postcode data.

Spatial covariates

Spatial covariate data were obtained from several sources. Data were obtained from the local index of Child Well-being (CWI), derived in a 2009 survey from the Department of Communities and Local Government of the UK Government [20]. While not solely a measure of deprivation, as it contains data that are not strictly deprivation related, it was designed to address the lack of child-specific small area data and is much more child specific than the commonly used indices of multiple deprivation. It includes a measurement for each of the 32482

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lower super output areas in England and is comprised of seven separate domains, covering different aspects of child well-being. These in turn comprise combinations of different indicator measurements as follows:

(i) *Material deprivation*: children living in households that are in receipt of both in-work and out-of-work means-tested benefits.
(ii) *Health*: all emergency hospital admissions, all outpatient attendances for children and children receiving disability living allowance as a proportion of all children in each area.
(iii) *Education*: school absence rates, standardized test and examination scores and entry into higher education rate.
(iv) *Crime*: police recorded crime data for burglary, theft, criminal damage and violence.
(v) *Housing*: access to housing (as measured by overcrowding rate, proportion of shared housing and homelessness) and quality of housing (proportion of children living in accommodation lacking central heating).
(vi) *Children in need*: expected rate of children requiring local authority social support.
(vii) *Environment*: environmental quality (air quality, percentage of green space and woodland, number of bird species and child road accident rate) and environmental access (average number of leisure and sports facilities within area and average road distance to school).

Measurements of ethnicity (proportion of non-Caucasian individuals within the district) and migration (all inward migrants, outward migrants and those moving within the district in the year prior to the census) were derived from the 2001 UK Census key statistics dataset [21]. Finally, it was feasible that postcode districts in close proximity to hospitals may have higher observed case numbers as a consequence of increased attendance rates given their relative ease of access. In order to evaluate this potentially pertubatory effect, the distance to each of the admitting hospitals from each postcode district was estimated using the centroids of each district and the centroid of the district containing each hospital. The shortest possible straight-line distance for each district was then used as a covariate. The average distance was 13·3 km, with the maximum distance 70·9 km for NE71, located at the northern tip of the study region on the Scottish border. For cases residing in the same district as a hospital the distance was taken as 0 km.

Statistical analysis

Bayesian conditional autoregressive (CAR) models (developed by Besag *et al.* [22]), were used to estimate the relative risk of hospitalization with pneumonia and empyema in individual postcode districts with a range of explanatory variables included as spatial covariates. These included metrics of deprivation, district ethnic composition, migration levels and distance from residence to admitting hospital.

These models were implemented as Poisson spatial models with observed cases as the dependent variable, expected cases as offset and random-effects terms that took the following into account: (*a*) effects that varied in a structured manner in space (postcode district contiguity) and (*b*) a component that models the effects that varied among census tracts in an unstructured manner (postcode district heterogeneity). The first of these represented an attempt to model unmeasured spatial dependency associated with the proximity of residential postcodes, while the second allows for significant differences between postcodes over the study area.

It was assumed that the observed cases (O_i) for each postcode district ($i = 1, \ldots, n$) followed a Poisson distribution with mean $\mu_i = E_i O_i$, where E_i is the expected number of cases for each postcode district obtained by indirect standardization, and μ_i is the relative risk for each specific area. The expected numbers of cases were calculated by distributing the total observed cases between the postcode districts according to each district's population estimate. Specifically, the proportion of the total age-specific population (aged 0–14 years, 2001 Census data), that resided within each postcode district was used to estimate the expected cases within that district.

The null model took the following form:

$$O_i \sim \mathrm{Po}(E_i \mu_i),$$
$$\log(\mu_i) = \log(E_i) + \alpha + b_i + h_i,$$

where O_i is the observed number of cases in area I, E_i is the expected number of cases, μ_i is the relative risk in area i, α is the intercept, h_i is the census tract heterogeneity term, and b_i is the spatial term. Initially, the null model included no explanatory variable. Subsequent iterations were fitted to include a covariate effect, using the following general model:

$$O_i \sim \mathrm{Po}(E_i \mu_i),$$
$$\log(\mu_i) = \log(E_i) + \alpha + \beta \mathrm{cov}_i + b_i + h_i,$$

where cov_i is the covariate value in area i. Models were fitted with a variety of covariates using this

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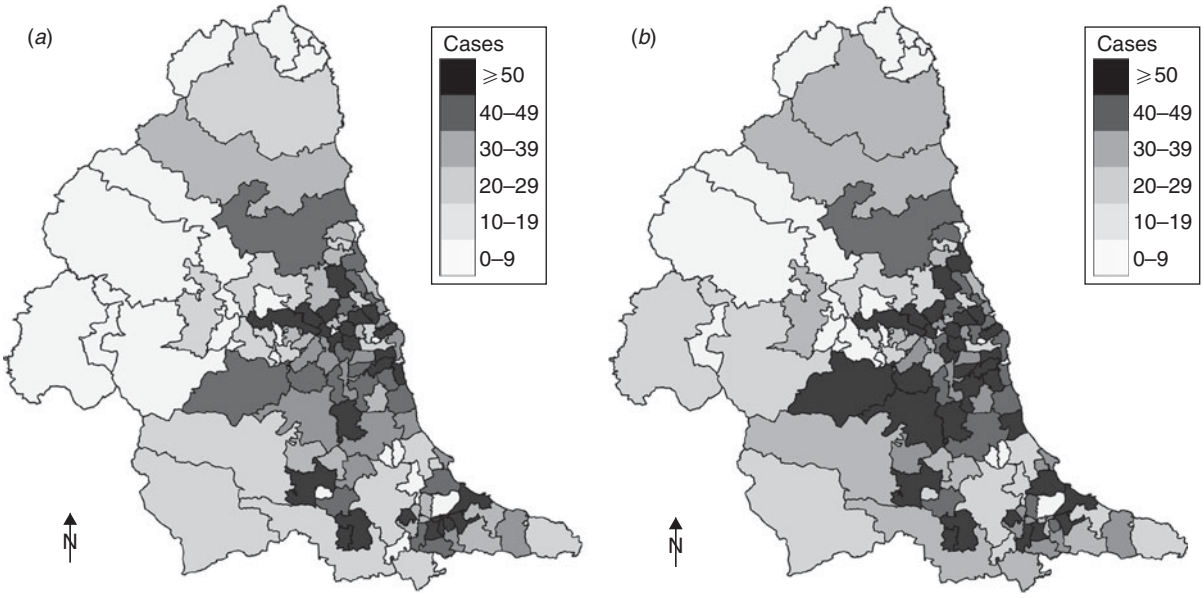

Fig. 2. The number of (*a*) observed and (*b*) expected cases of pneumonia across the postcode districts of North East England.

general model structure. The null model was compared with models from three groups containing covariates for (*a*) overall CWI, ethnicity, migration and distance from admitting unit separately, (*b*) the seven individual CWI domains that make up the CWI, (*c*) all possible combinations of those covariates from (*a*) and (*b*) that were shown to be significant at 95% Bayesian Credibility Intervals (BCIs).

The models were fitted using Bayesian Markov chain Monte Carlo (MC) simulation methods within WinBUGS 1.14 [23]. A 10000 iteration 'burn-in' was followed by a 50000 iteration sample. In all cases, the MC error for each area was <5% of the standard deviation, indicating sufficient iterations of the model had been run after convergence. Model assessment involved the comparison of DIC (Deviance Information Criterion) scores for each model, with the model with the lower DIC score preferred. A difference in DIC >3 indicates a significant difference in model performance [24]. Following the principle of parsimony, the best performing model was judged to be the one with the lowest DIC which contained only significant variables.

We considered as significant those areas where the 95% BCI around the estimated relative risk excluded 1. A covariate was considered significant if 97·5% of its distribution lay either above or below zero. To depict the spatial distribution of relative risk across the study area postcode district maps obtained from UK Borders were used alongside R 2.12.2 and WinBUGS [25–27].

RESULTS

Pneumonia

There were 3874 reported cases of pneumonia during the study period. The spatial distribution of these cases is presented at the postcode district level in Figure 2*a*. The most cases were found in TS3 (deprived suburbs to the east of Middlesbrough town centre, 128 cases) and NE4 (densely populated suburbs to the west of Newcastle-upon-Tyne city centre, 106 cases). The expected incidence of pneumonia for each postcode district is presented in Figure 2*b*.

Figure 3 presents the spatial distribution of those postcode districts that, according to the null model, were shown to have either a significantly low or high relative risk of childhood pneumonia.

Significant spatial variation in risk of admission to hospital with pneumonia was found, with 53 (47%) districts having either a significantly higher or lower risk compared to that predicted by child population alone [range of relative risk (RR) 0·32–2·34]. Most areas of highest risk were in the urban centres of the major cities of Newcastle and Middlesbrough. Large rural districts to the North and West of the region had the lowest risk.

Table 1 presents summaries of selected models of the spatial distribution of pneumonia cases. Table 2 contains details of significant spatial covariates. Relative childhood deprivation, as measured by the CWI, was associated with a significantly increased

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Table 1. *Summary statistics for selected models of relative risk of hospitalization with pneumonia*

Model group	No. of covariates	Covariates	Minimum RR	Maximum RR	No. significant low RR	No. significant high RR	Model DIC
Null	0		0·319	2·338	31	22	749·68
a	1	CWI	0·459	3·017	32	14	746·01
b	7	CWI individual scores	0·500	3·086	31	13	742·28
c	3	CWI significant scores (material deprivation, health, Children in Need)	0·437	2·915	37	13	741·50
a	1	Material deprivation	0·413	2·993	27	13	749·35
a	1	Children in Need	0·404	2·990	28	12	750·88
a	1	Health	0·406	2·898	36	16	743·93
a	1	Distance to hospital	0·279	2·938	29	12	746·34
c	4	Distance to hospital, health, material well-being, Children in Need	0·379	2·917	37	13	740·94
Best performing model							
c	3	CWI significant scores	0·437	2·915	37	13	741·50

CWI, Child Well-being Index; RR, relative risk; DIC, Deviance Information Criterion.

Table 2. *Significant spatial covariates for pneumonia*

Variable	Median (range)	Estimate of mean of posterior distribution	S.D. of posterior distribution
CWI	158·93 (47·82 to 393·21)	0·0027	0·00045
Distance to hospital (km)	6·83 (0 to 70·89)	−0·019	0·0057
Material well-being	0·21 (0·04 to 0·63)	3·92	1·14
Children in Need	0·03 (0·01 to 0·09)	−26·74	9·1
Health	0·47 (–1·103 to 1·62)	0·31	0·092

CWI, Child Well-being Index; S.D., standard deviation.

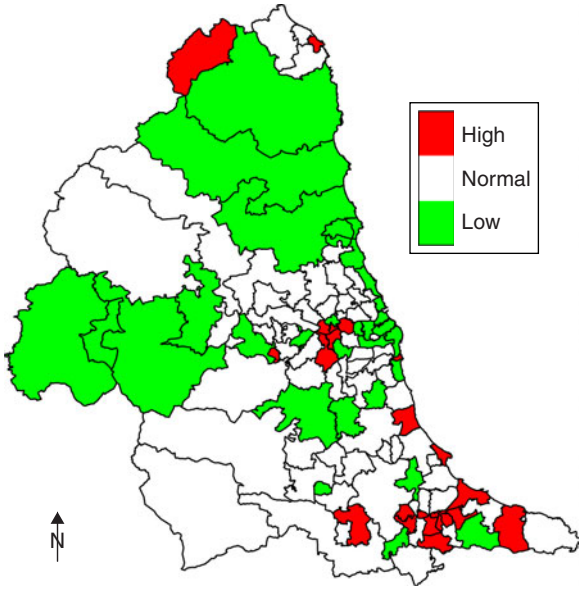

Fig. 3. [*colour online*]. The location of postcode districts with significantly high or low relative risk of pneumonia, according to the null model.

risk of admission in a district. Of the components of the CWI, greater material deprivation, higher health domain score (indicating higher rates of hospital admissions, clinic attendances and disability in an area) and a higher Children in Need score (indicating a greater number of children requiring local authority support) were significant predictors of increased risk. Distance to hospital was a significant covariate when added to the null model, with increased admissions in districts closest to hospitals. However, it was non-significant when added to a model containing the significant CWI covariates and did not improve the DIC sufficiently to warrant retention (DIC 740·94 *vs.* 741·50). Ethnicity, migration levels, education, housing, crime and the environment domains were all non-significant.

The best performing model contained the three significant CWI covariates alone (DIC 741·50), although the three models containing (i) all seven separate components of the CWI, (ii) health alone and (iii) distance

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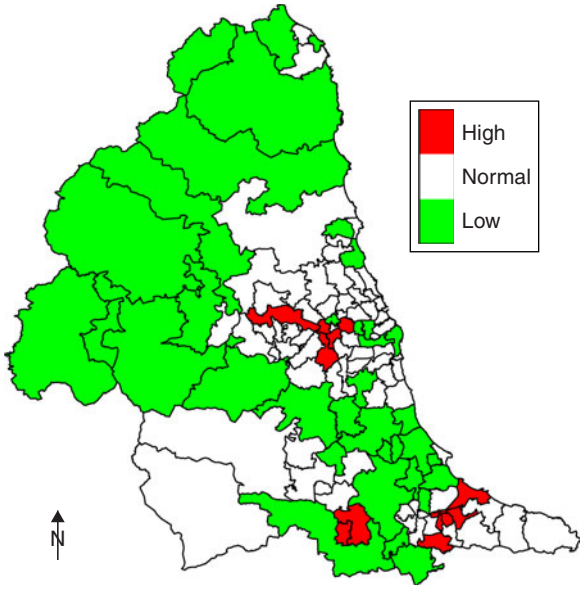

Fig. 4. [*colour online*]. The location of postcode districts with significantly high or low relative risk of pneumonia, according to the best performing model.

to hospital, health, material deprivation and Children in Need, were not significantly inferior compared to DIC scores (DIC 742·48, 743·93, 740·94, respectively). In the best performing model 50 (44%) districts had a significantly increased ($n = 13$) or decreased ($n = 37$) risk (range of RR 0·44–2·92) and are shown in Figure 4.

Empyema

Figure 5*a* shows the distribution of cases of empyema across the study region. The expected incidence of empyema for each postcode district is presented in Figure 5*b*.

In total, there were 293 cases spread across 150 postcode districts. The most cases in any district were found in DH8 (Consett, old industrial mining town 20 km south west of Newcastle-upon-Tyne) and NE6 (deprived suburbs to the east of Newcastle city centre), where eight instances were recorded in each. Forty postcode districts contained no reported cases of empyema.

Figures 5 illustrates the sparse spread of empyema cases across the study region. The low numbers of observed and expected cases resulted in no postcode districts showing significantly high or low relative risks. This remained the case when the credible interval was lowered to 90% and also when the spatial boundaries were increased to the coarser scale of postcode area. An analysis using expected cases calculated from the rate of bacterial or lobar pneumonia in each district was also performed. This identified four areas of significantly lower risk. However, there was no suggestion of clustering and the expected counts of disease in each were low (<5 cases). Consequently, we do not feel that this finding represents reliable evidence of spatial variation in risk of empyema.

DISCUSSION

There was significant spatial variation in the risk of hospitalization of children with pneumonia between postcode districts in the North East of England. The range of relative risks was 0·44–2·92 indicating an approximately sixfold variation in risk between districts. Significant covariates in explaining the variation in risk were material deprivation, CWI health domain score, number of children requiring local authority support and distance to hospital. Ethnicity, migration levels, housing, education, crime and environment were not significant covariates. There was no evidence of spatial variation in the risk of hospitalization with empyema.

The existence of significant spatial variation in risk of hospital admission for pneumonia has been noted elsewhere [9, 10]. Direct comparisons of the magnitude of the effect between studies are difficult to make, because of differences in statistical methodology. The variation in pneumonia and influenza admission rates between counties described by Crighton *et al.* [10] was up to threefold, which is lower than our finding of a sixfold variation in risk (0·44–2·92). These differences may reflect the size of the units sampled [28, 29].

A number of other studies have reported an association between deprivation and increased risk of hospitalization for respiratory tract infections in children and this study further adds to this evidence base [10, 14, 30]. Identifying the mechanisms underpinning this increased risk has been controversial [10]. Proposed hypotheses have included increased pathogen transmission from overcrowding and increased host susceptibility resulting from exposure to tobacco smoke and poor nutrition [14, 31]. Absolute material deprivation is rare in the UK child population and primary healthcare access free at the point of use, suggesting that other co-linked factors are likely to be relevant [32]. The most obvious is exposure to exhaled tobacco smoke through living with adult smokers. Smoking rates are highly correlated with socioeconomic status and have been linked to

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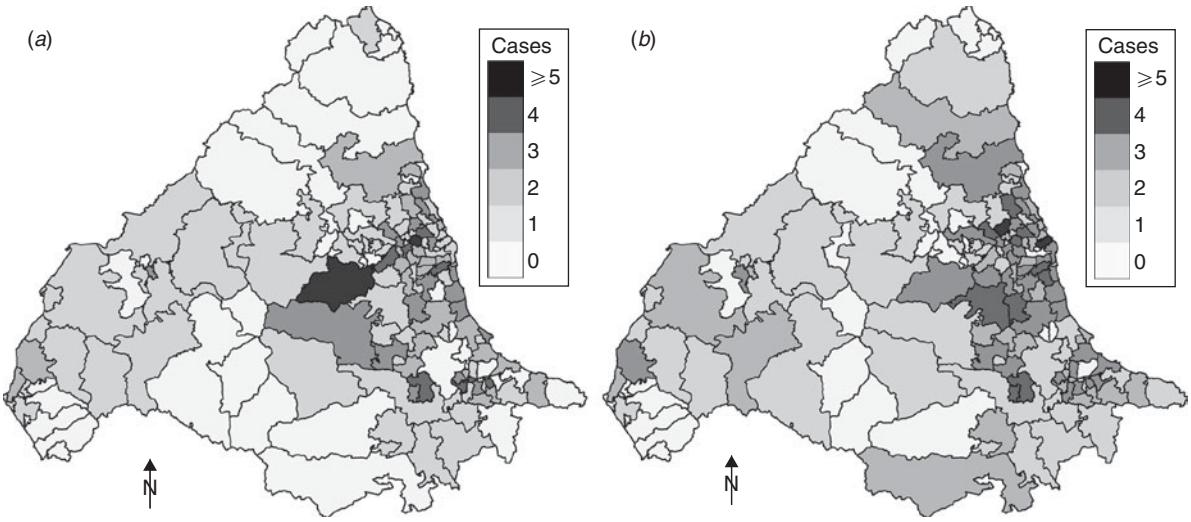

Fig. 5. The number of (*a*) observed and (*b*) expected cases of empyema across the postcode districts of North East England.

increasing hospitalizations for childhood respiratory infections [30, 33, 34]. It is not possible to separate the contribution of smoking from that of material deprivation within this dataset. However, given the size of disparity in risk between different areas smoking would be a plausible potential area for public health intervention in order to reduce these inequalities.

The health domain was also a significant explanatory variable for the variation in risk between districts. It is comprised of three indicators, total child hospital admissions, total child hospital outpatient attendances and the proportion of children receiving disability living allowance. Factors within a community that modify overall admissions to hospital will therefore contribute to both the number of pneumonia admissions in a district and the health domain score, reducing the independence of this domain in the model. Access to healthcare resources has been reported as a significant factor in variation in childhood hospital admissions in other settings and may be relevant [10, 35]. The significance of distance to hospital as a covariate would suggest this in our population. Admission policies for children with pneumonia at individual hospitals may vary, which would also contribute to the variation in risk. These variations are insufficient to explain the magnitude of variation between areas alone, as national guidelines for the management of childhood pneumonia were widely implemented during the study period [36]. Children who have comorbidities such as cerebral palsy that may predispose them to pneumonia are more likely to be in receipt of disablity living allowance which will also contribute to the association with the health domain [37].

The Children in Need domain was also a significant predictor, but the direction of the association was counter-intuitive with districts with lower numbers of children requiring local authority social support having higher levels of risk. It is recognized that children in local authority care suffer from worse health outcomes [38]. However, as there were difficulties with missing data, this domain was partially estimated using a combination of income and education scores, and is highly correlated with the material deprivation domain (correlation coefficient 0·96) [20]. Consequently, correlation and potential collinearity with other predictors are likely to account for this unexpected result.

Housing characteristics, both in terms of overcrowding and quality of housing, were not significant determinants of risk at the community level. This was surprising as individual-level studies have identified both as risk factors for pneumonia [39, 40]. It may be as a consequence of the community-level aggregation.

No spatial variation in the relative risk of hospitalization was found for empyema at any scale, in keeping with previous findings of no spatial variation in empyema [12], but it could also be a consequence of the low number of cases per district. CAR models have been shown to be conservative in their risk estimates and may not identify significant variation in risk, if the variation between areas is less than twofold and the expected number of cases less than 50 [41].

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Strengths and limitations

The strengths of the study include the use of child-specific deprivation measurements which have not been previously available for this type of analysis in this population, the use of a well-validated and reported statistical methodology which is robust in the handling of spatial autocorrelation and a comprehensive geographical dataset.

This ecological study has the limitations common to this design that stem from the assumption that population-specific factors are relevant to events occurring in individuals. A source of potential confounding arises from the use of a point estimate of child-specific well-being (from 2005) to apply across the whole study period (1997–2007 for pneumonia and 1995–2010 for empyema). It is difficult to be certain of the impact of this, in the absence of contemporaneous spatial demographic data. There has been considerable political focus on child health inequalities in the UK, with the incoming 1997 UK Government targeting child health outcome inequalities. It is therefore conceivable that political changes may have been an unrecognized factor in our results. However, we judge this a small risk. Subsequent analyses of the UK Government's attempts to address child health inequalities have been unfavourable and we judge the timescale for their enactment too slow to have directly impacted on our data [42–44]. We are not aware of any specific policy initiatives that were relevant to respiratory tract infections in children, except for the introduction of legislation banning tobacco smoking in enclosed spaces introduced after the pneumonia study period but which may have impacted on the empyema study. Given there is no published data on the association between tobacco smoke exposure and empyema it is difficult to be certain of any direction of effect and given that we found no evidence of spatial variation this is unlikely to be relevant. Legitimate concerns have been raised about the specificity of hospital coding data in childhood pneumonia; however, inaccuracies introduced by this process are unlikely to have been spatially distributed and therefore are unlikely have caused any material impact on the results [45, 46].

Implications and future research

There was a sixfold variation in children's risk of admission to hospital with pneumonia in different postcode districts in the North East of England between 1997 and 2007. These variations appear to be associated with deprivation, specifically levels of material deprivation and levels of childhood illness and disability. The relationship between hospital admissions data and the true incidence of disease is not straightforward, with many factors such as coding accuracy, physician behaviour, and access to secondary care involved [21]. However, such wide variations must be to some degree driven by differences in true disease incidence. This variation in disease incidence has important public health implications, particularly given the increasing evidence of an association between childhood pneumonia and later adult morbidity [47].

CONCLUSIONS

There is significant spatial variation in the risk of hospital admission with pneumonia, above that explained by population density alone. There was no such pattern in the case of empyema in the North of England. Levels of material deprivation, childhood illness and disability help explain these variations in pneumonia but significant unexplained variation remains. Further studies are required to quantify to what extent the spatial differences in risk represent differences in health behaviour or in disease risks. Investigation directed at understanding the impact of public health measures such as smoking cessation campaigns on hospital admissions for childhood pneumonia at the community level could also help to elucidate which factors are truly relevant in determining variations in risk of pneumonia.

DECLARATION OF INTEREST

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