Published in final edited form as:

Paediatr Perinat Epidemiol. 2009 March ; 23(2): 116–124. doi:10.1111/j.1365-3016.2008.00992.x.

Neural tube defects: an analysis of neighbourhood- and individual-level socio-economic characteristics

Jagteshwar Grewal^a, Suzan L. Carmichael^b, Jun Song^b, and Gary M. Shaw^b

^a Division of Epidemiology, Statistics and Prevention Research, National Institute of Child Health and Human Development, National Institutes of Health, Bethesda, MD

^b March of Dimes, California Research Division, Oakland, CA, USA

Summary

Several studies have reported that neural tube defects (NTD) occur more frequently among children born to women of lower socio-economic status (SES). This study investigated the relationship between individual- and neighbourhood-level SES and the risk of an NTD-affected pregnancy. Data were drawn from a population-based case-control study of fetuses and infants among a cohort of California births between July 1999 and June 2003. Information on individual SES was obtained via telephone interviews with mothers of 337 (76% of eligible) cases and 626 (79% of eligible) non-malformed liveborn controls. Respondents' addresses were linked to the 2000 US Census to characterise six measures of neighbourhood SES (education, poverty, unemployment, occupation, crowding and rental occupancy).

The analyses indicated that relative to women with a high school education, those with less than a high school education had a 1.7-fold increased risk of delivering infants with NTDs [95% CI 1.2, 2.6]. Twofold elevated risks for NTDs were observed for women with less than a high school education who lived in neighbourhoods where a majority of residents had not graduated from high school [95% CI 1.3, 3.1]. No consistent risk gradients were observed between NTD-affected pregnancies and indicators of lower neighbourhood SES. Results for phenotype subgroups were similar to those for all cases. Low maternal education was associated with an elevated risk of NTD in offspring. This risk varied by the education profile of the neighbourhood: women who did not graduate from high school and lived in less educated neighbourhoods exhibited a higher risk.

Keywords

neighbourhood characteristics; neural tube defects; congenital malformations; maternal education; socio-economic status

Introduction

The higher frequency of neural tube defects (NTD) – malformations secondary to abnormal neural tube closure that occur between the third and fourth weeks of gestational age – among children born to women of lower socio-economic status (SES) has been well documented in the epidemiological literature. As early as 1958, several studies in the British Isles showed a two-to fourfold increase in the risk of anencephaly and spina bifida among lower socio-economic groups.¹ The elevated risk associated with lower SES has been observed in several

other countries, including Australia,² Canada,³ Mexico⁴ and China.⁵ In the United States, this association was reported in one of the earliest studies on the prevalence of NTDs.⁶ Subsequent studies that examined the association between SES and risk of NTD-affected pregnancies offered mixed results: four studies indicated an increased risk,^{7–10} while two others reported no association.^{11,12}

In the aforementioned research, however, the SES measures were generally limited to individual attributes and did not consider the features of the neighbourhoods where the study respondents resided. Although individual and neighbourhood characteristics tend to be correlated, each can nonetheless exert an independent effect. For example, a mother with low individual-level SES can live in and derive benefits (e.g. better access to health clinics) from a community where the neighbourhood SES is comparatively high. In fact, several studies have suggested an association between increased health risks and the attributes of socio-economically deprived neighbourhoods.^{13–16} Meanwhile, other studies have linked the variation in the prevalence of NTDs to the differing socio-economic characteristics of small geographical areas.^{17–19} In theory, therefore, evaluations of the influence of SES upon the risk of NTDs in the offspring ought to consider the contributions of both individual attributes and neighbourhood characteristics.

An important exception along these lines was the publication by Wasserman and colleagues⁹ of a case-control study of California pregnancies between 1989 and 1991 which found that lower individual SES as well as residence in a lower SES neighbourhood increased the risk of NTD-affected pregnancies. The current study builds directly upon that example by seeking to re-evaluate the relationship between SES and NTD risk, using more recent data from a similar geographical setting. The analysis employs data from a large, population-based case-control study in California to simultaneously investigate the role of individual and neighbourhood socio-economic characteristics as NTD risk factors.

Methods

The study was confined to deliveries that had estimated dates of delivery (EDD) between July 1999 and June 2003. Eligible as cases were all liveborn, stillborn (i.e. fetal deaths at >20 weeks' gestation) and prenatally diagnosed, electively terminated cases that occurred to mothers residing in Los Angeles, San Francisco and Santa Clara counties. Data collection specialists ascertained information on cases from multiple hospital reports and medical records, and this information was reviewed by a clinical geneticist to determine eligibility. A total of 441 cases of NTDs, including anencephaly and spina bifida, were identified. Infants with trisomies, 22q11 microdeletions, other unbalanced chromosomal abnormalities or known single gene disorders were not eligible for this study. In addition, a total of 786 non-malformed, liveborn controls were randomly selected from the same birth hospitals as cases to represent the general population from which cases were derived.

Mothers of cases and controls were eligible to be interviewed if they were the biological mother, carried the pregnancy of the selected study subject, were not in prison and used English or Spanish as their primary language. Overall, 337 mothers (76% of those eligible) in the case group and 626 mothers (79% of those eligible) in the control group were interviewed. Interviews were conducted in English or Spanish and took place primarily over the telephone, no earlier than 6 weeks after the relevant EDD. The median time between EDD and interview completion was 10 months for cases and 8 months for controls.

A standardised, computer-based questionnaire was used to elicit details on individual-level SES measures and potential covariates during the 4-month periconceptional time period, defined as 2 months before to 2 months after conception. Indicators of individual-level SES

included maternal education (<high school, high school, some college, and ≥ 4 years of college); employment during the periconceptional period, including paid, voluntary or military service, and part- and full-time jobs (yes or no); paternal employment during the periconceptional period, including paid, voluntary or military service and part- and full-time jobs (yes or no); and household income (<\$10 000, \$10 000–\$19 999, \$20 000–\$29 999, \$30 000–\$39 999, \$40 000–\$49 999 and $\geq$ \$50 000). The respondents were also asked to report addresses for all residences at which they had lived for at least a month during the periconceptional period. These addresses were geocoded to the 2000 US Census tracts and block groups using EZ-Locate, an online geocoding service (<http://www.geocode.com>). In case of multiple geocoded addresses for a single individual, one address was selected at random for analysis. The Census information was linked and incorporated into the analytical data set.

Following the approach of Wasserman and colleagues,⁹ we employed six census measures to reflect neighbourhood-level (i.e. block group) SES: (1) education (proportion of the population aged ≥ 25 who did not graduate from high school or its equivalent), (2) poverty (proportion of the non-institutionalised population living below poverty level, which was \$17 029 for a family of four in 1999), (3) unemployment (proportion of the population aged ≥ 16 that is not working), (4) operator/labourer occupation (proportion of the employed population aged ≥ 16 years in occupations that include operators, fabricators and labourers), (5) crowding (proportion of occupied housing units with an average of more than one person per room), and (6) rental occupancy (proportion of occupied housing units that are rented). Each census measure was divided into quartiles based on the distribution among the control population. Values below the 25th percentile reflect the highest SES category for each measure, whereas values greater than the 75th percentile reflect the lowest SES category. In addition to the six separate census-based indicators of neighbourhood SES, we created an SES index to examine a potential gradient in risk across these measures.⁹ For each neighbourhood measure, lower SES – as represented by the highest quartile – was assigned a value of 1, and 0 otherwise. The SES index value for a respondent equalled the sum of these values across the six measures. For example, if she resided in a neighbourhood that had no census-based measures in the highest quartile, she was assigned an SES index value of zero; if her neighbourhood had all six measures in the highest quartile, her SES index value would be 6.

Analyses were conducted using SAS version 9.1 (SAS Institute, Cary, NC, USA). Odds ratios (OR) and corresponding 95% confidence intervals [CI] were estimated from logistic regression models, with the analytic data set limited to women with complete block group data. First, we examined the association of each measure of individual-level SES with NTD risk. Next, we estimated the risk for NTDs across quartiles of the neighbourhood (i.e. block group) SES measures, with the highest SES quartile serving as the reference group. Finally, we investigated the potential combined effects of individual- and neighbourhood-level SES measures. All analyses were conducted with and without adjustment for the following covariates: maternal age at the time of conception, body mass index (BMI), maternal race/ethnicity (US-born Hispanic, foreign-born Hispanic, White, Asian, African American, or other), gravidity defined as number of prior pregnancies including the index pregnancy (0, 1, 2 or ≥ 3), and intake of folic acid-containing supplements (yes or no).

Results

Maternal characteristics for cases and controls are presented in Table 1. A majority of mothers of both groups were 25–34 years of age, with an average age of approximately 29 years. Relative to controls, mothers of cases were more likely to be foreign-born Hispanic and to have less than a high school education (Table 1), and less likely to have used folic acid-containing supplements during the periconceptional period (Table 2).

Geocoding at the block group level was successful for 283 (84%) of interviewed cases and 552 (88%) of interviewed controls. The primary reason for the lack of success with geocoding was invalid or incomplete street addresses. Relative to women with incomplete block group data, women with complete block group data were more likely to be US-born Hispanics, have completed high school and some college education, be employed, and have used folic acid-containing supplements (Table 2). With the exception of the intake of folic acid, the magnitude of these differences tended to be slightly greater for cases than for controls.

Unadjusted risk estimates indicated that relative to women with high school education, those with less than high school education had 1.7-fold increased risk of delivering infants with NTDs [95% CI 1.2, 2.6] (Table 3). The results for the phenotype subgroups, anencephaly and spina bifida, were similar to those reported for all NTD cases combined. The results did not tend to support our hypothesis that higher NTD risk would be associated with decreasing household income or with parental unemployment. In general, these patterns persisted after adjustment for the covariates maternal age, race/ethnicity, BMI, gravidity and intake of folic acid-containing supplements (data not shown).

The unadjusted risk estimates associated with the four SES quartiles were close to unity for all six neighbourhood measures, thus offering no evidence that neighbourhood SES was associated with the risk of NTDs (Table 4). Moreover, results for the estimations that employed the SES index revealed no consistent risk gradients in the relationship between NTD-affected pregnancies and indicators of lower neighbourhood SES (Table 5).

A twofold elevated risk for NTDs was observed among women who had less than a high school education and lived in lower education neighbourhoods [OR 2.0, 95% CI 1.3, 3.1] (Table 6). The results for the phenotype subgroups, anencephaly and spina bifida, were similar to those reported for all NTD cases combined (data not shown). Similar results for NTDs were observed in regards to unemployed fathers who lived in neighbourhoods with high unemployment (OR 2.0; 95% CI 0.9, 4.6). This increase can be attributed largely to the phenotype subgroup spina bifida, for which nearly a threefold increase in risk was observed (OR 2.9; 95% CI 1.2, 7.0). Other contextual analysis of individual- and neighbourhood-level SES measures provided no additional evidence that the risk of NTDs associated with individual-level SES measures varied by the socio-economic characteristics of the neighbourhood. Analyses adjusted for potential covariates revealed attenuated risk estimates; however, they did not significantly alter the conclusions based on the crude estimates (data not shown).

Discussion

This study employed a multilevel approach, assessing several different measures of individual- and neighbourhood-level SES as risk factors of NTDs, using data derived from births subsequent to the introduction of mandatory folic acid fortification. Only one measure of individual SES – mother's education – was associated with elevated risks of NTDs. None of the neighbourhood SES measures exhibited such a relationship on its own. The average education level of the neighbourhood, however, acted in conjunction with the mother's education level to affect risk of NTDs in offspring, which was elevated among women who did not graduate from high school and lived in a predominantly less educated neighbourhood. In addition, the results suggested an increased risk of NTDs among offspring of unemployed fathers who lived in neighbourhoods with high unemployment. The conclusions remained the same in analyses that considered relevant covariates, as well as separate analyses for the two phenotypes, anencephaly and spina bifida.

Our finding of an association between low levels of maternal education and an increased risk of NTDs is consistent with the conclusions of Wasserman *et al.*⁹ Their results have been

substantiated by several subsequent studies, where the reported risk estimates for NTDs ranged between 1.8 and 2.3 for mothers with less than a high school education.^{4,5,10} These findings, however, diverge from the conclusions of two other studies that observed no association between risk of NTDs and educational level of the mother.^{11,12}

At the same time, we did not detect any significant effects associated with the other measures of individual- and neighbourhood-level SES, whereas Wasserman *et al.* found that lower income, employment in manual occupations and residence in a lower SES neighbourhood were associated with increased risk of an NTD-affected pregnancy.⁹ Although the methodologies of the two studies are similar, one potential source of the difference is the timing of the data collection. The cases for the Wasserman study were ascertained prior to the mandatory fortification of enriched cereal-grain products with folic acid to help prevent pregnancies affected by NTDs, which began in January 1998. In contrast, our data were collected from the period after the mandatory fortification policy was instituted. Thus, it is possible that the pattern of occurrence of NTDs between the two studies is different because the NTDs prevented by fortification have been removed from consideration. These NTD cases may have contributed to the Wasserman findings. This is speculation, however, and cannot be answered by this study.

Direct comparison of our findings with those in the existing literature is difficult because of the differences in the SES indicators employed in the analyses, the time period over which data were collected, the geographical areas where the studies were conducted, and the characteristics of the study populations. Only Wasserman *et al.* evaluated both individual- and neighbourhood-level SES measures in relation to California births; as was mentioned previously, however, their data were collected prior to mandatory fortification.⁹ Two of the other studies were conducted in Colorado¹⁰ and Texas,²⁰ respectively, and limited their study population to Hispanic women who were born either in the US or Mexico, in all cases prior to fortification. Two further studies focused on women who resided in Mexico⁴ and Spain¹² respectively. In addition, the studies did not derive the samples of infants with malformations in an equivalent manner – one included all liveborn, stillborn and electively terminated cases with NTDs,⁹ another used livebirths and stillbirths,²⁰ and a third used only livebirths.¹⁰

The increased risk of NTD-affected pregnancies associated with lower levels of maternal education – as an indicator of low SES – may reflect several circumstances. First, although our study included electively terminated cases, the ascertainment of those cases may have been incomplete. The latter circumstance could explain some of the observed increased risk of NTDs associated with lower levels of maternal education. That is, low education is correlated with low SES, and low education is inversely correlated with women seeking prenatal diagnosis and termination of NTDs.²¹ Thus, our study population may have been artificially enriched with case mothers of lower SES. Second, low maternal education could be associated with poor access to a well-balanced diet that includes food rich in folate.⁹ Our results indicate, however, that the association of low SES with NTDs persists even after controlling for folate intake, which suggests that the relationship may be multifactorial, reflecting SES, dietary habits and access to primary health care services. Finally, residual confounding cannot be ruled out as a possible explanation for our findings. Although all of the analyses were ultimately adjusted for several covariates known to be associated with both the exposures and the outcome, it is possible that the omission of additional unmeasured confounders contributed to our results.

The current study has several key features that make it a significant contribution to the existing literature. One is the evaluation of both individual socioeconomic attributes and neighbourhood characteristics. This multilevel approach has been utilised successfully when evaluating the association between SES and other reproductive outcomes, e.g. low birth-weight,^{21,22} preterm delivery²³ and stillbirth.²⁴ Only two studies to date, however, have extended this approach to the study of birth defects; one examined NTDs,⁹ the other conotruncal heart defects and clefts.

²⁵ We build upon and extend this prior research, using data from a large population-based case-control study conducted with a diverse sample. Another strength of our analysis is the consideration of multiple indicators of both individual- and neighbourhood-level SES, which demonstrated that the results are not sensitive to alternative forms of measurement. The analysis was further enhanced by examining NTDs as an aggregate group and as the two primary phenotypes, anencephaly and spina bifida, which is particularly crucial given the prospect that aetiologies may differ.

A limitation of the study could be the prospect of selection bias resulting from two sources. The first potential source is the inability to geocode all residential addresses. This circumstance may present a problem if the control mothers who were excluded from the analyses because of unmatched addresses were disproportionately lower on both the individual- and neighbourhood-level SES measures when compared with the case mothers with unmatched addresses. The data indicate, however, that the opposite may be true: the case mothers whose addresses could not be geocoded actually had lower incomes and were more likely to have less than a high school education and be foreign-born Hispanic as compared with the unmatched control mothers. The fact that we had to omit these cases from the study could be a reason for the lack of findings with respect to several of the individual- and neighbourhood-level SES measures. The second potential source of selection bias is factors associated with non-participation in the study. We are unable to estimate the impact of these factors, as data were not available to compare study participants with non-participants.

In conclusion, we found that low maternal education, a measure of individual SES, was associated with an elevated risk of NTD in offspring. In addition, this risk varied by the educational profile of the neighbourhood: the risk was higher among women who did not graduate from high school and lived in predominantly less educated neighbourhoods. The results offer no evidence that neighbourhood SES *per se* has an independent role in the aetiology of NTDs and no consistent risk gradients were observed between NTD-affected pregnancies and indicators of lower neighbourhood SES.

Acknowledgments

We thank Makinde Falade (Department of Health Services, Richmond, CA) for his help with the geocoding of the data and Chen Ma (March of Dimes California Research Division, Oakland, CA) for her research assistance.

This research was supported by NIH grant number R01 HD 42538-03 and a cooperative agreement from the Centers for Disease Control and Prevention, Centers of Excellence Award No. U50/CCU913241.

References

1. Elwood, JM.; Little, J.; Elwood, JH. Epidemiology and Control of Neural Tube Defects. Oxford: Oxford University Press; 1992.
2. Bower C, Hobbs M, Carney A, Simpson D. Neural tube defects in Western Australia 1966–81 and a review of Australian data 1942–81. *Journal of Epidemiology and Community Health* 1984;38:208–213. [PubMed: 6470597]
3. Horowitz I, McDonald AD. Anencephaly and spina bifida in the Province of Quebec. *Canadian Medical Association Journal* 1969;100:748–755. [PubMed: 4888983]
4. Munoz JB, Lacasana M, Aburto VHB, Sanchez LET, Garcia AM, Carrillo LL. Socioeconomic factors and the risk of anencephaly in a Mexican population: a case-control study. *Public Health Reports* 2005;120:39–45. [PubMed: 15736330]
5. Li Z, Ren A, Zhang L, Guo Z, Li Z. A population-based case-control study of risk factors for neural tube defects in four high-prevalence areas of Shanxi province, China. *Paediatric and Perinatal Epidemiology* 2006;20:43–53. [PubMed: 16420340]

6. Naggan L, MacMahon B. Ethnic differences in the prevalence of anencephaly and spina bifida in Boston, Massachusetts. *New England Journal of Medicine* 1967;277:1119–1123. [PubMed: 4861562]
7. Nevin NC, Johnston WP, Merrett JD. Influence of social class on the risk of recurrence of anencephalus and spina bifida. *Developmental Medicine and Child Neurology* 1981;23 :155–159. [PubMed: 7011887]
8. Feldman JG, Stein SC, Klein RJ, Kohl S, Casey G. The prevalence of neural tube defects among ethnic groups in Brooklyn, New York. *Journal of Chronic Diseases* 1982;35:53–60. [PubMed: 7200098]
9. Wasserman CR, Shaw GM, Selvin S, Gould JB, Syme SL. Socioeconomic status, neighborhood social conditions, and neural tube defects. *American Journal of Public Health* 1998;88:1674–1680. [PubMed: 9807535]
10. Farley TF, Hambidge SJ, Daley MF. Association of low maternal education with neural tube defects in Colorado, 1989–1998. *Public Health* 2002;116:89–94. [PubMed: 11961676]
11. Rouhani P, Fleming LE, Frías J, Martínez-Frías ML, Bermejo E, Mendioroz J. Pilot study of socioeconomic class, nutrition and birth defects in Spain. *Maternal and Child Health Journal* 2007;11:403–405. [PubMed: 17318404]
12. Velie EM, Shaw GM. Impact of prenatal diagnosis and elective termination on prevalence and risk estimates of neural tube defects in California, 1989–1991. *American Journal of Epidemiology* 1996;144:473–479. [PubMed: 8781462]
13. Haan M, Kaplan GA, Camacho T. Poverty and health. Prospective evidence from the Alameda County Study. *American Journal of Epidemiology* 1987;125:989–998. [PubMed: 3578257]
14. Diez Roux AV, Merkin SS, Arnett D, Chambless L, Massing M, Nieto FJ, et al. Neighborhood of residence and incidence of coronary heart disease. *New England Journal of Medicine* 2001;345:99–106. [PubMed: 11450679]
15. Pickett KE, Pearl M. Multilevel analyses of neighbourhood socioeconomic context and health outcomes: a critical review. *Journal of Epidemiology and Community Health* 2001;55 :111–122. [PubMed: 11154250]
16. Borrell LN, Diez Roux AV, Rose K, Catellier D, Clark BL. Atherosclerosis Risk in Communities Study. Neighbourhood characteristics and mortality in the Atherosclerosis Risk in Communities Study. *International Journal of Epidemiology* 2004;33:398–407. [PubMed: 15082648]
17. Richards ID, Roberts CJ, Lloyd S. Area differences in prevalence of neural tube malformations in South Wales. A study of possible demographic determinants. *British Journal of Preventive and Social Medicine* 1972;26:89–93. [PubMed: 4558509]
18. Elwood JH, Elwood JM. Investigation of area differences in the prevalence at birth of anencephalus in Belfast. *International Journal of Epidemiology* 1984;13:45–52. [PubMed: 6538186]
19. Meyer RE, Siega-Riz AM. Sociodemographic patterns in spina bifida birth prevalence trends – North Carolina, 1995–1999. *MMWR Recommendations and Reports* 2002;51:12–15.
20. Canfield MA, Annegers JF, Brender JD, Cooper SP, Greenberg F. Hispanic origin and neural tube defects in Houston/Harris County, Texas. II. Risk factors. *American Journal of Epidemiology* 1996;143:12–24. [PubMed: 8533743]
21. O'Campo P, Xue X, Wang MC, Caughy M. Neighborhood risk factors for low birthweight in Baltimore: a multilevel analysis. *American Journal of Public Health* 1997;87 :1113–1118. [PubMed: 9240099]
22. Farley TA, Mason K, Rice J, Habel JD, Scribner R, Cohen DA. The relationship between the neighbourhood environment and adverse birth outcomes. *Paediatric and Perinatal Epidemiology* 2006;20:188–200. [PubMed: 16629693]
23. Pickett KE, Ahern JE, Selvin S, Abrams B. Neighborhood socioeconomic status, maternal race and preterm delivery: a case-control study. *Annals of Epidemiology* 2002;12:410–418. [PubMed: 12160600]
24. Joyce R, Webb R, Peacock J. Social class and census-based deprivation scores: which is the best predictor of stillbirth rates? *Paediatric and Perinatal Epidemiology* 1999;13:269–277. [PubMed: 10440047]
25. Carmichael SL, Nelson V, Shaw GM, Wasserman CR, Croen LA. Socio-economic status and risk of conotruncal heart defects and orofacial clefts. *Paediatric and Perinatal Epidemiology* 2003;17:264–271. [PubMed: 12839538]

Table 1Selected maternal characteristics (%) for cases and controls^a

	Neural tube defects (<i>n</i> = 283)	Controls (<i>n</i> = 552)
Maternal age (years)		
<20	7.4	7.1
20–24	20.1	22.4
25–29	25.4	21.8
30–34	27.2	30.4
35–39	16.6	14.0
40+	3.2	4.4
Maternal race/ethnicity		
US-born Hispanic	19.2	22.4
Foreign-born Hispanic	47.0	37.7
White	22.8	21.7
Black	3.6	7.5
Asian	5.0	9.3
Other	2.5	1.5
Maternal employment		
Yes	59.1	61.4
Paternal employment		
Yes	89.9	91.2
Gravidity		
0	23.7	28.6
1	24.0	26.8
2	21.2	19.4
3+	31.1	25.2
Maternal education		
<High school	39.9	28.8
High school	19.9	24.7
Some college	22.1	21.4
≥Bachelor's degree	18.2	25.1
Household income		
<\$10 000	21.7	24.8
\$10 000–\$19 999	20.9	17.4
\$20 000–\$29 999	15.3	12.2
\$30 000–\$39 999	6.8	7.7
\$40 000–\$49 999	8.0	4.3
\$50 000+	27.3	33.7

^aPercentages may not equal 100 because of rounding or missing data for some participants.

Table 2

Selected maternal characteristics (%) by availability of census block group data

	Complete block group data		Incomplete block group data	
	Cases (n = 276)	Controls (n = 551)	Cases (n = 54)	Controls (n = 74)
Maternal race/ethnicity				
US-born Hispanic	19.2	22.4	7.4	15.9
Foreign-born Hispanic	47.0	37.7	59.3	42.0
White	22.8	21.7	20.4	20.3
Black	3.6	7.5	3.7	7.3
Asian	5.0	9.3	7.4	11.6
Other	2.5	1.5	1.9	2.9
Maternal education				
<High school	39.9	28.8	53.7	30.4
High school	19.9	24.7	13.0	20.3
Some college	22.1	21.4	7.4	26.1
≥Bachelor's degree	18.2	25.1	25.9	23.2
Maternal employment				
yes	59.1	61.4	48.2	53.6
Intake of folic acid-containing supplements				
yes	54.8	63.0	50.0	53.4

Table 3

Unadjusted association of risk of neural tube defects with individual-level indicators of socio-economic status

	Neural tube defects (<i>n</i> = 283)		Anencephaly (<i>n</i> = 123)		Spina bifida (<i>n</i> = 160)		Controls (<i>n</i> = 552)
	Cases	OR [95% CI]	Cases	OR [95% CI]	Cases	OR [95% CI]	No.
Maternal education							
<High school	112	1.7 [1.2, 2.6]	49	1.6 [1.0, 2.7]	63	1.8 [1.1, 3.0]	157
High school	56	1.0 Reference	26	1.0 Reference	30	1.0 Reference	135
Some college	62	1.3 [0.8, 2.0]	26	1.2 [0.6, 2.1]	36	1.4 [0.8, 2.4]	117
≥Bachelor's degree	51	0.9 [0.6, 1.4]	22	0.8 [0.4, 1.5]	29	0.9 [0.5, 1.7]	137
Household income							
<\$10 000	54	0.7 [0.4, 1.2]	19	0.6 [0.3, 1.1]	35	0.8 [0.4, 1.5]	122
\$10 000–\$19 999	52	1.0 [0.6, 1.6]	22	0.9 [0.4, 1.8]	30	1.0 [0.5, 1.9]	86
\$20 000–\$29 999	38	1.0 Reference	17	1.0 Reference	21	1.0 Reference	60
\$30 000–\$39 999	17	0.7 [0.4, 1.4]	7	0.7 [0.3, 1.7]	10	0.8 [0.3, 1.8]	38
\$40 000–\$49 999	20	1.5 [0.7, 3.1]	7	1.2 [0.4, 3.2]	13	1.8 [0.8, 4.1]	21
\$50 000+	68	0.6 [0.4, 1.1]	33	0.7 [0.4, 1.4]	35	0.6 [0.3, 1.1]	166
Maternal employment							
Yes	166	0.9 [0.7, 1.2]	76	1.0 [0.7, 1.5]	90	0.8 [0.6, 1.2]	338
Paternal employment							
Yes	269	0.9 [0.5, 1.4]	116	1.5 [0.7, 3.4]	153	0.6 [0.4, 1.1]	530

OR, odds ratio; CI, confidence interval.

Table 4
Unadjusted association of risk of neural tube defects with neighbourhood-level SES measures^a

		Neural tube defects (<i>n</i> = 283)		Anencephaly (<i>n</i> = 123)		Spina bifida (<i>n</i> = 160)		Controls (<i>n</i> = 552)
		Cases ^b	OR [95% CI]	Cases ^b	OR [95% CI]	Cases ^b	OR [95% CI]	No. ^b
Education								
Q4	71	1.0 [0.7, 1.6]		30	1.2 [0.7, 2.1]	41	0.9 [0.5, 1.5]	137
Q3	84	1.3 [0.9, 2.0]		34	1.3 [0.7, 2.3]	50	1.3 [0.8, 2.2]	139
Q2	65	1.0 [0.7, 1.6]		33	1.3 [0.7, 2.2]	32	1.1 [0.7, 1.8]	138
Q1	63	1.0 Reference		26	1.0 Reference	37	1.0 Reference	138
Poverty								
Q4	64	0.9 [0.6, 1.4]		33	1.2 [0.7, 2.0]	31	0.8 [0.5, 1.4]	137
Q3	83	1.2 [0.8, 1.8]		31	1.1 [0.6, 1.9]	52	1.3 [0.8, 2.1]	139
Q2	68	1.0 [0.7, 1.5]		30	1.0 [0.6, 1.8]	38	1.0 [0.6, 1.6]	138
Q1	68	1.0 Reference		29	1.0 Reference	39	1.0 Reference	138
Unemployment								
Q4	87	1.2 [0.8, 1.8]		37	1.2 [0.7, 2.1]	50	1.2 [0.7, 1.9]	138
Q3	66	0.9 [0.6, 1.4]		30	1.0 [0.6, 1.7]	36	0.9 [0.5, 1.4]	138
Q2	56	0.8 [0.5, 1.2]		25	0.9 [0.5, 1.5]	31	0.8 [0.5, 1.3]	134
Q1	74	1.0 Reference		31	1.0 Reference	43	1.0 Reference	142
Operator/labourer occupation								
Q4	75	1.3 [0.8, 1.9]		31	1.1 [0.7, 2.0]	44	1.3 [0.8, 2.2]	138
Q3	78	1.3 [0.9, 2.0]		34	1.3 [0.7, 2.2]	44	1.3 [0.8, 2.2]	138
Q2	70	1.2 [0.8, 1.8]		31	1.1 [0.7, 2.0]	39	1.2 [0.7, 2.0]	138
Q1	60	1.0 Reference		27	1.0 Reference	33	1.0 Reference	138
Crowding								
Q4	72	1.1 [0.7, 1.7]		27	0.9 [0.5, 1.7]	45	1.3 [0.8, 2.1]	136
Q3	75	1.1 [0.8, 1.7]		33	1.1 [0.7, 2.0]	42	1.2 [0.7, 1.9]	139
Q2	71	1.1 [0.7, 1.6]		34	1.2 [0.7, 2.0]	37	1.0 [0.6, 1.7]	139
Q1	65	1.0 Reference		29	1.0 Reference	36	1.0 Reference	138
Rental occupancy								
Q4	61	0.8 [0.5, 1.2]		26	0.8 [0.5, 1.5]	35	0.8 [0.5, 1.2]	137
Q3	73	0.9 [0.6, 1.4]		30	1.0 [0.6, 1.7]	43	0.9 [0.6, 1.5]	138

	Neural tube defects (<i>n</i> = 283)		Anencephaly (<i>n</i> = 123)		Spina bifida (<i>n</i> = 160)		Controls (<i>n</i> = 552)
	Cases ^b	OR [95% CI]	Cases ^b	OR [95% CI]	Cases ^b	OR [95% CI]	No. ^b
Q2	71	0.9 [0.6, 1.3]	36	1.2 [0.7, 2.0]	35	0.7 [0.5, 1.2]	139
Q1	78	1.0 Reference	31	1.0 Reference	47	1.0 Reference	138

^aSee *Methods* section for definitions of each census-based SES measure.

^bThe count represents the number of mothers in each quartile; e.g. the count for Q4 reflects the number of individuals in the lowest quartile for each SES measure.
OR, odds ratio; CI, confidence interval; SES, socio-economic status.

Table 5

Unadjusted association of risk of neural tube defects with the SES Index

Neural tube defects (<i>n</i> = 283)		Anencephaly (<i>n</i> = 123)		Spina bifida (<i>n</i> = 160)		Controls (<i>n</i> = 552)	
Cases	OR [95% CI]	Cases	OR [95% CI]	Cases	OR [95% CI]	No.	No.
SES Index ^a							
0	1.0 Reference	54	1.0 Reference	70	1.0 Reference	260	
1	56 1.2 [0.8, 1.8]	25	1.2 [0.7, 2.1]	31	1.2 [0.7, 1.9]	97	
2	24 1.2 [0.7, 2.0]	9	1.0 [0.5, 2.2]	15	1.3 [0.7, 2.5]	43	
3	29 1.4 [0.8, 2.3]	14	1.5 [0.8, 2.9]	15	1.2 [0.7, 2.4]	45	
4	20 0.9 [0.5, 1.6]	8	0.8 [0.4, 1.9]	12	1.0 [0.5, 2.0]	45	
5	21 0.9 [0.5, 1.6]	11	1.1 [0.5, 2.3]	10	0.8 [0.4, 1.6]	47	
6	9 1.3 [0.5, 3.0]	2	0.6 [0.1, 2.9]	7	1.7 [0.7, 4.4]	15	

^aThe value of the index equals the number of census-based measures that were scored in the quartile reflecting the lowest SES (i.e. the fourth quartile). For example, if a woman had no measures in the lowest SES quartile, her SES index score would be 0; if she had all six measures in the lowest quartile, her score would be 6. The index takes on values from 0 to 6.

OR, odds ratio; CI, confidence interval; SES, socio-economic status.

Table 6

Unadjusted association of risk of neural tube defects with combined individual and neighbourhood SES characteristics

SES measure		Neural tube defects (<i>n</i> = 283)		Controls (<i>n</i> = 552)
Neighbourhood		Cases	OR [95% CI]	No.
Maternal education ^a				
Low	Low	90	2.0 [1.3, 3.1]	118
Middle	Low	57	1.1 [0.7, 1.8]	131
High	Low	8	0.9 [0.4, 2.1]	24
Low	High	22	1.5 [0.8, 2.8]	39
Middle	High	61	1.3 [0.8, 2.1]	121
High	High	43	1.0 Reference	113
Poverty ^b				
<\$20 000	High	29	1.0 [0.6, 1.8]	55
≥\$20 000	High	96	0.9 [0.6, 1.4]	196
<\$20 000	Low	77	1.0 [0.6, 1.5]	153
≥\$20 000	Low	47	1.0 Reference	89
Maternal employment ^c				
No	High unemployment	45	0.9 [0.6, 1.5]	91
Yes	High unemployment	81	0.9 [0.6, 1.2]	177
No	Low unemployment	70	1.1 [0.7, 1.6]	121
Yes	Low unemployment	85	1.0 Reference	161
Paternal employment ^c				
No	High unemployment	13	2.0 [0.9, 4.6]	11
Yes	High unemployment	111	0.8 [0.6, 1.0]	251
No	Low unemployment	15	0.7 [0.4, 1.3]	36
Yes	Low unemployment	137	1.0 Reference	233

^aMaternal education: low if less than high school, middle if high school graduation, and high if some college or college degree. Neighbourhood education was defined as low if 58% or more of the residents ≥25 years of age did not graduate from high school or its equivalent (i.e. the lowest quartile of the distribution among the controls).

^bThe individual income cut-off at \$20 000 was selected to approximate the federal poverty level which was \$17 029 for a family of four in 1999. A neighbourhood was characterised as having high poverty where at least 26.5% of the residents were living below the federal poverty level (i.e. the lowest quartile of the distribution among the controls).

^cThe unemployment level of a neighbourhood was defined as high if at least 12.2% of its civilian labour force ≥16 years of age was unemployed (i.e. the lowest quartile of the distribution among the controls). OR, odds ratio; CI, confidence interval; SES, socio-economic status.