# Early life second-hand smoke exposure and serious infectious morbidity during the first 8 years: evidence from Hong Kong's "Children of 1997" birth cohort

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## ABSTRACT

**Background:** Second-hand smoke (SHS) exposure is a modifiable cause of ill health. Despite the smoking ban in public places introduced in Hong Kong in 2007, infants and children continue to be exposed within the home.

**Aims:** To determine the critical windows of SHS exposure and the duration of its impact on serious infectious morbidity in the first 8 years of life.

**Methods:** The Hong Kong "Children of 1997" birth cohort is a prospective, population-based study of 8327 children comprising 88% of all births in April and May 1997, of whom 7402 (89%) were followed up until their eighth birthday in 2005. We used multivariable Cox regression to assess the relation between postnatal SHS exposure and risk of first admission to public hospitals (together accounting for >95% total bed-days overall) for respiratory, other and all infections from birth to 8 years of age, for all individuals and for vulnerable subgroups.

**Results:** Overall, household SHS exposure within 3 metres in early life was associated with a higher risk of admission for infectious illness up until 8 years of age (hazard ratio 1.14, 95% CI 1.00 to 1.31), after adjustment for sex, birthweight, gestational age, feeding method, maternal age, highest parental education and proxies of preferred service sector. The association was strongest in the first 6 months of life (HR 1.45, 95% CI 1.15 to 1.83). In vulnerable subgroups such as premature babies, the association held through to 8 years of age (HR 2.00, 95% CI 1.08 to 3.72). Infants exposed to SHS in the first 3 months of life were most vulnerable to infectious causes of hospitalisation.

**Conclusion:** Household SHS exposure in early infancy increases severe infectious morbidity requiring hospital admission. Reducing SHS exposure in infants and particularly in more vulnerable infants will lower the bed-days burden due to infectious causes.

Second-hand smoke (SHS) exposure is a common, modifiable exposure adversely affecting infant and child health.[1 2] In Hong Kong, most women do not smoke (<4%)[3] and smoking has recently (in 2007) been largely banned in public spaces and workplaces, nevertheless infants and children remain exposed to SHS in their homes. The detrimental effects of postnatal SHS exposure on the respiratory tract are strongest in the first 2 years of life,[3–5] whereas weaker and usually insignificant (at the 0.05 level) trends persist for school-age children.[6 7] In contrast, the impact on other infections, eg, meningococcal disease[8 9] or allergic sensitisation,[10] has been less well explored. It is biologically plausible that the early postnatal period represents a critical window of exposure as both alveolar proliferation and maturation of lymphocytes continue throughout early infancy.[11] Evaluating the impact of SHS exposure at different ages on respiratory and other infections will help identify whether there are any critical periods for SHS exposure.[12]

Moreover, some developmentally vulnerable infants such as premature and low birthweight infants, which are also linked to antenatal SHS exposure,[13 14] may be more susceptible to SHS in early life.[15] To our knowledge, however, this has not been systematically examined previously despite the potentially compromised lung function[16] and impaired adaptive immunity[17] of these infants.

We therefore examined prospectively the impact of SHS exposure on serious infectious morbidity requiring hospitalisation from 0 to 8 years of age in a large, well-established Hong Kong Chinese birth cohort "Children of 1997". We aimed to elucidate the impact of SHS on all infections, to identify the timing of any critical windows of postnatal exposure and to clarify the effects in more vulnerable subgroups.

## METHODS

### Setting and subjects: "Children of 1997" birth cohort

The "Children of 1997" birth cohort recruited infants born in Hong Kong in April and May 1997 and brought to one of any of the 47 government-run Maternal and Child Health Centres (MCHC) for their first postnatal visit. For the index year, 92% of infants born in Hong Kong paid at least one visit to the MCHC, which provides free-of-charge preventive care and immunisations.[18] There are 8327 infants in the birth cohort, accounting for 88% of all births in the recruitment period. The detailed methods have been reported previously.[3] In brief, mothers were approached at the MCHC for recruitment and baseline data collection. The infants were further followed up at 3, 9 and 18 months of age. A standardised self-administered questionnaire in Chinese was used on each occasion. Infant characteristics, family sociodemographics and mother's SHS exposure in pregnancy and household smoking habits after birth were collected at the first interview and questions on

**Table 1** Proportion of cohort members with different characteristics by baseline SHS exposure

| Characteristics | Baseline SHS exposure None (n = 4317) | Yes, but not within 3 months (n = 2316) | Yes, within 3 months (n = 769) | p Value |
|---|---|---|---|---|
| Sex | | | | |
| Male | 57.1 | 32.3 | 10.6 | 0.07 |
| Female | 59.7 | 30.1 | 10.2 | |
| Birthweight (g) | | | | |
| <2500 | 58.9 | 29.6 | 11.6 | 0.30 |
| 2500–2999 | 58.7 | 31.1 | 10.1 | |
| 3000–3499 | 57.8 | 32.3 | 10.0 | |
| 3500–3999 | 58.9 | 30.5 | 10.6 | |
| ⩾4000 | 58.9 | 26.5 | 14.6 | |
| Gestational age (weeks) | | | | |
| ⩽36 | 58.6 | 31.6 | 9.8 | <0.001 |
| 37 | 61.4 | 28.3 | 10.3 | |
| 38 | 61.9 | 29.4 | 8.6 | |
| 39 | 59.4 | 30.4 | 10.3 | |
| 40 | 56.5 | 33.1 | 10.5 | |
| 41 | 53.3 | 34.0 | 12.7 | |
| ⩾42 | 44.5 | 38.0 | 17.5 | |
| SGA status | | | | |
| Non-SGA | 58.9 | 31.0 | 10.2 | 0.01 |
| SGA | 53.1 | 34.3 | 12.6 | |
| Breastfeeding history | | | | |
| Never breastfed | 55.2 | 33.9 | 10.9 | <0.001 |
| Mixed breast and formula-fed | 65.5 | 25.7 | 8.8 | |
| Exclusively breastfed for ⩽1 month | 60.5 | 31.4 | 8.2 | |
| Exclusively breastfed for 2–3 months | 62.0 | 28.5 | 9.5 | |
| Exclusively breastfed for ⩾4 months | 58.4 | 28.0 | 13.7 | |
| Maternal age (years) | | | | |
| ⩽24 | 34.6 | 51.7 | 13.7 | <0.001 |
| 25–29 | 52.8 | 35.7 | 11.5 | |
| 30–34 | 65.9 | 24.8 | 9.3 | |
| ⩾35 | 67.6 | 23.8 | 8.6 | |
| Highest parental education level | | | | |
| Grade 9 or below | 44.8 | 38.0 | 17.2 | <0.001 |
| Grade 10–11 | 54.6 | 35.3 | 10.1 | |
| Grade 12 or above | 79.2 | 17.5 | 3.3 | |
| Type of hospital during delivery | | | | |
| Public | 52.4 | 34.9 | 12.7 | <0.001 |
| Private | 72.6 | 22.6 | 4.9 | |
| Household income per head (in HK$)* quintiles (mean ± SD) | | | | |
| 1 ($1750 ± 415) | 43.1 | 39.5 | 17.4 | <0.001 |
| 2 ($2854 ± 326) | 50.1 | 35.2 | 14.8 | |
| 3 ($4371 ± 557) | 53.7 | 35.6 | 10.8 | |
| 4 ($6836 ± 887) | 66.7 | 27.6 | 5.7 | |
| 5 ($14 926 ± 15 861) | 79.8 | 17.2 | 3.0 | |
| Missing | 51.8 | 35.9 | 12.3 | |
| SHS exposure at 3 months | | | | |
| None | 91.5 | 7.0 | 1.5 | |
| Yes, but not within 3 metres | 16.6 | 70.7 | 12.7 | |
| Yes, within 3 metres | 10.0 | 51.0 | 39.0 | |
| SHS exposure at 9 months | | | | |
| None | 89.4 | 8.6 | 2.0 | |
| Yes, but not within 3 metres | 18.0 | 68.9 | 13.1 | |
| Yes, within 3 metres | 12.8 | 52.4 | 34.7 | |
| SHS exposure at 18 months | | | | |
| None | 88.2 | 9.2 | 2.6 | |
| Yes, but not within 3 metres | 19.6 | 65.3 | 15.1 | |
| Yes, within 3 metres | 12.6 | 55.0 | 32.4 | |

SGA, small for gestational age; SHS, second-hand smoke.
*US$1 = HK$7.8.

current household smoking were repeated at each of the three follow-up visits. In 2005–6, more detailed information on family socioeconomic status was retrieved from the original paper records held at the MCHC and linked using the original MCHC reference numbers. In view of the universal coverage (actually accounting for >95% total bed-days overall) by the Hospital Authority managed public hospitals,[19] all public hospital discharge records were obtained for the period from birth to the end of 2005. Record linkage to the Hospital Authority master database was primarily by birth certificate or Hong Kong identity number, available for 97% of the cohort. Records were also linked by English or Chinese name (full name and then if not available there were matches by partial names), sex and date of birth; all these potential matches were then individually verified by at least two independent members of the research team.

### Exposure to household SHS

We focused on the health impact of home SHS exposure after birth in this analysis. Given that few pregnant mothers smoked (4.6%) and approximately half (47.2%) stopped within the first 5 months of conception, in utero exposure via active maternal smoking was presumably low. Although underreporting due to social desirability bias is possible, self-reported parental smoking was found to have good validity in Hong Kong Chinese.[20] Although mother's exposure to SHS during pregnancy could be an important avoidable risk factor, we previously found that it was unlikely to explain the excess paediatric hospital use in full after adjustment for postnatal SHS exposure.[3]

Household postnatal SHS exposure was ascertained from questions concerning smoking status of the mother, father and other household members (eg, "Did the infant's mother smoke in the previous week?"). Respondents were also asked if any of these smokers smoked within a 3-metre radius of the infant (eg. "Did the infant's mother smoke within 3 metres of the infant"). Consistent with previous analysis in this cohort,[21] SHS exposure at baseline (first MCHC visit) was categorised as "none" (ie, no smokers at home), "yes, but not within 3 metres" (ie, all smokers smoked 3 metres away from the infant) and "yes, within 3 metres" (ie, at least one smoker at home smoked within 3 metres of the infant). To facilitate identification of critical periods for SHS exposure, the household SHS exposure at each time point (baseline, 3 months, 9 months and 18 months) was also categorised as "not within 3 metres" (ie, no smokers at home or all smokers smoked at least 3 metres away from the infant) or "within 3 metres" (ie, at least one smoker at home smoked within 3 metres of the infant).

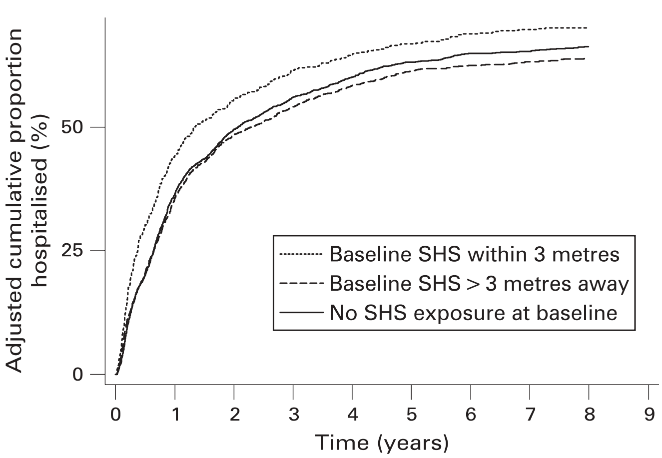


**Figure 1** Adjusted* cumulative proportion hospitalised for all infections from 9 days to 8 years of age in relation to baseline second-hand smoke (SHS) exposure.
*Adjusted for sex, birthweight, gestational age, breastfeeding history, maternal age, highest parental education level, type of hospital at birth, household income per head, mother's smoking and mother's SHS exposure in pregnancy.

### Outcomes: hospitalisations

The primary outcome was time to first admission for an infectious illness (ie, all infections) until 8 years of age, because initial analysis revealed that findings were broadly similar when hospital use was considered as ever admission, number of admissions, number of bed-days or time to first admission. Time to first admission for all causes, two different types of infections (respiratory and other) and accidents were also considered as outcomes. Accidents were included as a "control" disease to check for the specificity of SHS exposure, because accidents should not be related to SHS exposure but may be socially patterned.

Admissions (including same-day discharge and in-patient admission for at least 24 h) were coded at discharge according to the International Classification of Diseases, ninth version Clinical Modification (ICD-9CM). As previously, admissions with a principal diagnosis of ICD-9CM 33, 34.0, 381–2, 460–6, 477, 480–7, 477 or 493 were classified as respiratory (and related) infections,[22] ICD-9CM 1–32, 34.1–139, 320–1, 370, 372.0–372.3, 390–2, 540–2, 590, 595, 599.0, 680–6, 771, 780.3, 780.6 or 787.91 were classified as other infections, ICD-9CM 800–999 or E800–E999 were classified as accidents.

Admissions within the first 8 days of life were not counted as child-related hospitalisation because, according to routine aggregate statistics in 2004, the average hospital stay for infants delivered by Caesarean section was 7.9 days whereas that by natural birth was 3 days. Inclusion of admissions in the immediate neonatal period may produce a bias because these admissions are recorded as infant healthcare use for the vaginally born whereas the surgically born with the same condition would have been cared for as part of the initial birth hospitalisation.[23]

### Statistical analysis

We used multivariable Cox regression adjusted for potential confounders to assess the effect of baseline SHS exposure on first admission to public hospital, from which hazard ratios (HR) with 95% CI are presented. An adjusted cumulative proportion hospitalised curve was plotted to visualise the association between SHS exposure and the time to first hospitalisation for all infections until 8 years of age.

We also stratified by age at admission to identify whether the impact of baseline SHS exposure extended into childhood. Age at admission groups were chosen to reflect nutritional transitions, motor development and increasing social contact, ie, 0–<6 months, 6–<24 months, 2–<5 years and 5–<8 years. In addition, children with an admission in a younger age group might be more susceptible to admission when older, so we considered admission in a younger age group as a potential confounding factor; however, results were very similar with and without such adjustment. In age-stratified analysis we did not adjust for admission at an earlier age (ie, in a younger age group).

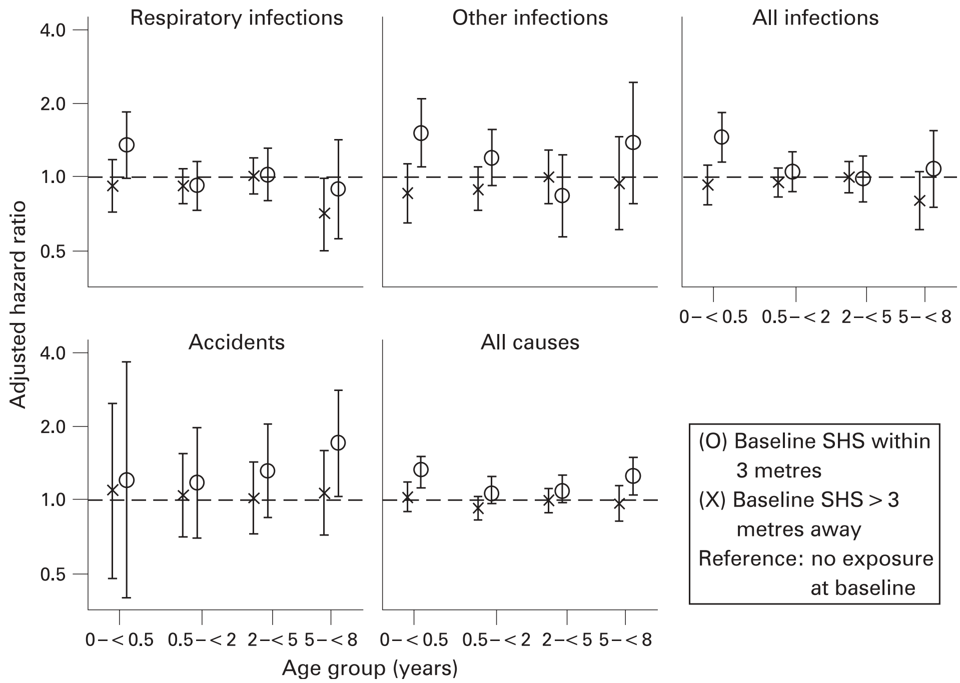


**Figure 2** Adjusted* hazard ratios with 95% CI for first hospitalisation by causes and age groups in relation to baseline second-hand smoke (SHS) exposure (compared with no SHS exposure). *Adjusted for sex, birthweight, gestational age, breastfeeding history, maternal age, highest parental education level, type of hospital at birth, household income per head, mother's smoking and mother's SHS exposure in pregnancy.

To identify any critical periods of exposure, we used multivariable Cox regression models to examine the effect of SHS exposure at different ages (baseline, 3, 9 and 18 months) on first hospitalisation in the subsequent periods. So, for example, we examined the impact of SHS exposure at baseline and 3 months on first hospitalisation between the ages of 3 and 9 months. We used this approach in preference to using exposures at baseline, 3, 9 and 18 months as time-varying covariates in one model, because in a single model the effect of exposure in later time periods (eg, at 3–9 months) is only considered for those without an admission in a previous period and thereby biases the model towards identifying early exposure as critical.

The proportional hazards assumption was checked by visual inspection of plots of log (−log (S)) against time, where S was the estimated survival function. Whether the effect of SHS exposure on hospitalisation varied in different groups of infants was assessed from the significance of interaction terms and the heterogeneity of effect across strata.

Potential confounders were retained based on subject matter relevance and a change in estimate criterion[24] for the association of baseline SHS exposure with ever admission for all infections. Confounders retained in the final models were sex, birthweight, gestational age, maternal age, breastfeeding history, highest parental education, maternal smoking during pregnancy, mother's SHS exposure in pregnancy and proxies of preferred service sector (type of hospital at birth, household income per head), as categorised in table 1. Several other measures of family socioeconomic status, eg, father's or mother's occupation, type of housing and neighbourhood socioeconomic status were considered but not included because they had a negligible effect on the estimates.

To reduce the bias by treating potential emigrants (ie, having moved out of town since birth) as no hospitalisation and missing the private hospital records (comprising <5% of total bed-days), as a sensitivity analysis, we repeated the analysis for birth cohort members born in public hospitals with recent contact, ie, responded to a newsletter or birthday card in 2007, or had contact with the Hospital Authority, MCHC or the Student Health Service after 2002.

## RESULTS

After excluding 925 birth cohort members with missing relevant baseline information, 7402 (89%) remained. Half (n = 3692) had at least one admission to a public hospital by the age of 8 years, of whom 50.7% (n = 1872) had at least one admission for a respiratory infection and 33.9% (n = 1252) for other infections. At baseline, 41.7% of infants were exposed to some form of household SHS; these infants had younger mothers and came from lower socioeconomic status families. They were also more likely to be born in public hospitals and less likely to have been breastfed (table 1).

Figure 1 shows the adjusted cumulative proportion hospitalised for all infections until the age of 8 years by baseline

**Table 2** Adjusted* hazard ratios with 95% CI for first hospitalisation until 8 years of age by causes in relation to baseline SHS exposure

| | Respiratory infections | Other infections | All infections | Accidents | All causes |
|---|---|---|---|---|---|
| Baseline SHS exposure | HR (95% CI) | HR (95% CI) | HR (95% CI) | HR (95% CI) | HR (95% CI) |
| No | 1 | 1 | 1 | 1 | 1 |
| Yes, but not within 3 metres | 0.90 (0.81 to 1.01) | 0.94 (0.82 to 1.09) | 0.94 (0.86 to 1.04) | 1.09 (0.88 to 1.34) | 0.98 (0.91 to 1.07) |
| Yes, within 3 metres | 1.03 (0.88 to 1.21) | 1.25 (1.03 to 1.50) | 1.14 (1.00 to 1.31) | 1.43 (1.09 to 1.88) | 1.19 (1.06 to 1.33) |

HR, hazard ratio; SHS, second-hand smoke.
*Adjusted for sex, birthweight, gestational age, breastfeeding history, maternal age, highest parental education level, type of hospital at birth, household income per head, mother's smoking and mother's SHS exposure in pregnancy.

**Table 3** Adjusted* hazard ratios with 95% CI for first hospitalisation for respiratory infections by infant characteristics in relation to baseline SHS exposure

| Group | Age | Baseline SHS exposure | HR (95% CI) |
|---|---|---|---|
| Low birthweight (n = 372) | 0–8 years | No | 1 |
| | | Yes, but not within 3 metres | 0.87 (0.51 to 1.48) |
| | | Yes, within 3 metres | 1.75 (0.98 to 3.14) |
| | 0–<6 months | No | 1 |
| | | Yes, but not within 3 metres | 0.53 (0.20 to 1.42) |
| | | Yes, within 3 metres | 1.48 (0.51 to 4.34) |
| | 6 months–8 years | No | 1 |
| | | Yes, but not within 3 metres | 0.84 (0.47 to 1.48) |
| | | Yes, within 3 metres | 1.66 (0.89 to 3.10) |
| Premature (n = 389) | 0–8 years | No | 1 |
| | | Yes, but not within 3 metres | 0.84 (0.51 to 1.38) |
| | | Yes, within 3 metres | 2.00 (1.08 to 3.72) |
| | 0–<6 months | No | 1 |
| | | Yes, but not within 3 metres | 0.42 (0.16 to 1.07) |
| | | Yes, within 3 metres | 1.50 (0.50 to 4.48) |
| | 6 months–8 years | No | 1 |
| | | Yes, but not within 3 metres | 1.01 (0.59 to 1.73) |
| | | Yes, within 3 metres | 1.92 (0.97 to 3.81) |
| Other (n = 6840) | 0–8 years | No | 1 |
| | | Yes, but not within 3 metres | 0.92 (0.82 to 1.04) |
| | | Yes, within 3 metres | 0.98 (0.83 to 1.16) |
| | 0–<6 months | No | 1 |
| | | Yes, but not within 3 metres | 0.98 (0.76 to 1.27) |
| | | Yes, within 3 metres | 1.34 (0.96 to 1.86) |
| | 6 months–8 years | No | 1 |
| | | Yes, but not within 3 metres | 0.93 (0.82 to 1.06) |
| | | Yes, within 3 metres | 0.93 (0.77 to 1.12) |

HR, hazard ratio; SHS, second-hand smoke.
*Adjusted for sex, birthweight (whenever appropriate), gestational age (whenever appropriate), breastfeeding history, maternal age, highest parental education level, type of hospital at birth, household income per head, mother's smoking and mother's SHS exposure in pregnancy.

household SHS exposure. Infants with baseline SHS exposure within 3 metres had their first admission due to infections earlier than the unexposed and most of the difference emerged in infancy. Approximately one out of three infants exposed to baseline SHS within 3 metres had been hospitalised for an infection by 12 months of age. Adjusted for potential confounders, baseline SHS exposure within 3 metres was associated with a higher risk of admission for all infections by the age of 8 years (table 2). Figure 2 also shows the effect of baseline SHS exposure by age group for each cause. The higher risk of admission for all infections mainly occurred in the first 6 months of life (HR 1.45, 95% CI 1.15 to 1.83), with similar risks for respiratory and other infections. Smoking at least 3 metres away from the infant consistently yielded insignificant hazard ratios, most of which approximated unity. In contrast, a higher risk of admission for accidents associated with baseline SHS exposure was mainly at older ages.

The effect of SHS exposure on hospitalisation was mainly within the first 6 months, so we used two age groups (0–<6 months and 6 months–<8 years) when considering whether the effect of baseline SHS exposure differed in vulnerable infants. There was little evidence that the effect of baseline SHS exposure on respiratory infections varied with small for gestational age status either in the first 6 months of life (p value for interaction 0.80) or until the age of 8 years ($p = 0.66$). There was, however, some evidence of a different effect of baseline SHS exposure on respiratory infections by low birthweight status ($p = 0.02$, 0–8 years; $p = 0.27$, 0–6 months) and prematurity ($p = 0.05$, 0–8 years; $p = 0.03$, 0–6 months). Low birthweight and premature infants exposed to baseline SHS within 3 metres possibly had a higher risk of admission for respiratory infections than other infants, with broadly similar impacts in infancy and into childhood, as shown in table 3.

### Critical periods for SHS exposure

In contrast to fig 2, which shows the effect of baseline (reported just after birth) household SHS exposure on hospital admissions at different ages (ie, 0–<6 months, 6–<24 months, 2–<5 years, 5–<8 years and 0–8 years), fig 3 shows the effect of household SHS exposure at different ages (baseline, 3 months, 9 months and 18 months) on subsequent hospital admission. Baseline SHS exposure increased the risk of hospitalisation for all infections, particularly for other infections at 0–3 months and its impact persisted into later infancy, as did SHS exposure at 3 months for the risk of hospitalisation for all infections at 3–9 months. Household SHS exposure at 9 months and 18 months had less effect.

A sensitivity analysis including only members of the birth cohort born in public hospitals with recent contact gave similar point estimates, with no indication of systematic differences from the whole sample (see Appendix).

## DISCUSSION

Consistent with our previous findings in this cohort up until age 18 months[21] and with other studies,[25 26] infants with proximate (within 3 metres) SHS exposure from any household member in early life were at an elevated risk of serious infectious morbidity after adjusting for several measures of

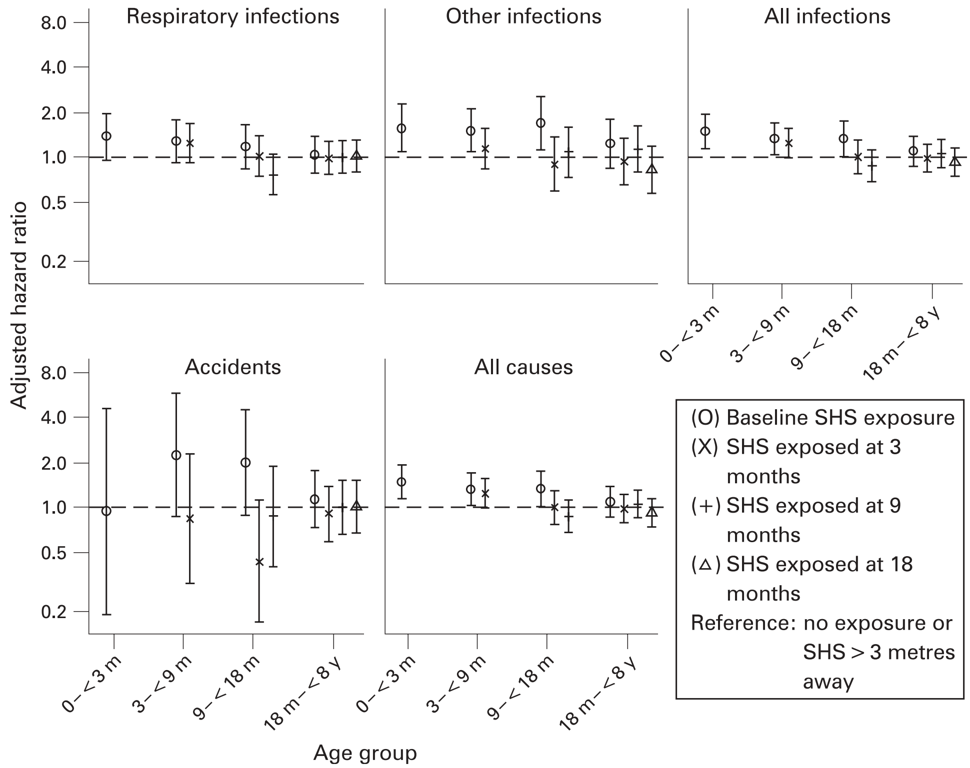


**Figure 3** Adjusted* hazard ratios with 95% CI for first hospitalisation in subsequent time periods in relation to second-hand smoke (SHS) exposure within 3 metres (compared with no SHS exposure or exposed at 3 metres away) at all earlier time points (ie, baseline, 3, 9 and 18 months).
Number of subjects included in the analyses at each age of exposure (at birth: 7401, at 3 months: 6167, at 9 months: 5476, at 18 months: 4422).
*Adjusted for sex, birthweight, gestational age, breastfeeding history, maternal age, highest parental education level, type of hospital at birth, household income per head, mother's smoking and mother's SHS exposure in pregnancy.

socioeconomic status, infant characteristics, maternal smoking and prenatal SHS exposure. What this study adds is evidence of a window of greater vulnerability to SHS exposure in early infancy, which extends to all infectious illnesses not just respiratory and related infections, and which may have a larger and more long-lasting impact in developmentally more vulnerable subgroups, such as premature or low birthweight infants.

Despite adjusting for several measures of socioeconomic status in a prospective design using a population representative birth cohort and case ascertainment from doctor diagnoses on hospital discharge records, there are several limitations. First, SHS exposure was based on parental reports rather than cotinine measurements,[27] with inevitable misclassification and loss of discrimination, which makes our results conservative. Second, private hospital admissions are missing, most likely of children from socioeconomically advantaged families, who might be less likely to be exposed to SHS. We included measures of social strata as covariables in the models, however, and sensitivity analysis restricted to children born in public hospitals, who would be least likely to use private facilities, produced similar results. Although we cannot rule out residual confounding by other unmeasured or unmeasurable aspects of socioeconomic status, these should be minimal because at time periods when significant associations between SHS exposure and admission for infections were found, there were no significant associations between SHS exposure and another outcome that was also strongly socially patterned, ie, admission for accidents. Moreover, if our results were merely a reflection of socioeconomic status, we would have expected a systematic effect of SHS exposure on admissions for infections throughout life rather than in infancy but not childhood, particularly as there was in childhood an association between SHS exposure and admissions for, undoubtedly socially patterned, accidents. Finally, we only considered the impact of SHS exposure on serious morbidity requiring hospitalisation, which may have reduced the power of our study to detect the impact of SHS exposure on specific types of infection, such as respiratory infections, particularly in our setting in which there is little maternal smoking and perhaps a smaller impact of postnatal exposure might be expected.[7] SHS may have other more subtle long-term impacts on growth and development, as seen elsewhere,[28] which we could not detect.

Despite these limitations, there are some aetiological implications if our findings were real. First, an excess risk of severe morbidity from both respiratory and other infections for all infants exposed to SHS suggests that such exposure, as well as acting via direct contact with the respiratory tract, may also affect the immune system. Infant exposure to SHS may impede the development of the lung vasculature and networks resulting in reduced pulmonary volumes[29] and SHS may also suppress the innate or adaptive humoral or cell-mediated immunities.[30] Second, the first few months of life appear to be a window of particular vulnerability to SHS exposure, especially in low birthweight and premature infants for whom the effects remain evident into childhood. Physiological and anatomical lung development continues throughout gestation and into infancy[31] and is likely to be compromised in premature infants[32] who have

### What this paper adds

- ► Exposure of infants to household second-hand smoke (SHS) increases serious morbidity from infectious diseases due to both respiratory and other infections
- ► Infants are most vulnerable to serious infectious morbidity from household SHS exposure in the first few months of life
- ► Low birthweight and premature infants may be more vulnerable than other infants to SHS exposure with longer lasting effects up until 8 years of age

poorer respiratory function,[16 33] hence their more evident vulnerability. We did not measure more sensitive markers of long-term respiratory health, such as lung function. We cannot distinguish whether the more detrimental impact of SHS observed in vulnerable infants is because of a greater impact of SHS on their development or because these infants are acting as a sentinel for long-lasting detrimental impacts in all infants. General deficits in lung function associated with SHS exposure have been observed,[34] but might not be sufficient to have a noticeable impact on severe morbidity in childhood, although such deficits could become more evident at older ages, for example as less "reserve" when function starts to decline in old age.

## CONCLUSION

Early life SHS exposure increased the risk of serious morbidity from infections, with the greatest impact from exposure in the early months of life. The impact of SHS exposure was greater and more long lasting in low birthweight and premature babies. Whether this greater impact of SHS in more vulnerable infants is because of a larger impact of SHS on their developing respiratory and immune systems or is because they are acting as a sentinel for all infants remains to be determined. Nevertheless, reducing household SHS exposure in infants and particularly in more vulnerable infants can reduce infectious morbidity and corresponding hospital use. Policy options to protect infants and children from household SHS exposure should be implemented.

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**Competing interests:** None declared.

**Ethics approval:** The study obtained ethical approval from the University of Hong Kong Hospital Authority, Hong Kong West Cluster Joint Institutional Review Board and the Ethics Committee of the Department of Health, Government of the Hong Kong SAR.

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## APPENDIX

Adjusted* hazard ratios with 95% CI for first hospitalisation by causes, age groups and infant characteristics in relation to baseline SHS exposure after excluding 2334 born in private hospital with no recent contact

| | | | Respiratory infections | Other infections | All infections | Accidents | All causes |
|---|---|---|---|---|---|---|---|
| Group | Age | Baseline SHS exposure | HR (95% CI) | HR (95% CI) | HR(95% CI | HR (95% CI) | HR (95% CI) |
| Low birthweight | 0–8 years | No | 1 | 1 | 1 | 1 | 1 |
| (n = 266) | | Yes, but not within 3 metres | 0.96 (0.54 to 1.74) | 0.74 (0.39 to 1.42) | 0.76 (0.46 to 1.25) | 0.46 (0.11 to 1.98) | 0.93 (0.63 to 1.38) |
| | | Yes, within 3 metres | 1.62 (0.86 to 3.06) | 1.21 (0.57 to 2.57) | 1.18 (0.68 to 2.04) | 0.59 (0.10 to 3.41) | 1.22 (0.77 to 1.96) |
| | 0–<6 months | No | 1 | 1 | 1 | n/a† | 1 |
| | | Yes, but not within 3 metres | 0.81 (0.29 to 2.23) | 0.49 (0.17 to 1.44) | 0.70 (0.33 to 1.51) | | 1.09 (0.63 to 1.87) |
| | | Yes, within 3 metres | 1.41 (0.44 to 4.51) | 1.75 (0.56 to 5.49) | 1.34 (0.57 to 3.14) | | 1.12 (0.57 to 2.20) |
| | 6 months–8 years | No | 1 | 1 | 1 | 1 | 1 |
| | | Yes, but not within 3 metres | 0.89 (0.47 to 1.70) | 1.05 (0.51 to 2.13) | 0.87 (0.51 to 1.47) | 0.45 (0.10 to 2.00) | 0.81 (0.53 to 1.24) |
| | | Yes, within 3 metres | 1.51 (0.75 to 3.03) | 1.42 (0.59 to 3.39) | 1.34 (0.72 to 2.47) | 0.39 (0.04 to 3.51) | 1.11 (0.66 to 1.87) |
| Premature | 0–8 years | No | 1 | 1 | 1 | 1 | 1 |
| (n = 277) | | Yes, but not within 3 metres | 0.85 (0.49 to 1.47) | 1.00 (0.53 to 1.89) | 0.79 (0.50 to 1.26) | 0.30 (0.09 to 1.00) | 0.97 (0.66 to 1.41) |
| | | Yes, within 3 metres | 1.69 (0.88 to 3.24) | 1.81 (0.84 to 3.90) | 1.53 (0.86 to 2.73) | 0.83 (0.23 to 3.00) | 1.42 (0.88 to 2.29) |
| | 0–<6 months | No | 1 | 1 | 1 | n/a† | 1 |
| | | Yes, but not within 3 metres | 0.39 (0.14 to 1.05) | 0.62 (0.23 to 1.72) | 0.53 (0.25 to 1.10) | | 1.07 (0.64 to 1.79) |
| | | Yes, within 3 metres | 1.13 (0.34 to 3.78) | 1.70 (0.54 to 5.35) | 1.32 (0.56 to 3.11) | | 0.97 (0.47 to 1.98) |
| | 6 months–8 years | No | 1 | 1 | 1 | 1 | 1 |
| | | Yes, but not within 3 metres | 1.17 (0.64 to 2.13) | 1.26 (0.59 to 2.71) | 1.14 (0.68 to 1.91) | 0.41 (0.12 to 1.33) | 0.96 (0.62 to 1.47) |
| | | Yes, within 3 metres | 1.62 (0.78 to 3.40) | 1.99 (0.80 to 4.94) | 1.69 (0.87 to 3.26) | 0.85 (0.22 to 3.29) | 1.61 (0.95 to 2.73) |
| Other | 0–8 years | No | 1 | 1 | 1 | 1 | 1 |
| (n = 4675) | | Yes, but not within 3 metres | 0.96 (0.84 to 1.09) | 0.92 (0.78 to 1.08) | 0.97 (0.86 to 1.08) | 1.18 (0.93 to 1.51) | 0.97 (0.89 to 1.07) |
| | | Yes, within 3 metres | 1.02 (0.85 to 1.22) | 1.20 (0.97 to 1.48) | 1.12 (0.96 to 1.30) | 1.45 (1.06 to 1.97) | 1.14 (1.00 to 1.29) |
| | 0–<6 months | No | 1 | 1 | 1 | 1 | 1 |
| | | Yes, but not within 3 metres | 0.99 (0.75 to 1.30) | 0.88 (0.64 to 1.20) | 0.98 (0.79 to 1.21) | 1.16 (0.45 to 2.99) | 1.00 (0.85 to 1.19) |
| | | Yes, within 3 metres | 1.41 (1.00 to 1.99) | 1.57 (1.09 to 2.27) | 1.51 (1.16 to 1.96) | 0.78 (0.19 to 3.18) | 1.35 (1.09 to 1.67) |
| | 6 months–8 years | No | 1 | 1 | 1 | 1 | 1 |
| | | Yes, but not within 3 metres | 0.97 (0.85 to 1.12) | 0.89 (0.74 to 1.06) | 0.96 (0.85 to 1.08) | 1.18 (0.92 to 1.51) | 0.96 (0.87 to 1.07) |
| | | Yes, within 3 metres | 0.97 (0.79 to 1.17) | 0.99 (0.77 to 1.26) | 0.98 (0.83 to 1.16) | 1.48 (1.08 to 2.04) | 1.08 (0.94 to 1.23) |

HR, hazard ratio; SHS, second-hand smoke.
*Adjusted for sex, birthweight, gestational age, breastfeeding history, maternal age, highest parental education level, type of hospital at birth, household income per head, mother's smoking and mother's SHS exposure in pregnancy.
†n/a, Risk could not be determined due to small cell size.