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# BMJ Open

## Neighbourhood material deprivation and severe maternal morbidity: A population-based cohort study in Ontario, Canada.

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3 1 **TITLE PAGE**  
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6 2 **Neighbourhood material deprivation and severe maternal morbidity:**  
78 3 **A population-based cohort study in Ontario, Canada**  
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3 26 **ABSTRACT**  
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6 27 **Objectives:** Rates of age-associated severe maternal morbidity (SMM) have increased in  
7  
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9 28 Canada, and an association with neighbourhood income is well established. Our aim was to  
10  
11 29 examine SMM trends according to neighbourhood material deprivation quintile, and to  
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13  
14 30 assess whether neighbourhood deprivation effects are moderated by maternal age.  
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16  
17 31 **Design, setting, participants:** A population-based retrospective cohort study using linked  
18  
19 32 administrative databases in Ontario, Canada. We included primiparous women with a live  
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21  
22 33 birth or stillbirth at  $\geq 20$  weeks gestational age.  
23

24  
25 34 **Primary outcome:** SMM from pregnancy onset to 42 days postpartum. We calculated SMM  
26  
27 35 rate differences (RD) and rate ratios (RR) by neighbourhood material deprivation quintile for  
28  
29 36 each of four 4-year cohorts from 1 April 2002 to 31 March 2018. Log-binomial multivariable  
30  
31 37 regression adjusted for maternal age, demographic, and pregnancy-related variables.  
32  
33

34  
35 38 **Results:** There were 1,048,845 primiparous births during the study period. The overall rate  
36  
37 39 of SMM was 18.0 per 1,000 births. SMM rates were elevated for women living in areas with  
38  
39 40 high material deprivation. In the final 4-year cohort, the RD between women living in high  
40  
41 41 versus low deprivation neighbourhoods was 3.91 SMM cases per 1,000 births (95% CI: 2.12,  
42  
43 42 5.70). This was higher than the difference observed during the first 4-year cohort (RD 2.09,  
44  
45 43 95% CI: 0.62, 3.56). SMM remained associated with neighbourhood material deprivation  
46  
47 44 following multivariable adjustment in the pooled sample (RR 1.16, 95% CI: 1.11, 1.21). There  
48  
49 45 was no evidence of interaction with maternal age.  
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55  
56 46 **Conclusion:** SMM rate increases were more pronounced for primiparous women living in  
57  
58 47 neighbourhoods with high material deprivation compared to those living in low deprivation  
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3 48 areas. This raises concerns of a widening social gap in maternal health disparities and  
4  
5  
6 49 highlights an opportunity to focus risk reduction efforts toward disadvantaged women  
7  
8 50 during pregnancy and postpartum.  
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13  
14 52 **Keywords:** severe maternal morbidity; maternal mortality; maternal health; pregnancy;  
15  
16  
17 53 perinatal epidemiology; social epidemiology; social inequalities; deprivation  
18  
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21 54

### 22 23 55 **Strengths and Limitations of this Study**

- 24  
25  
26  
27 56 • Data were from population linked administrative and health registries that capture  
28  
29 57 all hospital births in Ontario, Canada  
30  
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32  
33 58 • Neighbourhood material deprivation was measured using the Ontario  
34  
35 59 Marginalization Index, which was developed using theoretical frameworks on  
36  
37 60 marginalization and deprivation specific to Ontario  
38  
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40  
41 61 • Limiting our study to primiparous women enabled the evaluation of population SMM  
42  
43 62 trends and reduced confounding from previous births  
44  
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46  
47 63 • It was not possible to control for all covariates associated with SMM, including body  
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49 64 mass index and the use of assisted reproductive technology  
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## 66 INTRODUCTION

67 Each year, approximately 4,000 Canadian women survive a maternal “near-miss”—a life-  
68 threatening event associated with pregnancy.[1] To characterize maternal near-misses in a  
69 standardized way, the World Health Organization proposed the concept of severe maternal  
70 morbidity (SMM), a composite of conditions that represent end-organ dysfunction or states  
71 of heightened maternal mortality risk associated with pregnancy, birth, or the postpartum  
72 period.[2, 3] Advances in the recognition and management of SMM have resulted in low  
73 maternal mortality rates in economically developed nations. Women living in high income  
74 countries are now more likely to survive a life-threatening pregnancy condition and,  
75 correspondingly, the rates of SMM are 100-fold higher than maternal mortality rates in  
76 Canada.[1] However, recent trends in Canada and other high income countries show an  
77 increase in SMM rates coinciding with advancing maternal age [4-7]. In a recent Canadian  
78 study, women from low-income neighbourhoods had a higher risk of SMM.[4] Women of  
79 advanced maternal age tend to come from more advantaged socioeconomic backgrounds  
80 and are more likely to have planned pregnancies.[8-10] The effects of maternal age and  
81 neighbourhood-level marginalization may therefore interact, with the highest SMM risk  
82 among older mothers living in neighbourhoods with higher material deprivation.

83 Our first objective was to evaluate trends in SMM rates among primiparous women in  
84 Ontario by neighbourhood material deprivation quintile between 1 April 2002 and 31 March  
85 2018. Our second objective was to determine if maternal age moderates the effect of  
86 neighbourhood material deprivation. We hypothesized that SMM rates would increase  
87 disproportionately over time among women living in neighbourhoods with high material

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3 88 deprivation. We further hypothesized that the highest risk of SMM would be among women  
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5 89 of advanced maternal age living in neighbourhood with the highest material deprivation.  
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## 9 90 **METHODS**

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12 91 This population-based retrospective cohort study used linked administrative datasets for  
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14 92 Ontario, held at ICES, which is an independent non-profit research institute whose legal  
15  
16 93 status under Ontario's health information privacy law allows it to collect and analyze health  
17  
18 94 care and demographic data, without consent, for health system evaluation and  
19  
20 95 improvement. The use of data in this project was authorized under section 45 of Ontario's  
21  
22 96 Personal Health Information Protection Act, which does not require review by a Research  
23  
24 97 Ethics Board. We followed the RECORD guidelines (REporting of studies Conducted using  
25  
26 98 Observational Routinely-collected Data) for reporting this study.[11]  
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### 32 99 **Patient and public involvement**

33  
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35  
36 100 There was no direct patient or public involvement in this study.  
37  
38

### 39 101 **Study population and data sources**

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41  
42 102 The Canadian Institute for Health Information Discharge Abstract Database (DAD) was used  
43  
44 103 to capture all hospital admissions for birth and link to newborn records using the ICES-  
45  
46 104 derived MOMBABY dataset. We included primiparous women aged 10-55 years who had a  
47  
48 105 hospital birth in Ontario and were enrolled in the province's universal health insurance  
49  
50 106 program (OHIP). We identified the first live birth or stillbirth delivery at a gestational age of  
51  
52 107  $\geq 20$  weeks. We used gestational age at birth to calculate pregnancy onset. Women were  
53  
54 108 included if the onset of their first pregnancy was on or after 1 April 2002 and the  
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3 109 corresponding birth occurred on or before 17 February 2018—allowing 42 days of  
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6 110 postpartum follow-up through the study end date of 31 March 2018. Women who had a  
7  
8 111 previous birth within 14 years prior to the index date were excluded. We linked these data  
9  
10 112 with the Registered Persons Database (RPDB), DAD, and OHIP Claims Database to identify  
11  
12 113 exposures and outcomes of interest. To identify women who had recently immigrated to  
13  
14 114 Ontario, we used the Ontario portion of the federal Immigration, Refugees and Citizenship  
15  
16 115 Canada (IRCC) Permanent Resident Database. For neighbourhood material deprivation, we  
17  
18 116 used the 2001 and 2006 Canadian Census, and Ontario Marginalization Index (ON-MARG)  
19  
20 117 database.[12] These datasets were linked using unique encoded identifiers and analyzed at  
21  
22 118 ICES and are shown in **Appendix 1**.

### 119 **Main outcome**

120 The main outcome was a composite of medical conditions and interventions that comprise  
121 SMM. Previously validated indicators for Canada have been used to identify cases of SMM  
122 with diagnosis and procedural codes (International Statistical Classification of Diseases and  
123 Related Health Problems, 10<sup>th</sup> revision [ICD-10] and Canadian Classification of Health  
124 Interventions, respectively) within administrative databases.[9, 13-15] The composite SMM  
125 outcome included: 1) causes of direct obstetric death and conditions related to these  
126 (ante-partum, intra-partum, and post-partum hemorrhage; hypertensive disorders of  
127 pregnancy; eclampsia, and HELLP syndrome; puerperal sepsis; uterine rupture; obstetric  
128 embolus); 2) severe organ system dysfunction (cardiac arrest, failure, or arrhythmia; renal or  
129 hepatic failure; coagulation defect; thromboembolism; respiratory failure; coma or non-  
130 eclamptic seizure; psychosis); 3) procedures or interventions accompanying life-threatening  
131 conditions or health states (cesarean or postpartum hysterectomy; pelvic vessel ligation;

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3 132 surgical repair of bowel, bladder, or urethra; endotracheal or tracheostomy ventilation;  
4  
5  
6 133 dialysis; blood transfusion in the context of severe blood loss); and 4) deaths that were ill-  
7  
8 134 defined or sudden, as these could not reliably be classified as non-obstetric deaths.

9  
10 135 **Appendix 1** shows the list of SMM indicators for this study. We specified a binary SMM  
11  
12  
13 136 outcome variable for the presence of one or more indicators occurring from the onset of  
14  
15 137 pregnancy up to and including 42 days after birth.

### 18 138 **Exposures and covariates**

19  
20  
21  
22 139 Our main exposure of interest was neighbourhood material deprivation quintile from the  
23  
24 140 Ontario Marginalization Index (ON-MARG).[12] The index is a neighbourhood-level  
25  
26  
27 141 composite measure of income, educational attainment, single-parent families, and housing  
28  
29 142 quality and is based on Census data from 2001 and 2006. We used the 2001 material  
30  
31 143 deprivation index for births between years 2002-2003, and the 2006 index for years 2004-  
32  
33  
34 144 2018. The change from mandatory Census reporting to the voluntary National Household  
35  
36 145 Survey and resulting data quality concerns meant that the 2011 index was comprised from  
37  
38  
39 146 alternate data sources.[12] We used the 2006 version for all years after 2004 to avoid  
40  
41 147 operationalizing this variable differently between study years. ON-MARG has been used to  
42  
43  
44 148 demonstrate inequalities in various health measures and is stable over time.[16-18] The ON-  
45  
46 149 MARG index is a continuous variable which we modelled in quintiles, with quintile 1  
47  
48  
49 150 representing neighbourhoods with the lowest material deprivation, and quintile 5  
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51 151 representing neighbourhoods with the highest deprivation.

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54 152 We included maternal age at birth, categorized in 5-year bands. We adjusted for rural  
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57 153 setting using the 2004 and 2008 Rurality Index of Ontario (RIO).[19] We used the 2004 RIO  
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3 154 index for pregnancies between years 2002 and 2006, and the 2008 index for years 2007 to  
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5  
6 155 2018. We adjusted for number of years since immigration using data from the IRCC.  
7  
8 156 Additional demographic and pregnancy related variables included delivery mode and  
9  
10 157 multiple gestations. For multiple gestation pregnancies, delivery mode was specified based  
11  
12  
13 158 on highest level of intervention: unassisted vaginal birth of all fetuses (lowest), assisted  
14  
15 159 vaginal birth of one or more fetuses, assisted vaginal breech birth of one or more fetuses,  
16  
17  
18 160 and caesarean birth of one or more fetuses (highest). We examined SMM rates by  
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20 161 gestational age at birth, induction of labour, and the use of epidural analgesia, however  
21  
22  
23 162 these variables were not adjusted-for in the multivariable models.  
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### 26 163 **Statistical analysis**

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29 164 We summarized baseline characteristics and SMM rates overall for the study population.  
30  
31 165 Due to low birth counts for ages 10-14 years, we collapsed these into an age <20 years  
32  
33  
34 166 group for analysis. We plotted SMM rates by year for the whole study population, and then  
35  
36  
37 167 to evaluate changes over time, we divided the population into four, 4-year cohorts based on  
38  
39 168 pregnancy onset: 1 April 2002 to 31 March 2006 (cohort 1); 1 April 2006 to 31 March 2010  
40  
41 169 (cohort 2); 1 April 2010 to 31 March 2014 (cohort 3); and 1 April 2014 to 31 March 2018  
42  
43  
44 170 (cohort 4). To address our first objective, we calculated average annual SMM rates for each  
45  
46  
47 171 4-year cohort by neighbourhood material deprivation quintile. Within each cohort, we  
48  
49 172 estimated unadjusted absolute rate differences (RD) and rate ratios (RR) with 95%  
50  
51 173 confidence intervals (CI) comparing women in quintile 5 (highest deprivation) with women  
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54 174 in quintile 1 (lowest deprivation).  
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3 175 Our second objective was to evaluate the effect of neighbourhood material deprivation,  
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6 176 adjusting for covariates and testing for interaction with maternal age for the overall study  
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8 177 population. We constructed multivariable log-binomial regression models. We initially fit a  
9  
10 178 model with neighbourhood material deprivation, adjusting only for year of pregnancy onset  
11  
12  
13 179 (model 1). We then added maternal age (model 2), followed by demographic and  
14  
15 180 pregnancy-related covariates, immigration status, and rurality (model 3). We tested for  
16  
17  
18 181 interaction between material deprivation and maternal age using a cross product term. We  
19  
20 182 did not adjust for stillbirth or gestational age at birth, as these variables are considered  
21  
22 183 colliders rather than true confounders of outcomes associated with SMM.[20] We did not  
23  
24 184 include induction of labour or epidural analgesia, as these interventions are associated with  
25  
26 185 clinical decisions surrounding birth rather than SMM risk factors. We excluded women with  
27  
28 186 missing information for neighbourhood material deprivation from the multivariable analysis,  
29  
30 187 as these women represented less than 2 percent of the study population (n=17,130).  
31  
32  
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34  
35 188 We performed two additional analyses evaluating SMM rate trends (RD and RR) over the  
36  
37 189 study period, comparing the 4-year average annual rates during cohort 4 to cohort 1  
38  
39 190 separately by maternal age and by neighbourhood material deprivation quintile. We also  
40  
41 191 examined the 4-year average rates of SMM excluding cases defined by HIV disease. This was  
42  
43 192 done in reference to recently proposed changes to the Canadian SMM composite indicator  
44  
45 193 excluding chronic, asymptomatic HIV disease.[21, 22] Statistical analyses were performed  
46  
47 194 using SAS (version 7.15, SAS Institute Inc., Cary, NC) and STATA (version 13, StataCorp.,  
48  
49 195 College Station, TX).

## 196 **RESULTS**

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2  
3 197 There were 2,143,045 hospital-based births in Ontario between 1 April 2002 and 17  
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5  
6 198 February 2018, of which 1,048,845 were primiparous births and included in the study  
7  
8 199 (**Figure 1**). The overall SMM rate across the study period was 18.0 per 1,000 births, and  
9  
10 200 increased from 16.7 per 1,000 births in 2002/03 (95% CI: 15.6, 17.9) to 23.0 per 1,000 births  
11  
12 201 in 2017/18 (95% CI: 21.2, 25.0, **Supplementary Figure 1**). Baseline characteristics and SMM  
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14 202 rates for each characteristic are presented in **Table 1**. SMM rates were higher at the  
15  
16 203 extremes of maternal age, and among women living in neighbourhoods with the highest  
17  
18 204 material deprivation.

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20  
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22  
23 205 **Table 2** presents SMM rates by material deprivation quintile for each of the four 4-year  
24  
25 206 cohorts. The RD was 2.09 cases per 1,000 births (95% CI: 0.62, 3.56), corresponding with a  
26  
27 207 RR of 1.13 (95% CI: 1.04, 1.23) comparing women in quintile 5 with women in quintile 1  
28  
29 208 during the first 4-year cohort. This increased to a RD of 3.91 cases per 1,000 births (95% CI:  
30  
31 209 2.12, 5.70) and RR of 1.21 (95% CI: 1.11, 1.32) in the final 4-year cohort of the study period.  
32  
33 210 Average annual SMM rates increased between cohort 1 and cohort 4 for women aged 30-  
34  
35 211 34, and  $\geq 40$  years (**Supplementary Table 1, Supplementary Figure 2**). For the latter group,  
36  
37 212 the absolute increase was 14.69 cases per 1,000 births (95% CI: 7.96-21.43, **Supplementary**  
38  
39 213 **Table 2**). SMM rates increased over time for women in each quintile of neighbourhood  
40  
41 214 deprivation, and this increase was most pronounced for women in the highest quintile of  
42  
43 215 neighbourhood deprivation (RD 4.19 cases per 1,000 births 95% CI: 4.13-4.24,  
44  
45 216 **Supplementary Table 2**).

46  
47  
48 217 In the multivariable regression analysis for the overall study population, women living in  
49  
50 218 neighbourhoods with the highest material deprivation had higher rates of SMM compared  
51  
52 219 those in neighbourhoods with the lowest after adjusting for pregnancy year (RR: 1.11, 95%  
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3 220 CI: 1.06, 1.16, **Table 3**). Full adjustment for age, demographic, pregnancy-related variables,  
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6 221 and rurality had minimal effect on the association between material deprivation and SMM  
7  
8 222 rates (adjusted RR: 1.16, 95% CI: 1.11, 1.21, **Table 3**). The association between age and SMM  
9  
10 223 persisted in the fully adjusted model, with higher risk for women <20 and ≥30 years of age.  
11  
12  
13 224 We did not find evidence of statistical interaction between maternal age and  
14  
15 225 neighbourhood material deprivation quintile.

## 18 226 **DISCUSSION**

### 21 227 **Main findings**

22 228 This study demonstrated an association between neighbourhood material deprivation and  
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24  
25 229 severe maternal morbidity among primiparous women in Ontario from 2002-2018. Rates of  
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28 230 SMM increased across all material deprivation quintiles, and we found some evidence that  
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30  
31 231 women in the highest deprivation quintile experienced a higher magnitude SMM rate  
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33  
34 232 increase over the 16-year study period compared with women in the lowest deprivation  
35  
36  
37 233 quintile. This finding suggests a possible widening of the gap between the most and least  
38  
39  
40 234 deprived.

### 43 235 **Strengths/ limitations**

44  
45  
46 236 The current study was a population-based analysis of all primiparous hospital births at ≥20  
47  
48  
49 237 weeks' gestational age in Ontario. Hospital births account for over 98% of births in the  
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51  
52 238 province. We used a measure of neighbourhood marginalization that includes income along  
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55 239 with other measures of material resources, and that is stable across different health  
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58 240 outcomes.[16, 23] Our study nonetheless had some limitations. We were unable to account  
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60 241 for births prior to 20 weeks' gestation or births that occurred outside of the province. Our

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2  
3 242 measure of SMM was based on validated perinatal health data for Canada.[9, 15] A revision  
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5  
6 243 of the Canadian SMM composite was recently proposed which resolves issues surrounding  
7  
8 244 the inclusion of some pre-eclampsia and HELLP syndrome measures, as well as the exclusion  
9  
10 245 of HIV infection—a condition that is unlikely to represent SMM when asymptomatic [21,  
11  
12 246 22]. We elected to use the former SMM composite for comparison with other world  
13  
14  
15 247 literature, recognizing this may complicate direct comparison with recent Canadian studies  
16  
17 248 [4, 6, 21, 22]. The proportion of women with SMM defined by HIV disease was around 2%  
18  
19 249 for each of the 4-year cohorts, and thus we do not believe these cases substantively altered  
20  
21 250 the results of this study. Several patient-related risk factors, including pre-pregnancy co-  
22  
23 251 morbidities and obesity, contribute to rising SMM rates.[24] Additionally, increased use of  
24  
25 252 assisted reproductive technologies may partially explain SMM trends.[25, 26]. Unfortunately  
26  
27 253 we were unable to control for these factors. Information on immigrants arriving prior to  
28  
29 254 1985 is not captured in the IRCC Permanent Resident Database. In addition, the IRCC  
30  
31 255 database available at ICES is not able to identify immigrants who landed in other provinces  
32  
33 256 and subsequently moved to Ontario. Although we used a measure of neighbourhood  
34  
35 257 material deprivation developed for Ontario [12], the ON-MARG index does not include  
36  
37 258 individual-level indicators of marginalization or socioeconomic status. Important social  
38  
39 259 determinants may differ among individuals living in areas characterized by similar measures  
40  
41 260 of neighbourhood deprivation.[27]

## 261 **Interpretation**

262 The present study contributes to our understanding of the association between  
263 neighbourhood marginalization and SMM and provides preliminary evidence of a possible  
264 widening of this health disparity over time in Ontario. The association between

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2  
3 265 neighbourhood-level measures of inequality and risk of SMM has been demonstrated  
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5  
6 266 previously in several high-income countries. [6, 26, 28-34] Notably in Canada, Aoyama and  
7  
8 267 colleagues reported a rise in SMM linked to the relative increase in maternal age and found  
9  
10 268 a significant association between SMM and neighbourhood income quintile.[4]. Our study  
11  
12  
13 269 confirms this finding using a measure that encompasses income along with additional  
14  
15 270 measures of neighbourhood material deprivation. Moreover, we extend the current  
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18 271 understanding of this association by providing evidence suggesting a possible  
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20 272 disproportionate rise in SMM risk experienced by women living in marginalized  
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23 273 neighbourhoods over time. We interpret this last finding with caution, however, as our  
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25 274 study showed significant rate differences by neighbourhood marginalization only during the  
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27  
28 275 first and final 4-year cohorts of the 16-year study period. SMM risks have been  
29  
30 276 demonstrated among other social determinants of health; For example, lower occupational  
31  
32 277 class, Black ethnicity,[35] and non-private health insurance[29] are associated with higher  
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34  
35 278 risk of SMM in the US. Interaction between socioeconomic indicators—including ethnicity,  
36  
37 279 education, and poverty—likely contribute to the social gradient of risk such that the  
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40 280 protective effects afforded by higher education and income do not fully ameliorate racial  
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42 281 disparities in SMM.[30] Our study showed an association between neighbourhood  
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45 282 deprivation and SMM suggesting the effects of marginalization persist even in the context of  
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47 283 universal healthcare. This is a consistent finding across countries that have similar publicly  
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50 284 funded healthcare systems.[33, 36, 37] The factors contributing to social inequality are  
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52 285 myriad; ethnicity and country of origin, rurality and access to care, income, material  
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55 286 resources, education, and psychosocial supports all have worrisome associations with  
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57 287 maternal reproductive health risks.[6, 22, 29, 30, 33, 35-41] How these factors contribute to  
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3 288 widening health gaps, and what interventions may attenuate their effects will be imperative  
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6 289 lines of inquiry going forward as the global challenge to lower SMM continues.  
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9 290 **Conclusion**

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12 291 Our study found that women living in areas with higher neighbourhood material  
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14 292 deprivation experienced the highest risk of SMM, and this was not fully explained by  
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17 293 maternal age. Additionally, women living in high-deprivation neighbourhoods may have  
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19 294 experienced a disproportionate increase in the risk of SMM over time. Future work must  
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22 295 focus on addressing the widening social gap in maternal health disparities.  
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307 **TABLES**

308 **Table 1.** Baseline characteristics of the study population, 2002/03-2017/18. N=1,048,845  
 309 births.

| Variable                           | Number of births | Percent | SMM rate per 1,000 births |
|------------------------------------|------------------|---------|---------------------------|
| Overall study population           | 1,048,845        | 100     | 18.00                     |
| Maternal age at birth, years       |                  |         |                           |
| 10-14                              | 1,330            | 0.1     | 26.32                     |
| 15-19                              | 72,579           | 6.9     | 17.79                     |
| 20-24                              | 178,074          | 17.0    | 15.07                     |
| 25-29                              | 342,003          | 32.6    | 15.57                     |
| 30-34                              | 305,898          | 29.2    | 18.48                     |
| 35-39                              | 123,698          | 11.8    | 24.39                     |
| ≥40                                | 25,263           | 2.4     | 34.68                     |
| Gestational age at birth, weeks    |                  |         |                           |
| 20-23                              | 2,751            | 0.3     | 53.44                     |
| 24-27                              | 4,158            | 0.4     | 73.59                     |
| 28-33                              | 17,688           | 1.7     | 62.42                     |
| 34-36                              | 59,040           | 5.6     | 33.30                     |
| 37-41                              | 961,322          | 91.7    | 15.89                     |
| ≥42                                | 3,886            | 0.4     | 20.33                     |
| Induced labour                     | 275,262          | 26.2    | 21.20                     |
| Epidural                           | 655,107          | 62.5    | 16.35                     |
| Delivery mode                      |                  |         |                           |
| Vaginal unassisted                 | 579,814          | 55.3    | 11.01                     |
| Vaginal assisted                   | 156,383          | 14.9    | 17.42                     |
| Vaginal breech                     | 2,328            | 0.2     | 40.81                     |
| Caesarean                          | 310,320          | 29.6    | 31.18                     |
| Multiple gestations                | 20,850           | 2.0     | 54.53                     |
| Stillbirth                         | 3,645            | 0.3     | 54.60                     |
| Rurality                           |                  |         |                           |
| Urban                              | 993,282          | 94.7    | 17.93                     |
| Rural                              | 55,563           | 5.3     | 19.19                     |
| Immigration Status                 |                  |         |                           |
| Non-immigrant / before 1985        | 739,252          | 70.5    | 17.89                     |
| Immigrated >10 years               | 62,381           | 5.9     | 18.68                     |
| Immigrated 5-10 years              | 62,090           | 5.9     | 20.12                     |
| Immigrated <5 years                | 185,122          | 17.7    | 17.52                     |
| Neighbourhood material deprivation |                  |         |                           |

|                             |         |      |       |
|-----------------------------|---------|------|-------|
| Quintile 1 (least deprived) | 237,877 | 22.7 | 17.58 |
| Quintile 2                  | 186,550 | 17.8 | 16.68 |
| Quintile 3                  | 189,575 | 18.1 | 17.55 |
| Quintile 4                  | 191,376 | 18.2 | 17.89 |
| Quintile 5 (most deprived)  | 226,337 | 21.6 | 19.43 |
| Missing                     | 17,130  | 1.6  | 25.57 |

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312 **Table 2.** Four-year average SMM rates per 1,000 births for neighbourhood material  
 313 deprivation quintiles, by study period cohort.

| Cohort <sup>a</sup> | <i>SMM rates by material deprivation quintile</i> |       |       |       |           | <i>Q5 vs Q1</i>          |                      |
|---------------------|---|-------|-------|-------|-----------|--------------------------|----------------------|
|                     | Q1 (least)  | Q2    | Q3    | Q4    | Q5 (most) | Rate difference (95% CI) | Rate ratio (95% CI)  |
| 1                   | 16.05   | 16.36 | 17.46 | 16.49 | 18.14     | 2.09 (0.62, 3.56)**      | 1.13 (1.04, 1.23)**  |
| 2                   | 16.58   | 15.97 | 15.73 | 16.37 | 17.32     | 0.75 (-0.70, 2.20)       | 1.05 (0.96, 1.14)    |
| 3                   | 19.36   | 16.17 | 18.34 | 19.19 | 20.78     | 1.41 (-0.20, 3.02)       | 1.07 (0.99, 1.16)    |
| 4                   | 18.41   | 18.52 | 18.99 | 20.18 | 22.32     | 3.91 (2.12, 5.70)***     | 1.21 (1.11, 1.32)*** |

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315 <sup>a</sup>cohort 1: 1 April 2002 to 31 March 2006; cohort 2: 1 April 2006 to 31 March 2010; cohort 3:

316 1 April 2010 to 31 March 2014; cohort 4: 1 April 2014 to 31 March 2018

317 \*p<0.05, \*\*p<0.01, \*\*\*p<0.001

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322 **Table 3.** Neighbourhood material deprivation and risk of SMM: Adjusted multivariable  
 323 models, RR (95% CI). N=1,031,715 births.

| Variable             | Model 1 <sup>a</sup> | Model 2 <sup>b</sup> | Model <sup>c</sup> |
|----------------------|----------------------|----------------------|--------------------|
| Maternal age (years) |                      |                      |                    |
| <20                  |                      | 1.05 (0.99, 1.12)    | 1.20 (1.13, 1.28)  |
| 20-24                |                      | 0.95 (0.90, 0.99)    | 1.01 (0.96, 1.06)  |
| 25-29                |                      | 1 (ref)              | 1 (ref)            |
| 30-34                |                      | 1.19 (1.14, 1.23)    | 1.10 (1.06, 1.15)  |
| 35-39                |                      | 1.56 (1.49, 1.63)    | 1.34 (1.28, 1.40)  |
| ≥40                  |                      | 2.21 (2.06, 2.37)    | 1.73 (1.61, 1.86)  |
| Material deprivation |                      |                      |                    |
| Quintile 1 (least)   | 1 (ref)              | 1 (ref)              | 1 (ref)            |
| Quintile 2           | 0.95 (0.91, 0.99)    | 0.97 (0.93, 1.02)    | 0.97 (0.92, 1.01)  |
| Quintile 3           | 1.00 (0.96, 1.05)    | 1.04 (0.99, 1.08)    | 1.03 (0.98, 1.07)  |
| Quintile 4           | 1.02 (0.98, 1.07)    | 1.07 (1.02, 1.12)    | 1.06 (1.01, 1.11)  |
| Quintile 5 (most)    | 1.11 (1.06, 1.16)    | 1.17 (1.12, 1.22)    | 1.16 (1.11, 1.21)  |

<sup>a</sup>adjusted for pregnancy year

<sup>b</sup>adjusted for pregnancy year, age

<sup>c</sup>adjusted for pregnancy year, age, delivery mode, multiple gestations, immigration status, rurality

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3 333 **FIGURE CAPTIONS**  
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6 334 **Figure 1.** Study inclusion / exclusion flow chart, primiparous births.  
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13 336 **SUPPLEMENTARY MATERIAL CAPTIONS**  
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16 337 **Supplementary Appendix 1.** Data sources for the project.  
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19 338 **Supplementary Figure 1.** Annual crude SMM rate per 1,000 births, 2002/03-2017/18.  
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22 339 **Supplementary Figure 2.** Average annual SMM rates per 1,000 births by maternal age.  
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25 340 **Supplementary Table 1.** Four-year average SMM rates per 1,000 births by age and by  
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28 341 material deprivation, and rate change over study period.  
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15 355 **Declaration of competing interests**  
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18 356 The authors declare no conflicts of interest.  
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21 357 **Author contributions**  
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23  
24 358 JWS, DF, KEM, and LCR contributed to the overall conception of the study. JWS, ML, LR, DF,  
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26  
27 359 and LCR contributed to study design and protocol. TW had full access to data used in the  
28  
29 360 study. JWS, TW, and LCR take responsibility for the integrity of the data analysis. JWS wrote  
30  
31 361 the manuscript. All authors made substantial contributions to the data analysis  
32  
33 362 interpretation, and manuscript editing and revising for this project. All authors approve the  
34  
35 363 final submitted version and agree to be accountable for all aspects of the work.  
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40 364 **Ethical approval**  
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43 365 ICES is a prescribed entity under section 45 of Ontario's Personal Health Information  
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45 366 Protection Act. Section 45 authorizes ICES to collect personal health information, without  
46  
47 367 consent, for the purpose of analysis or compiling statistical information with respect to the  
48  
49 368 management of, evaluation or monitoring of, the allocation of resources to or planning for  
50  
51 369 all or part of the health system. Projects conducted under section 45, by definition, do not  
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53 370 require review by a Research Ethics Board. This project was conducted under section 45,  
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55 371 and approved by ICES' Privacy and Legal Office.  
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3 372 **Patient consent for publication**  
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6 373 None required.  
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10 374 **Data availability statement**  
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13 375 The dataset from this study is held securely in coded form at ICES. While data sharing

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15 376 agreements prohibit ICES from making the dataset publicly available, access may be granted

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17 377 to those who meet pre-specified criteria for confidential access, available at

18  
19 378 [www.ices.on.ca/DAS](http://www.ices.on.ca/DAS). The full dataset creation plan and underlying analytic code are

20  
21 379 available from the authors upon request, understanding that the computer programs may

22  
23 380 rely upon coding templates or macros that are unique to ICES and are therefore either

24  
25 381 inaccessible or may require modification.  
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3 393 and statements expressed herein are solely those of the authors and do not reflect those of  
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6 394 the funding or data sources; no endorsement is intended or should be inferred.  
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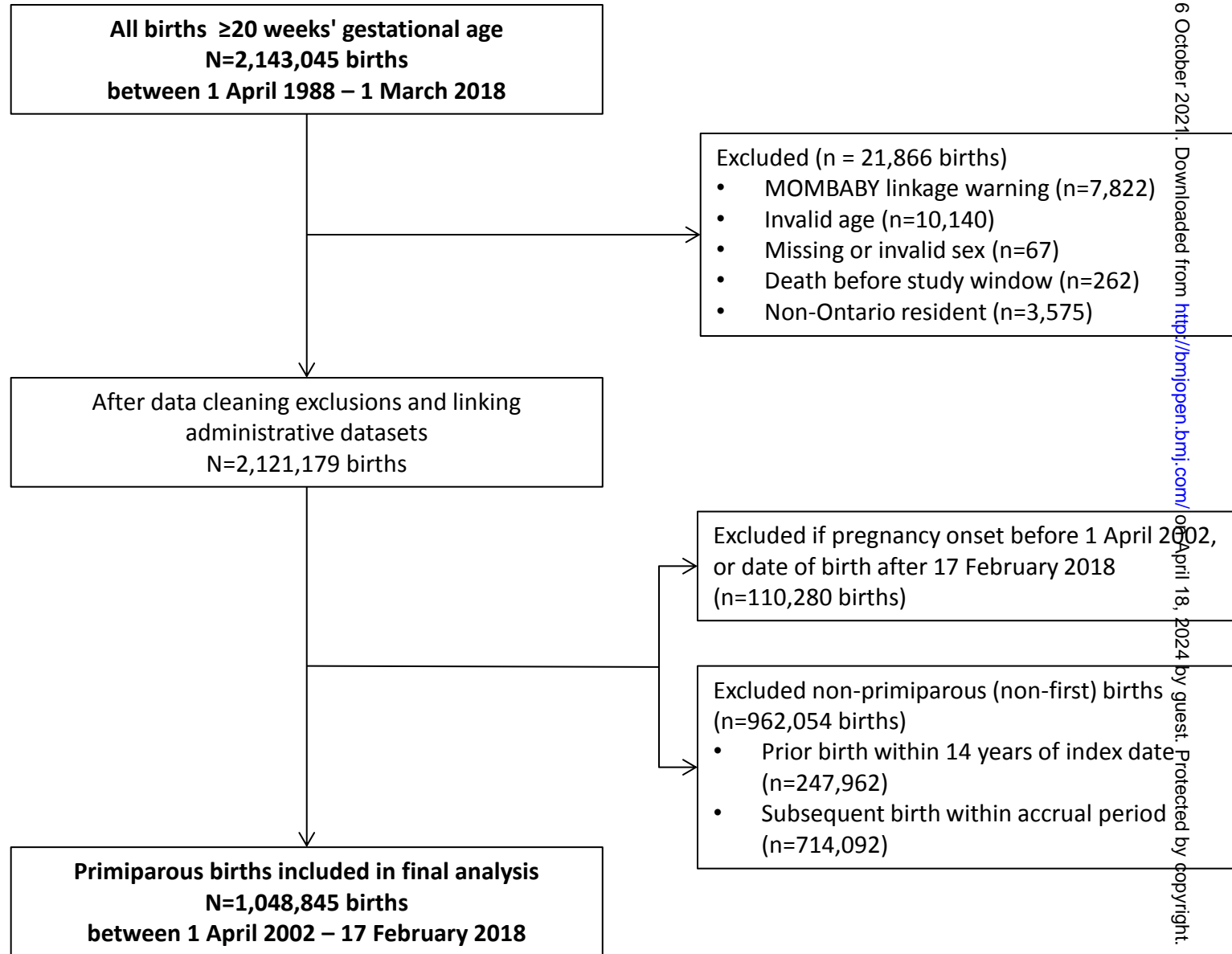
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**Figure 1.** Study inclusion / exclusion flow chart, primiparous births.



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## Supplementary Appendix 1. Data sources for project

### Discharge Abstract Database (DAD)

The DAD is compiled by the Canadian Institute for Health Information and contains administrative, clinical (diagnoses and procedures/interventions), demographic, and administrative information for all admissions to acute care hospitals, rehab, chronic, and day surgery institutions in Ontario. At ICES, consecutive DAD records are linked together to form 'episodes of care' among the hospitals to which patients have been transferred after their initial admission.

### MOMBABY

The ICES MOMBABY Database is an ICES-derived cohort that links the DAD inpatient admission records of delivering mothers and their newborns. From 2002 onward, this linkage is performed deterministically using a maternal-newborn chart matching number. Prior to 2002, mothers were linked to their children by matching on the institutions they were admitted, their postal codes, and their admission/discharge dates.

### Registered Persons Database (RPDB)

The RPDB provides basic demographic information (age, sex, location of residence, date of birth, and date of death for deceased individuals) for those issued an Ontario health insurance number. The RPDB also indicates the time periods for which an individual was eligible to receive publicly funded health insurance benefits and the best known

### Ontario Health Insurance Plan (OHIP)

The OHIP claims database contains information on inpatient and outpatient services provided to Ontario residents eligible for the province's publicly funded health insurance system by fee-for-service health care practitioners (primarily physicians) and "shadow billings" for those paid through non-fee-for-service payment plans. The main data elements include patient and physician identifiers (encrypted), code for service provided, date of service, associated diagnosis, and fee paid.

### Immigration, Refugees, and Citizenship Canada's (IRCC) Permanent Resident Database

The Ontario portion of the IRCC Permanent Resident Database includes immigration application records for people who initially applied to land in Ontario since 1985. The dataset contains permanent residents' demographic information such as country of citizenship, level of education, mother tongue, and landing date. New immigrants who are currently residing in Ontario but originally landed in another province are not captured in this dataset.

### Ontario Marginalization Index (ONMARG)

ONMARG is a geographically (census) based index developed to quantify the degree of marginalization occurring across the province of Ontario. It is comprised of four major dimensions thought to underlie the construct of marginalization: residential instability, material deprivation, dependency, and ethnic concentration. The dataset contains census divisions (CD), census tracts (CT), census subdivisions (CSD), consolidated municipal service manager areas (CMSM), public health units (PHU), local health integration networks (LHIN), sub-LHINs, and dissemination areas (DA).

These datasets were linked using unique encoded identifiers and analyzed at ICES.

The dataset from this study is held securely in coded form at ICES. While data sharing agreements prohibit ICES from making the dataset publicly available, access may be granted to those who meet pre-specified criteria for confidential access, available at [www.ices.on.ca/DAS](http://www.ices.on.ca/DAS). The full dataset creation plan and underlying analytic code are available from the authors upon request, understanding that the computer programs may rely upon coding templates or macros that are unique to ICES and are therefore either inaccessible or may require modification.

**Neighbourhood material deprivation and severe maternal morbidity: A population-based cohort study in Ontario, Canada**  
*Snelgrove JW et al.*

**Inclusion/Exclusion Criteria**

| Concept  | Data Sources | Code Type  | Window                                     | Notes<br>(including Dataset references)   |
|--|--------------|--|--|---|
| <i>Inclusion Criteria</i>  |              |  |  |   |
| Hospital birth (live or stillbirth) at gestational age $\geq 20$ weeks | DAD, MOMBABY | ICD-10 main patient service code for "Obstetrical birth" | Accrual window: 1 April 2002 – 17 Feb 2018 | Canadian Institute for Health Information Discharge Abstract Database (DAD, linked to newborn record in MOMBABY dataset)<br>See:<br><a href="https://datadictionary.ices.on.ca/Applications/DataDictionary/Library.aspx?Library=MOMBABY">https://datadictionary.ices.on.ca/Applications/DataDictionary/Library.aspx?Library=MOMBABY</a> |
| <i>Exclusion Criteria</i>  |              |  |  |   |
| Missing or invalid IKN   | RPDB         |  | Index date                                 | Registered Persons Database<br>See:<br><a href="https://datadictionary.ices.on.ca/Applications/DataDictionary/Library.aspx?Library=RPDB">https://datadictionary.ices.on.ca/Applications/DataDictionary/Library.aspx?Library=RPDB</a>  |
| MOMBABY linkage warning  | MOMBABY      |  | Index date                                 |   |
| Missing or invalid age (<10 or >55)                                    | RPDB         |  | Index date                                 |   |
| Missing or invalid sex   | RPDB         |  | Index date                                 |   |
| Death before the index date  | RPDB         |  | Index date                                 |   |
| Non-Ontario residents / invalid OHIP number                            | RPDB         |  | Index date                                 |   |
| Any births with an index date occurring outside of the accrual period  | MOMBABY      |  | Accrual window                             | Pregnancy onset before 1 April 2002   |
| Any births occurring after accrual end date                            | MOMBABY      |  | Accrual window                             | Births after 17 February 2018   |
| Not first birth  | MOMBABY      |  | 14 years prior to index date               | Prior record in MOMBABY within past 14 years of index date  |
| Not first birth in accrual period                                      | MOMBABY      |  | Accrual window                             | Subsequent records in MOMBABY   |



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**Outcome**

| Concept                         | Data Sources | Code Type     | Window   | Notes<br>(including Dataset references)  |
|---------------------------------|--------------|---------------|--|--|
| Severe maternal morbidity (SMM) | DAD          | ICD 10<br>CCI | Start of lookback period ("pregnancy onset" = index date – gestational age at birth) to end of observation window (42 days following index date) | <p>Patient considered to have outcome IF ANY code in ANY of the following:</p> <ol style="list-style-type: none"> <li>1) Obstetric/ ill-defined or sudden death</li> <li>2) Hypertensive heart/renal disease</li> <li>3) Eclampsia</li> <li>4) Cerebral venous thrombosis</li> <li>5) Complications of anaesthesia – non-cardiac</li> <li>6) Complications of anaesthesia – cardiac</li> <li>7) Cardiac diseases (cardiac arrest, infarction, failure, pulmonary edema)</li> <li>8) Placental abruption c/ coagulation defect</li> <li>9) Antepartum hemorrhage c/ coagulation defect</li> <li>10) Intrapartum hemorrhage c/ coagulation defect</li> <li>11) Uterine rupture – before labour</li> <li>12) Uterine rupture – during labour</li> <li>13) Obstetric shock (including septic shock)</li> <li>14) Septecemia during labour</li> <li>15) Puerperal sepsis</li> <li>16) Pulmonary embolism</li> <li>17) Obstetric embolism</li> <li>18) Cardiomyopathy</li> <li>19) Acute renal failure</li> <li>20) HIV disease</li> <li>21) Cerebrovascular disease</li> <li>22) Acute respiratory distress syndrome</li> <li>23) Acute abdomen</li> <li>24) Hepatic failure</li> <li>25) Acute psychosis</li> <li>26) Cerebral edema, coma</li> <li>27) Disseminated intravascular coagulation</li> <li>28) Sickle cell anemia crisis</li> <li>29) Status asthmaticus</li> <li>30) Status epilepticus</li> <li>31) Assisted ventilation (endotracheal tube or tracheostomy)</li> <li>32) Caesarean hysterectomy</li> <li>33) Postpartum hysterectomy</li> <li>34) Dialysis</li> <li>35) Evacuation of incisional hematoma</li> <li>36) Surgical repair of bladder, urethra, intestine</li> <li>37) Intrapartum hemorrhage with no coagulation defect AND blood transfusion</li> <li>38) Postpartum hemorrhage AND blood</li> </ol> |

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|  |  |  |  | transfusion<br>39) Placenta previa AND blood transfusion<br>40) Embolization/ ligation/ suturing AND postpartum hemorrhage<br><br>See:<br>Joseph KS et al, 2009, <sup>1</sup> Joseph KS et al, 2010, <sup>2</sup> ICD-10CA, 2009, <sup>3</sup> and CCHI, 2012. <sup>4</sup> |
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**Study exposures, covariates**

| Concept                    | Data Sources   | Code Type                 | Window                       | Notes<br>(including Dataset references)   |
|----------------------------|----------------|---------------------------|------------------------------|---|
| Age                        | RPDB           |                           | Index date                   |   |
| Index year                 | DAD            |                           | Index date                   |   |
| Material deprivation index | ONMARG         |                           | Index date                   | Ontario Marginalization Index, Material Deprivation, in quintiles.<br><br>Use version of ONMARG closest to year of index date:<br>2001 for 2002-2003<br>2006 for 2004-2018<br>See:<br><a href="https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=ONMARG">https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=ONMARG</a> |
| Income quintile            | RPDB<br>Census |                           | Index date                   | Ontario Census area profile: income quintile.<br><br>Use Census closest to year of index date:<br>2001 for 2002-2003<br>2006 for 2004-2018<br>See:<br><a href="https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=CENSUS">https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=CENSUS</a>                                 |
| Rurality                   | RPDB           |                           | Index date                   | Rurality Index for Ontario (RIO).<br>Use version of RIO closest to year of index date:<br>RIO2004 for 2002-2006<br>RIO2008 for 2007-2018  |
| Gestational age at birth   | MOMBABY        |                           | Index date                   |   |
| Induction of labour        | DAD            | CCI code                  | Within index hospitalization | Canadian Classification of Health Interventions (CCI)   |
| Epidural                   | DAD<br>OHIP    | CCI code<br>OHIP fee code | Within index hospitalization | Canadian Classification of Health Interventions (CCI); Ontario Health Insurance Plan Claims Database (OHIP)   |
| Delivery mode              | DAD            | CCI code                  | Within index hospitalization |   |
| Multiple gestations        | MOMBABY        |                           | Within index hospitalization |   |
| Stillbirth                 | MOMBABY        |                           | Within index hospitalization |   |
| Immigration status         | IRCC           |                           | Index date                   | Immigration, Refugees and Citizenship   |

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|  |  |  |  | Canada (IRCC)'s Permanent Resident Database<br><br>Number of years since arrived in Ontario.<br>See:<br><a href="https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=CIC">https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=CIC</a> |
|--|--|--|--|---|

**References**

1. Joseph KS, Fahey J, Canadian Perinatal Surveillance S. Validation of perinatal data in the Discharge Abstract Database of the Canadian Institute for Health Information. *Chronic Diseases in Canada*. 2009;29:96-100.
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3. *International Statistical Classification of Diseases and Related Health Problems. 10th Revision. ICD-10CA*: Canadian Institute for Health Information;2009.
4. *Canadian Classification of Health Interventions*. Ottawa: Canadian Institute for Health Information;2012.

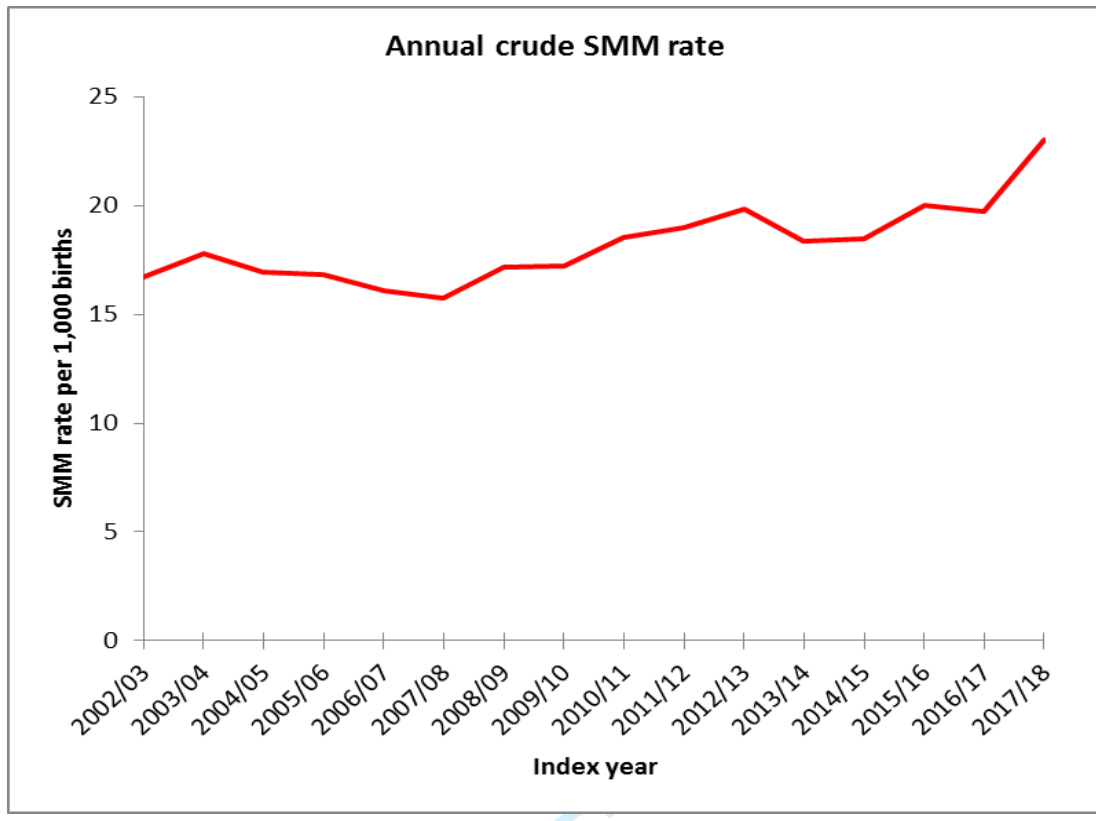
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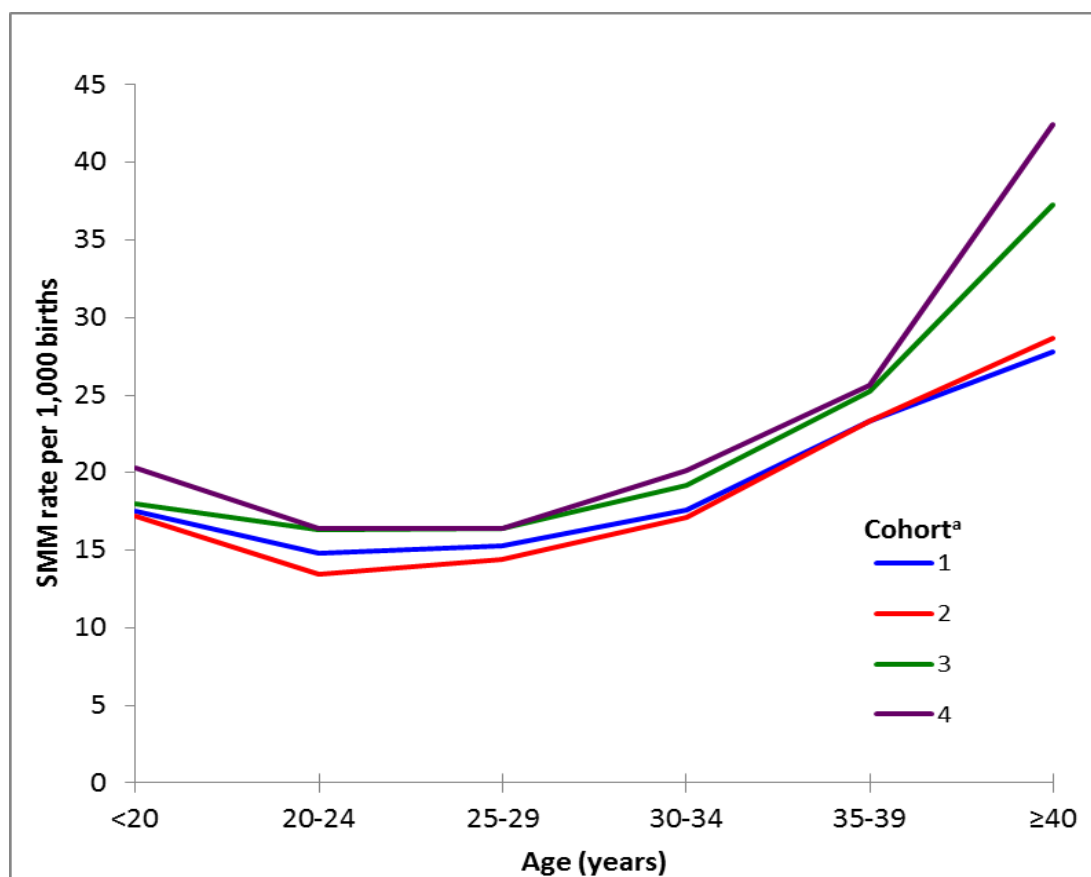
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Supplementary Figure 1. Annual crude SMM rate per 1,000 births, 2002/03-2017/18.



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**Supplementary Figure 2.** Average annual SMM rates per 1,000 births by maternal age.



<sup>a</sup>cohort 1: 1 April 2002 to 31 March 2006; cohort 2: 1 April 2006 to 31 March 2010; cohort 3: 1 April 2010 to 31 March 2014; cohort 4: 1 April 2014 to 31 March 2018

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**Average SMM rate per 1,000 deliveries by 4-year cohort**

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**Supplementary table 1. Four-year average SMM rates per 1,000 births by age and by material deprivation, and rate change over study period.**

| Variable                    | SMM rates by cohort <sup>a</sup> |       |       |       | SMM rate change, cohort 4 vs 1 <sup>a</sup> |                     |
|-----------------------------|----------------------------------|-------|-------|-------|---|---------------------|
|                             | 1                                | 2     | 3     | 4     | Rate difference (95% CI)                    | Rate ratio (95% CI) |
| Overall study population    | 17.10                            | 16.55 | 18.94 | 19.82 | 2.72 (1.96, 3.49)***                        | 1.16 (1.11, 1.21)** |
| <i>Maternal age (years)</i> |                                  |       |       |       |   |                     |
| <20                         | 17.54                            | 17.22 | 17.97 | 20.34 | 2.80 (-0.43, 6.04)                          | 1.15 (0.98, 1.37)   |
| 20-24                       | 14.80                            | 13.47 | 16.32 | 16.40 | 1.60 (-0.15, 3.35)                          | 1.11 (0.99, 1.24)   |
| 25-29                       | 15.26                            | 14.40 | 16.37 | 16.42 | 1.15 (-0.77, 2.39)                          | 1.08 (0.99, 1.16)   |
| 30-34                       | 17.58                            | 17.10 | 19.21 | 20.16 | 2.58 (1.18, 3.97)*                          | 1.15 (1.06, 1.23)   |
| 35-39                       | 23.31                            | 23.35 | 25.23 | 25.67 | 2.36 (-0.16, 4.88)                          | 1.10 (0.99, 1.22)   |
| ≥40                         | 27.78                            | 28.68 | 37.30 | 42.48 | 14.69 (7.96, 21.43)*                        | 1.53 (1.24, 1.89)   |
| <i>Material deprivation</i> |                                  |       |       |       |   |                     |
| Quintile 1 (least)          | 16.05                            | 16.58 | 19.36 | 18.41 | 2.36 (2.31, 2.41)***                        | 1.15 (1.14, 1.15)** |
| Quintile 2                  | 16.36                            | 15.97 | 16.17 | 18.52 | 2.16 (2.11, 2.22)***                        | 1.13 (1.13, 1.14)** |
| Quintile 3                  | 17.46                            | 15.73 | 18.34 | 18.99 | 1.54 (1.48, 1.59)***                        | 1.09 (1.08, 1.09)** |
| Quintile 4                  | 16.49                            | 16.37 | 19.19 | 20.18 | 3.69 (3.63, 3.74)***                        | 1.22 (1.22, 1.23)** |
| Quintile 5 (most)           | 18.14                            | 17.32 | 20.78 | 22.32 | 4.19 (4.13, 4.24)***                        | 1.23 (1.22, 1.23)** |

<sup>a</sup>cohort 1: 1 April 2002 to 31 March 2006; cohort 2: 1 April 2006 to 31 March 2010; cohort 3: 1 April 2010 to 31 March 2014; cohort 4: 1 April 2014 to 31 March 2018

\*p<0.05, \*\*p<0.01, \*\*\*p<0.001

The RECORD statement – checklist of items that should be reported in observational studies using routinely collected health data.

|                           | Item No. | STROBE items   | Location in manuscript where items are reported                          | RECORD items  | Location in manuscript where items are reported |
|---------------------------|----------|--|--|---|---|
| <b>Title and abstract</b> |          |  |  |   |   |
|                           | 1        | (a) Indicate the study’s design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found | Title page (p.1)   | RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included.<br><br>RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract.<br><br>RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract. | Title page, abstract (p. 1-3)                   |
| <b>Introduction</b>       |          |  |  |   |   |
| Background rationale      | 2        | Explain the scientific background and rationale for the investigation being reported   | Background p.4-5   |   |   |
| Objectives                | 3        | State specific objectives, including any prespecified hypotheses   | Background p.4-5   |   |   |
| <b>Methods</b>            |          |  |  |   |   |
| Study Design              | 4        | Present key elements of study design early in the paper  | Methods p.5-9  |   |   |
| Setting                   | 5        | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection  | Methods: <i>Study population and data sources, Main outcome</i> , p. 5-6 |   |   |

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|                                      |          |   |  |   |   |
|--------------------------------------|----------|---|--|---|---|
| <p>Participants</p>                  | <p>6</p> | <p>(a) <i>Cohort study</i> - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up<br/> <i>Case-control study</i> - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls<br/> <i>Cross-sectional study</i> - Give the eligibility criteria, and the sources and methods of selection of participants<br/><br/>                 (b) <i>Cohort study</i> - For matched studies, give matching criteria and number of exposed and unexposed<br/> <i>Case-control study</i> - For matched studies, give matching criteria and the number of controls per case</p> | <p>Cohort study, no matching:<br/><br/>                 Methods: <i>Study population and data sources, Main outcome, Exposures and covariates</i> p. 5-8; Appendix 1</p> | <p>RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided.<br/><br/>                 RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere detailed methods and results should be provided.<br/><br/>                 RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.</p> | <p>Methods: <i>Study population and data sources, Main outcome, Exposures and covariates</i> p. 5-8; Supplementary Appendix 1</p> |
| <p>Variables</p>                     | <p>7</p> | <p>Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.</p>  | <p>Methods: <i>Study population and data sources, Main outcome, Exposures and covariates</i> p. 5-8; Supplementary Appendix 1</p>  | <p>RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.</p>  | <p>Methods: <i>Study population and data sources, Main outcome, Exposures and covariates</i> p. 5-8; Supplementary Appendix 1</p> |
| <p>Data sources/<br/>measurement</p> | <p>8</p> | <p>For each variable of interest, give sources of data and details of methods of assessment (measurement).</p>  | <p>Methods: <i>Study population and data sources, Main outcome, Exposures</i></p>  |   |   |

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|                        |    | Describe comparability of assessment methods if there is more than one group  | <i>and covariates</i> p. 5-8; Supplementary Appendix 1   |  |  |
| Bias                   | 9  | Describe any efforts to address potential sources of bias   | Methods: <i>Exposures and covariates</i> p. 7-8; Interpretation: <i>Strengths/ limitations</i> p.11-12 |  |  |
| Study size             | 10 | Explain how the study size was arrived at   | Methods: <i>Study population and data sources</i> , p. 5-6; Figure 1                                   |  |  |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why   | Methods: <i>Statistical analysis</i> , p. 8-9  |  |  |
| Statistical methods    | 12 | (a) Describe all statistical methods, including those used to control for confounding<br>(b) Describe any methods used to examine subgroups and interactions<br>(c) Explain how missing data were addressed<br>(d) <i>Cohort study</i> - If applicable, explain how loss to follow-up was addressed<br><i>Case-control study</i> - If applicable, explain how matching of cases and controls was addressed<br><i>Cross-sectional study</i> - If applicable, describe analytical methods taking account of | Methods: <i>Statistical analysis</i> , p. 8-9, Results, p.9-11.  |  |  |

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|----------------------------------|----|---|---------------------------------|---|--|
|                                  |    | sampling strategy<br>(e) Describe any sensitivity analyses  |                                 |   |  |
| Data access and cleaning methods |    | ..  |                                 | <p>RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population.</p> <p>RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.</p>   | <p>Methods: <i>Study population and data sources</i>, p. 5-6; Supplementary Appendix 1; Author contributions, p. 20</p>  |
| Linkage                          |    | ..  |                                 | <p>RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.</p>  | <p>Methods: <i>Study population and data sources</i>, <i>Main outcome</i>, <i>Exposures and covariates</i> p. 5-8; Supplementary Appendix 1</p>                                  |
| <b>Results</b>                   |    |   |                                 |   |  |
| Participants                     | 13 | <p>(a) Report the numbers of individuals at each stage of the study (<i>e.g.</i>, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed)</p> <p>(b) Give reasons for non-participation at each stage.</p> <p>(c) Consider use of a flow diagram</p> | Results p.10; Table 1; Figure 1 | <p>RECORD 13.1: Describe in detail the selection of the persons included in the study (<i>i.e.</i>, study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.</p> | <p>Methods: <i>Study population and data sources</i>, <i>Main outcome</i>, <i>Exposures and covariates</i> p. 5-8; Results p.10; Table 1; Figure 1; Supplementary Appendix 1</p> |
| Descriptive data                 | 14 | (a) Give characteristics of study participants ( <i>e.g.</i> , demographic, clinical, social) and information   | Results p.10; Table 1           |   |  |

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|----------------|----|---|---|--|
|                |    | on exposures and potential confounders<br>(b) Indicate the number of participants with missing data for each variable of interest<br>(c) <i>Cohort study</i> - summarise follow-up time (e.g., average and total amount)  |   |  |
| Outcome data   | 15 | <i>Cohort study</i> - Report numbers of outcome events or summary measures over time<br><i>Case-control study</i> - Report numbers in each exposure category, or summary measures of exposure<br><i>Cross-sectional study</i> - Report numbers of outcome events or summary measures  | Results p.10; Figure 1; Table 1                 |  |
| Main results   | 16 | (a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included<br>(b) Report category boundaries when continuous variables were categorized<br>(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period | Results p.10; Table 1-3; Supplementary Figure 1 |  |
| Other analyses | 17 | Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses   | Results p.10-11                                 |  |

Snelgrove JW et al. **Neighbourhood material deprivation and severe maternal morbidity: A population-based cohort study in Ontario, Canada**

| <b>Discussion</b>   |    |  |   |  |  |
|---|----|--|---|--|--|
| Key results   | 18 | Summarise key results with reference to study objectives   | Interpretation, <i>Main findings</i> p.11                                       |  |  |
| Limitations   | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias                 | Interpretation, <i>Strengths/limitations</i> p.11-12                            | RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported. | Interpretation, <i>Strengths/limitations</i> p.11-12 |
| Interpretation  | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | Discussion, <i>Main findings</i> p. 11, <i>Strengths / Limitations</i> p. 11-12 |  |  |
| Generalisability  | 21 | Discuss the generalisability (external validity) of the study results  | Discussion, <i>Interpretation</i> p.11-12                                       |  |  |
| <b>Other Information</b>                                  |    |  |   |  |  |
| Funding   | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based              | Funding, p. 21-22   |  |  |
| Accessibility of protocol, raw data, and programming code |    | ..   |   | RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.   | p. 21; Supplementary Appendix 1                      |

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\*Reference: Benchimol EI, Smeeth L, Guttman A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langlois SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.

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# BMJ Open

## Neighbourhood material deprivation and severe maternal morbidity: A population-based cohort study in Ontario, Canada.

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3 1 **TITLE PAGE**  
45 2 **Neighbourhood material deprivation and severe maternal morbidity:**  
67 3 **A population-based cohort study in Ontario, Canada**  
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910 4  
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3 26 **ABSTRACT**  
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6 27 **Objectives:** Rates of age-associated severe maternal morbidity (SMM) have increased in  
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9 28 Canada, and an association with neighbourhood income is well established. Our aim was to  
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11 29 examine SMM trends according to neighbourhood material deprivation quintile, and to  
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14 30 assess whether neighbourhood deprivation effects are moderated by maternal age.  
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16  
17 31 **Design, setting, participants:** A population-based retrospective cohort study using linked  
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19 32 administrative databases in Ontario, Canada. We included primiparous women with a live  
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21  
22 33 birth or stillbirth at  $\geq 20$  weeks gestational age.  
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24  
25 34 **Primary outcome:** SMM from pregnancy onset to 42 days postpartum. We calculated SMM  
26  
27 35 rate differences (RD) and rate ratios (RR) by neighbourhood material deprivation quintile for  
28  
29 36 each of four 4-year cohorts from 1 April 2002 to 31 March 2018. Log-binomial multivariable  
30  
31 37 regression adjusted for maternal age, demographic, and pregnancy-related variables.  
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34  
35 38 **Results:** There were 1,048,845 primiparous births during the study period. The overall rate  
36  
37 39 of SMM was 18.0 per 1,000 births. SMM rates were elevated for women living in areas with  
38  
39 40 high material deprivation. In the final 4-year cohort, the RD between women living in high  
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41 41 versus low deprivation neighbourhoods was 3.91 SMM cases per 1,000 births (95% CI: 2.12,  
42  
43 42 5.70). This was higher than the difference observed during the first 4-year cohort (RD 2.09,  
44  
45 43 95% CI: 0.62, 3.56). SMM remained associated with neighbourhood material deprivation  
46  
47 44 following multivariable adjustment in the pooled sample (RR 1.16, 95% CI: 1.11, 1.21). There  
48  
49 45 was no evidence of interaction with maternal age.  
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56 46 **Conclusion:** SMM rate increases were more pronounced for primiparous women living in  
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58 47 neighbourhoods with high material deprivation compared to those living in low deprivation  
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3 48 areas. This raises concerns of a widening social gap in maternal health disparities and  
4  
5 49 highlights an opportunity to focus risk reduction efforts toward disadvantaged women  
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8 50 during pregnancy and postpartum.  
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11 51

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14 52 **Keywords:** severe maternal morbidity; maternal mortality; maternal health; pregnancy;  
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17 53 perinatal epidemiology; social epidemiology; social inequalities; deprivation  
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### 22 23 55 **Strengths and Limitations of this Study**

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27 56 • Data were from population linked administrative and health registries that capture  
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29 57 all hospital births in Ontario, Canada  
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33 58 • Neighbourhood material deprivation was measured using the Ontario  
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35 59 Marginalization Index, a comprehensive area-level measure based on Census data  
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37 60 developed using theoretical frameworks on marginalization and deprivation  
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41 61 • Limiting our study to primiparous women enabled the evaluation of population SMM  
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43 62 trends and reduced confounding from previous births  
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47 63 • It was not possible to control for all covariates associated with SMM, including body  
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49 64 mass index, co-morbidities, and the use of assisted reproductive technology  
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## 66 INTRODUCTION

67 Each year, approximately 4,000 Canadian women survive a maternal “near-miss”—a life-  
68 threatening event associated with pregnancy.[1] To characterize maternal near-misses in a  
69 standardized way, the World Health Organization proposed the concept of severe maternal  
70 morbidity (SMM), a composite of conditions that represent end-organ dysfunction or states  
71 of heightened maternal mortality risk associated with pregnancy, birth, or the postpartum  
72 period.[2, 3] Advances in the recognition and management of SMM have resulted in low  
73 maternal mortality rates in economically developed nations. Women living in high income  
74 countries are now more likely to survive a life-threatening pregnancy condition and,  
75 correspondingly, the rates of SMM are 100-fold higher than the rates of maternal mortality  
76 in Canada.[1] However, recent trends in Canada and other high income countries show an  
77 increase in SMM rates coinciding with advancing maternal age and corresponding increases  
78 in pre-existing co-morbidities and the use of assisted reproductive technology.[4-9]

79 The literature also shows persistent though complex associations between SMM and the  
80 social determinants of health. Low occupational class, Black ethnicity,[10] and non-private  
81 health insurance[11] are all associated with higher risk of SMM in the US. Canadian women  
82 who experience SMM are more likely to come from a low-income background, and to  
83 originate from an African or Caribbean country.[4, 6, 12] A systematic review found  
84 evidence for effects of material dimensions of inequality on SMM risk, though it pointed out  
85 the need for further work on other dimensions and in elucidating effect mechanisms.[13]

86 Women of advanced maternal age may be more likely to come from more advantaged  
87 socioeconomic backgrounds and to have planned pregnancies.[14-16] This suggests the  
88 possibility for effect modification, whereby the negative effects of advanced maternal age

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3 89 may be attenuated for women who come from more advantaged backgrounds, and  
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6 90 exacerbated for women from disadvantaged backgrounds. The effects of maternal age and  
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8 91 neighbourhood-level material deprivation may therefore interact, with the highest SMM risk  
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10 92 among older women living in neighbourhoods with higher deprivation.

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14 93 In this study, our first objective was to evaluate trends in SMM rates among primiparous  
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16 94 women in Ontario by neighbourhood material deprivation quintile between 1 April 2002  
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18 95 and 31 March 2018. Our second objective was to determine if maternal age moderates the  
19  
20 96 effect of neighbourhood material deprivation. We hypothesized that SMM rates would  
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22 97 increase disproportionately over time among women living in neighbourhoods with high  
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24 98 material deprivation. We further hypothesized that the highest risk of SMM would be  
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26 99 among women of advanced maternal age living in neighbourhoods with the highest material  
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31 100 deprivation.

## 32 33 34 101 **METHODS**

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37 102 This population-based retrospective cohort study used linked administrative datasets for  
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39 103 Ontario, held at ICES, which is an independent non-profit research institute whose legal  
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41 104 status under Ontario's health information privacy law allows it to collect and analyze health  
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43 105 care and demographic data, without consent, for health system evaluation and  
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45 106 improvement. The use of data in this project was authorized under section 45 of Ontario's  
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47 107 Personal Health Information Protection Act, which does not require review by a Research  
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49 108 Ethics Board. We followed the RECORD guidelines (REporting of studies Conducted using  
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51 109 Observational Routinely-collected Data) for reporting this study.[17]

## 52 53 54 55 56 57 58 110 **Patient and public involvement**



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3 111 There was no direct patient or public involvement in this study.  
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6 112 **Study population and data sources**  
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10 113 The Canadian Institute for Health Information Discharge Abstract Database (DAD) was used  
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12 114 to capture all hospital admissions for birth and link to newborn records using the ICES-  
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14 115 derived MOMBABY dataset. We included primiparous women aged 10-55 years who had a  
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16 116 hospital birth in Ontario and were enrolled in the province's universal health insurance  
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18 117 program (OHIP). We identified the first live birth or stillbirth delivery at a gestational age of  
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20 118  $\geq 20$  weeks. We used gestational age at birth to calculate pregnancy onset. Women were  
21  
22 119 included if the onset of their first pregnancy was on or after 1 April 2002 and the  
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24 120 corresponding birth occurred on or before 17 February 2018—allowing 42 days of  
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26 121 postpartum follow-up through the study end date of 31 March 2018. Women who had a  
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28 122 previous birth within 14 years prior to the index date were excluded. We linked these data  
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30 123 with the Registered Persons Database (RPDB), DAD, and OHIP Claims Database to identify  
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32 124 exposures and outcomes of interest. To identify women who had recently immigrated to  
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34 125 Ontario, we used the Ontario portion of the federal Immigration, Refugees and Citizenship  
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36 126 Canada (IRCC) Permanent Resident Database. For neighbourhood material deprivation, we  
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38 127 used the 2001 and 2006 Canadian Census, and Ontario Marginalization Index (ON-  
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40 128 MARG).[18] These datasets were linked using unique encoded identifiers and analyzed at  
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42 129 ICES and are shown in **Appendix 1**.  
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51 130 **Main outcome**  
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55 131 The main outcome was a composite of medical conditions and interventions that comprise  
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57 132 SMM. Cases of SMM were identified using diagnosis and procedural codes (International  
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3 133 Statistical Classification of Diseases and Related Health Problems, 10<sup>th</sup> revision [ICD-10] and  
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6 134 Canadian Classification of Health Interventions, respectively) within the DAD database.[15,  
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8 135 19-21] The DAD data have been validated and shown to accurately reflect the information in  
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10 136 medical records.[21, 22] The composite SMM outcome included: 1) causes of direct  
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12 137 obstetric death and conditions related to these (ante partum, intrapartum, and postpartum  
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14 138 hemorrhage; hypertensive disorders of pregnancy and eclampsia; puerperal sepsis; uterine  
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16 139 rupture; obstetric embolus); 2) severe organ system dysfunction (cardiac arrest, failure, or  
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18 140 arrhythmia; renal or hepatic failure; coagulation defect; thromboembolism; respiratory  
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20 141 failure; coma or non-eclamptic seizure; psychosis); 3) procedures or interventions  
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22 142 accompanying life-threatening conditions or health states (cesarean or postpartum  
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24 143 hysterectomy; pelvic vessel ligation; surgical repair of bowel, bladder, or urethra;  
25  
26 144 endotracheal or tracheostomy ventilation; dialysis; blood transfusion in the context of  
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28 145 severe blood loss); and 4) deaths that were ill-defined or sudden, as these could not reliably  
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30 146 be classified as non-obstetric deaths. **Appendix 1** shows the list of SMM indicators for this  
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32 147 study. We specified a binary SMM outcome variable for the presence of one or more  
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34 148 indicators occurring from the onset of pregnancy up to and including 42 days after birth.  
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### 43 **Exposures and covariates**

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46 150 Our main exposure of interest was neighbourhood material deprivation quintile from the  
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48 151 Ontario Marginalization Index (ON-MARG). ON-MARG is the Ontario-specific version of the  
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50 152 Canadian marginalization index (CAN-MARG).[23] The index was developed based on  
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52 153 theoretical frameworks of marginalization and deprivation, and derived empirically using  
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54 154 principal component analysis of Canadian Census variables.[18, 23]The material deprivation  
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56 155 dimension is comprised of the following Census measures, each expressed as a proportion:  
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3 156 population aged  $\geq 20$  without secondary school graduation, single parent families,  
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6 157 households receiving government transfer payments, population aged  $\geq 15$  who are  
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8 158 unemployed, population living below the low income cut-off (adjusted for community size,  
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10 159 household size, and inflation).[18] The geographical unit of aggregation is Dissemination  
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13 160 Areas, which average 400-700 people and cover the entirety of Canadian territory.[24] ON-  
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15 161 MARG can be operationalized as a standardized interval scale based on factor loadings from  
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17 162 the principal component analysis, or as quintiles each representing 20% of Dissemination  
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20 163 Areas.[18, 23] We modelled this exposure as quintiles, with quintile 1 representing  
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22 164 neighbourhoods with the lowest material deprivation, and quintile 5 representing  
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24 165 neighbourhoods with the highest deprivation.[18, 23] ON-MARG has been used to  
25  
26 166 demonstrate inequalities in various health measures and is stable over time.[25-27] We  
27  
28 167 used the 2001 material deprivation index for births between years 2002-2003, and the 2006  
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30 168 index for years 2004-2018. The change from mandatory Census reporting to the voluntary  
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32 169 National Household Survey and resulting data quality concerns meant that the 2011 index  
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34 170 was comprised from alternate data sources.[28] We used the 2006 version for all years after  
35  
36 171 2004 to avoid operationalizing this variable differently between study years.  
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38 172 We included maternal age at birth, categorized in 5-year bands. We adjusted for rural  
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40 173 setting using the 2004 and 2008 Rurality Index of Ontario (RIO).[29] We used the 2004 RIO  
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42 174 index for pregnancies between years 2002 and 2006, and the 2008 index for years 2007 to  
43  
44 175 2018. We adjusted for number of years since immigration using data from the IRCC.  
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46 176 Additional demographic and pregnancy related variables included delivery mode and  
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48 177 multiple gestations. For multiple gestation pregnancies, delivery mode was specified based  
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50 178 on highest level of intervention: unassisted vaginal birth of all fetuses (lowest), assisted  
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3 179 vaginal birth of one or more fetuses, assisted vaginal breech birth of one or more fetuses,  
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5 180 and caesarean birth of one or more fetuses (highest). We examined SMM rates by  
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8 181 gestational age at birth, induction of labour, and the use of epidural analgesia, however  
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10 182 these variables were not adjusted-for in the multivariable models.

### 13 183 **Statistical analysis**

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17 184 We summarized baseline characteristics and SMM rates overall for the study population.  
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19 185 Due to low birth counts for ages 10-14 years, we collapsed these into an age <20 years  
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21 186 group for analysis. We plotted SMM rates by year for the whole study population, and then  
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24 187 to evaluate changes over time, we divided the population into four, 4-year cohorts based on  
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27 188 pregnancy onset: 1 April 2002 to 31 March 2006 (cohort 1); 1 April 2006 to 31 March 2010  
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29 189 (cohort 2); 1 April 2010 to 31 March 2014 (cohort 3); and 1 April 2014 to 31 March 2018  
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31 190 (cohort 4). To address our first objective, we calculated average annual SMM rates for each  
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34 191 4-year cohort by neighbourhood material deprivation quintile. Within each cohort, we  
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37 192 estimated unadjusted absolute rate differences (RD) and rate ratios (RR) with 95%  
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39 193 confidence intervals (CI) comparing women in quintile 5 (highest deprivation) with women  
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41 194 in quintile 1 (lowest deprivation).

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45 195 Our second objective was to evaluate the effect of neighbourhood material deprivation,  
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47 196 adjusting for covariates and testing for interaction with maternal age for the overall study  
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49 197 population. We constructed multivariable log-binomial regression models. We initially fit a  
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52 198 model with neighbourhood material deprivation, adjusting only for year of pregnancy onset  
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54 199 (model 1). We then added maternal age (model 2), followed by demographic and  
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57 200 pregnancy-related covariates, immigration status, and rurality (model 3). We tested for

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3 201 interaction between material deprivation and maternal age using a cross product term. We  
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6 202 did not adjust for stillbirth or gestational age at birth, as these are variables are considered  
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8 203 colliders rather than true confounders of outcomes associated with SMM.[30] We did not  
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10  
11 204 include induction of labour or epidural analgesia, as these interventions are associated with  
12  
13 205 clinical decisions surrounding birth rather than SMM risk factors. We excluded women with  
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15 206 missing information for neighbourhood material deprivation from the multivariable analysis,  
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17  
18 207 as these women represented less than 2 percent of the study population (n=17,130).

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21 208 We performed two additional analyses evaluating SMM rate trends (RD and RR) over the  
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23  
24 209 study period, comparing the 4-year average annual rates during cohort 4 to cohort 1  
25  
26 210 separately by maternal age and by neighbourhood material deprivation quintile. We also  
27  
28 211 examined the 4-year average rates of SMM excluding cases defined by HIV disease. This was  
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31 212 done in reference to recently proposed changes to the Canadian SMM composite indicator  
32  
33 213 excluding chronic, asymptomatic HIV disease.[12, 31] Statistical analyses were performed  
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35  
36 214 using SAS (version 7.15, SAS Institute Inc., Cary, NC) and STATA (version 13, StataCorp.,  
37  
38 215 College Station, TX).

## 41 216 **RESULTS**

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45 217 There were 2,143,045 hospital-based births in Ontario between 1 April 2002 and 17  
46  
47 218 February 2018, of which 1,048,845 were primiparous births and included in the study  
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49 219 (**Figure 1**). The overall SMM rate across the study period was 18.0 per 1,000 births, and  
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52 220 increased from 16.7 per 1,000 births in 2002-03 (95% CI: 15.6, 17.9) to 23.0 per 1,000 births  
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54 221 in 2017-18 (95% CI: 21.2, 25.0, **Supplementary Figure 1**). Baseline characteristics and SMM  
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57 222 case number and rate for each characteristic are presented in **Table 1**. SMM rates were  
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223 higher at the extremes of maternal age, and among women living in neighbourhoods with  
224 the highest material deprivation.

225 **Table 2** presents SMM rates by material deprivation quintile for the pooled study sample  
226 (2002-2018) and each of the four 4-year cohorts. The RD was 2.09 cases per 1,000 births  
227 (95% CI: 0.62, 3.56), corresponding with a RR of 1.13 (95% CI: 1.04, 1.23) comparing women  
228 in quintile 5 with women in quintile 1 during the first 4-year cohort. This increased to a RD  
229 of 3.91 cases per 1,000 births (95% CI: 2.12, 5.70) and RR of 1.21 (95% CI: 1.11, 1.32) in the  
230 final 4-year cohort of the study period. Average annual SMM rates increased between  
231 cohort 1 and cohort 4 for women aged 30-34, and  $\geq 40$  years (**Supplementary Table 1**,  
232 **Supplementary Figure 2**). For the latter group, the absolute increase was 14.69 cases per  
233 1,000 births (95% CI: 7.96-21.43, **Supplementary Table 1**). SMM rates increased over time  
234 for women in each quintile of neighbourhood deprivation, and this increase was most  
235 pronounced for women in the highest quintile of neighbourhood deprivation (RD 4.19 cases  
236 per 1,000 births 95% CI: 4.13-4.24, **Supplementary Table 1**).

237 In the multivariable regression analysis for the overall study population, women living in  
238 neighbourhoods with the highest material deprivation had higher rates of SMM compared  
239 to those in neighbourhoods with the lowest after adjusting for pregnancy year (RR: 1.11,  
240 95% CI: 1.06, 1.16, **Table 3**). Full adjustment for age, demographics, pregnancy-related  
241 variables, and rurality had minimal effect on the association between material deprivation  
242 and SMM rates (adjusted RR: 1.16, 95% CI: 1.11, 1.21, **Table 3**). The association between age  
243 and SMM persisted in the fully adjusted model, with higher risk for women  $< 20$  and  $\geq 30$   
244 years of age. We did not find evidence of statistical interaction between maternal age and  
245 neighbourhood material deprivation quintile.

## 246 **DISCUSSION**

### 247 **Main findings**

248 This study demonstrated an association between neighbourhood material deprivation and  
249 severe maternal morbidity among primiparous women in Ontario from 2002-2018. Rates of  
250 SMM increased across all material deprivation quintiles, and we found some evidence that  
251 women in the highest deprivation quintile experienced a higher magnitude SMM rate  
252 increase over the 16-year study period compared with women in the lowest deprivation  
253 quintile. This finding suggests a possible widening of the gap between women living in the  
254 most and least deprived neighbourhoods.

### 255 **Strengths/ limitations**

256 The current study was a population-based analysis of all primiparous hospital births at  $\geq 20$   
257 weeks' gestational age in Ontario. Hospital births account for over 98% of births in the  
258 province. We used a measure of neighbourhood marginalization that includes income along  
259 with other measures of material resources, and that is stable across time and different  
260 health outcomes.[23, 25] Our study nonetheless had some limitations. We were unable to  
261 account for births prior to 20 weeks' gestation or births that occurred outside of the  
262 province. Our measure of SMM was based on validated perinatal health data for  
263 Canada.[15, 21] A revision of the Canadian SMM composite was recently developed which  
264 resolves issues surrounding the inclusion of some pre-eclampsia and HELLP syndrome  
265 measures, as well as the exclusion of HIV infection—a condition that is unlikely to represent  
266 SMM when asymptomatic [12, 31]. We elected to use the former SMM composite for  
267 comparison with previous literature, recognizing this may complicate direct comparison

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3 268 with recent Canadian studies [4, 6, 12, 31]. The proportion of women with SMM defined by  
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5 269 HIV disease was around 2 percent for each of the 4-year cohorts, and thus we do not believe  
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8 270 these cases substantively altered the results of this study. Information on immigrants  
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10 271 arriving prior to 1985 is not captured in the IRCC Permanent Resident Database, and the  
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12 272 database does not identify immigrants who landed in other provinces and subsequently  
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14 273 moved to Ontario. Although we used a measure of neighbourhood material deprivation  
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16 274 developed for Ontario using Canadian Census elements,[28] the ON-MARG index does not  
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18 275 include individual-level indicators of marginalization or socioeconomic status. Important  
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20 276 social determinants may differ among individuals living in areas characterized by similar  
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22 277 measures of neighbourhood deprivation, and it is not possible to elucidate the causal  
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24 278 pathways that link social disadvantage to poor health outcomes without incorporating such  
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26 279 factors.[32, 33] Finally, pre-pregnancy co-morbidities, obesity, and the use of assisted  
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28 280 reproductive technology, contribute to higher SMM rates and may partially explain SMM  
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30 281 trends.[8, 9, 34] We were unable to account for these factors. Obstetric comorbidity indices  
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32 282 have been developed for risk prediction and adjustment in clinical research. [35, 36] We did  
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34 283 not use an obstetric comorbidity index in our adjusted analysis as some index indicators  
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36 284 represent SMM outcomes themselves, or are mediators of SMM outcomes. In addition, our  
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38 285 aim was to examine population SMM trends rather than individual clinical risk factors.  
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## 48 286 **Interpretation**

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51 287 The present study contributes to our understanding of the association between  
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53 288 neighbourhood marginalization and SMM and provides preliminary evidence of a possible  
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55 289 widening of this health disparity over time in Ontario. The association between  
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57 290 neighbourhood-level measures of inequality and risk of SMM has been demonstrated  
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3 291 previously in several high-income countries.[6, 9, 11, 13, 37-41] Notably in Canada, Aoyama  
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6 292 and colleagues reported a rise in SMM linked to the relative increase in maternal age and  
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8 293 found a significant association between SMM and neighbourhood income quintile.[4]. Our  
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10 294 study confirms this finding using a measure that encompasses income along with additional  
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13 295 measures of neighbourhood material deprivation. Moreover, we extend the current  
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15 296 understanding of this association by providing evidence for a possible disproportionate rise  
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18 297 in SMM risk experienced by women living in marginalized neighbourhoods over time. We  
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20 298 interpret this last finding with caution, as our study showed significant rate differences by  
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23 299 neighbourhood marginalization only during the first and final 4-year cohorts of the 16-year  
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25 300 study period. SMM risks have been demonstrated among other social determinants of  
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28 301 health; for example, lower occupational class, Black ethnicity,[10] and non-private health  
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30 302 insurance[11] are associated with higher risk of SMM in the US. Interaction between  
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33 303 socioeconomic indicators—including ethnicity, education, and poverty—likely contribute to  
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35 304 the social gradient of risk such that the protective effects afforded by higher education and  
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38 305 income do not fully ameliorate racial disparities in SMM.[38] Our study showed an  
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40 306 association between neighbourhood deprivation and SMM suggesting the effects of  
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43 307 marginalization persist even in the context of universal healthcare. This is a consistent  
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45 308 finding across countries that have similar publicly funded healthcare systems.[41-43] The  
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47 309 factors contributing to social inequality are myriad; ethnicity and country of origin, rurality  
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50 310 and access to care, income, material resources, education, and psychosocial supports all  
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52 311 have worrisome associations with maternal reproductive health risks.[6, 10-12, 38, 41-47]  
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54 312 How these factors contribute to widening health gaps, and what interventions may  
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3 313 attenuate their effects will be imperative lines of inquiry going forward as the global  
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6 314 challenge to lower SMM continues.  
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9 315 **Conclusion**

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12 316 Ontario women living in areas with higher neighbourhood material deprivation experienced  
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15 317 the highest risk of SMM, and this association was not fully explained by maternal age.  
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17 318 Additionally, women living in high-deprivation neighbourhoods may have experienced a  
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19 319 disproportionate increase in the risk of SMM over time. Future work must focus on  
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22 320 addressing the widening social gap in maternal health disparities.  
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332 **TABLES**333 **Table 1.** Baseline characteristics of the study population, 2002-2018. N=1,048,845 births.

| Variable                        | Number of births | Percent | Number of SMM cases | SMM rate per 1,000 births |
|---------------------------------|------------------|---------|---------------------|---------------------------|
| Overall study population        | 1,048,845        | 100     | 18,880              | 18.00                     |
| Maternal age at birth, years    |                  |         |                     |                           |
| 10-14                           | 1,330            | 0.1     | 35                  | 26.32                     |
| 15-19                           | 72,579           | 6.9     | 1,291               | 17.79                     |
| 20-24                           | 178,074          | 17.0    | 2,684               | 15.07                     |
| 25-29                           | 342,003          | 32.6    | 5,324               | 15.57                     |
| 30-34                           | 305,898          | 29.2    | 5,653               | 18.48                     |
| 35-39                           | 123,698          | 11.8    | 3,017               | 24.39                     |
| ≥40                             | 25,263           | 2.4     | 876                 | 34.68                     |
| Gestational age at birth, weeks |                  |         |                     |                           |
| 20-23                           | 2,751            | 0.3     | 147                 | 53.44                     |
| 24-27                           | 4,158            | 0.4     | 306                 | 73.59                     |
| 28-33                           | 17,688           | 1.7     | 1,104               | 62.42                     |
| 34-36                           | 59,040           | 5.6     | 1,966               | 33.30                     |
| 37-41                           | 961,322          | 91.7    | 15,278              | 15.89                     |
| ≥42                             | 3,886            | 0.4     | 79                  | 20.33                     |
| Induced labour                  | 275,262          | 26.2    | 5,836               | 21.20                     |
| Epidural                        | 655,107          | 62.5    | 10,713              | 16.35                     |
| Delivery mode                   |                  |         |                     |                           |
| Vaginal unassisted              | 579,814          | 55.3    | 6,386               | 11.01                     |
| Vaginal assisted                | 156,383          | 14.9    | 2,724               | 17.42                     |
| Vaginal breech                  | 2,328            | 0.2     | 95                  | 40.81                     |
| Caesarean                       | 310,320          | 29.6    | 9,675               | 31.18                     |
| Multiple gestations             | 20,850           | 2.0     | 1,137               | 54.53                     |
| Stillbirth                      | 3,645            | 0.3     | 199                 | 54.60                     |
| Rurality                        |                  |         |                     |                           |
| Urban                           | 993,282          | 94.7    | 17,814              | 17.93                     |
| Rural                           | 55,563           | 5.3     | 1,066               | 19.19                     |
| Immigration Status              |                  |         |                     |                           |
| Non-immigrant / before 1985     | 739,252          | 70.5    | 13,222              | 17.89                     |
| Immigrated >10 years            | 62,381           | 5.9     | 1,165               | 18.68                     |
| Immigrated 5-10 years           | 62,090           | 5.9     | 1,249               | 20.12                     |
| Immigrated <5 years             | 185,122          | 17.7    | 3,244               | 17.52                     |
| Neighbourhood marginalization   |                  |         |                     |                           |
| Material deprivation            |                  |         |                     |                           |
| Quintile 1 (least deprived)     | 237,877          | 22.7    | 4,183               | 17.58                     |
| Quintile 2                      | 186,550          | 17.8    | 3,112               | 16.68                     |
| Quintile 3                      | 189,575          | 18.1    | 3,327               | 17.55                     |

|                            |         |      |       |       |
|----------------------------|---------|------|-------|-------|
| Quintile 4                 | 191,376 | 18.2 | 3,423 | 17.89 |
| Quintile 5 (most deprived) | 226,337 | 21.6 | 4,397 | 19.43 |
| Missing                    | 17,130  | 1.6  | 438   | 25.57 |

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336 **Table 2.** Four-year average SMM rates per 1,000 births for neighbourhood material  
 337 deprivation quintiles, by pooled sample (2002-2018) and by study period cohort.

| Cohort <sup>a</sup> | <i>SMM rates by material deprivation quintile</i> |       |       |       |              | <i>Q5 vs Q1</i>                  |                                  |
|---------------------|---|-------|-------|-------|--------------|----------------------------------|----------------------------------|
|                     | Q1<br>(least)                                     | Q2    | Q3    | Q4    | Q5<br>(most) | Rate difference (95%<br>CI)      | Rate ratio (95% CI)              |
| Pooled              | 17.58   | 16.68 | 17.55 | 17.89 | 19.43        | 1.84 (1.82,1.87) <sup>***</sup>  | 1.10 (1.10-1.11) <sup>***</sup>  |
| 1                   | 16.05   | 16.36 | 17.46 | 16.49 | 18.14        | 2.09 (0.62, 3.56) <sup>**</sup>  | 1.13 (1.04, 1.23) <sup>**</sup>  |
| 2                   | 16.58   | 15.97 | 15.73 | 16.37 | 17.32        | 0.75 (-0.70, 2.20)               | 1.05 (0.96, 1.14)                |
| 3                   | 19.36   | 16.17 | 18.34 | 19.19 | 20.78        | 1.41 (-0.20, 3.02)               | 1.07 (0.99, 1.16)                |
| 4                   | 18.41   | 18.52 | 18.99 | 20.18 | 22.32        | 3.91 (2.12, 5.70) <sup>***</sup> | 1.21 (1.11, 1.32) <sup>***</sup> |

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339 <sup>a</sup>cohort 1: 1 April 2002 to 31 March 2006; cohort 2: 1 April 2006 to 31 March 2010; cohort 3:  
 340 1 April 2010 to 31 March 2014; cohort 4: 1 April 2014 to 31 March 2018

341 \*p<0.05, \*\*p<0.01, \*\*\*p<0.001

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346 **Table 3.** Neighbourhood material deprivation and risk of SMM: Adjusted multivariable  
 347 models, RR (95% CI). N=1,031,715 births.

| Variable             | Model 1 <sup>a</sup> | Model 2 <sup>b</sup> | Model <sup>c</sup> |
|----------------------|----------------------|----------------------|--------------------|
| Maternal age (years) |                      |                      |                    |
| <20                  |                      | 1.05 (0.99, 1.12)    | 1.20 (1.13, 1.28)  |
| 20-24                |                      | 0.95 (0.90, 0.99)    | 1.01 (0.96, 1.06)  |
| 25-29                |                      | 1 (ref)              | 1 (ref)            |
| 30-34                |                      | 1.19 (1.14, 1.23)    | 1.10 (1.06, 1.15)  |
| 35-39                |                      | 1.56 (1.49, 1.63)    | 1.34 (1.28, 1.40)  |
| ≥40                  |                      | 2.21 (2.06, 2.37)    | 1.73 (1.61, 1.86)  |
| Material deprivation |                      |                      |                    |
| Quintile 1 (least)   | 1 (ref)              | 1 (ref)              | 1 (ref)            |
| Quintile 2           | 0.95 (0.91, 0.99)    | 0.97 (0.93, 1.02)    | 0.97 (0.92, 1.01)  |
| Quintile 3           | 1.00 (0.96, 1.05)    | 1.04 (0.99, 1.08)    | 1.03 (0.98, 1.07)  |
| Quintile 4           | 1.02 (0.98, 1.07)    | 1.07 (1.02, 1.12)    | 1.06 (1.01, 1.11)  |
| Quintile 5 (most)    | 1.11 (1.06, 1.16)    | 1.17 (1.12, 1.22)    | 1.16 (1.11, 1.21)  |

<sup>a</sup>adjusted for pregnancy year

<sup>b</sup>adjusted for pregnancy year, age

<sup>c</sup>adjusted for pregnancy year, age, delivery mode, multiple gestations, immigration status, rurality

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3 357 **FIGURE CAPTIONS**  
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6 358 **Figure 1.** Study inclusion / exclusion flow chart, primiparous births.  
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13 360 **SUPPLEMENTARY MATERIAL CAPTIONS**  
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16 361 **Supplementary Appendix 1.** Data sources for the project.  
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19 362 **Supplementary Figure 1.** Annual crude SMM rate per 1,000 births, 2002-2018.  
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23 363 **Supplementary Figure 2.** Average annual SMM rates per 1,000 births by maternal age.  
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26 364 **Supplementary Table 1.** Four-year average SMM rates per 1,000 births by age and by  
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29 365 material deprivation, and rate change over study period.  
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15 379 **Declaration of competing interests**  
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18 380 The authors declare no conflicts of interest.  
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21 381 **Author contributions**  
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23  
24 382 JWS, DF, KEM, and LCR contributed to the overall conception of the study. JWS, ML, LR, DF,  
25  
26  
27 383 and LCR contributed to study design and protocol. TW had full access to data used in the  
28  
29 384 study. JWS, TW, and LCR take responsibility for the integrity of the data analysis. JWS wrote  
30  
31 385 the manuscript. All authors made substantial contributions to the data analysis  
32  
33 386 interpretation, and manuscript editing and revising for this project. All authors approve the  
34  
35 387 final submitted version and agree to be accountable for all aspects of the work.  
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40 388 **Ethical approval**  
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43 389 ICES is a prescribed entity under section 45 of Ontario's Personal Health Information  
44  
45 390 Protection Act. Section 45 authorizes ICES to collect personal health information, without  
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47 391 consent, for the purpose of analysis or compiling statistical information with respect to the  
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49 392 management of, evaluation or monitoring of, the allocation of resources to or planning for  
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51 393 all or part of the health system. Projects conducted under section 45, by definition, do not  
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53 394 require review by a Research Ethics Board. This project was conducted under section 45,  
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55 395 and approved by ICES' Privacy and Legal Office.  
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3 396 **Patient consent for publication**  
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6 397 None required.  
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10 398 **Data availability statement**  
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13 399 The dataset from this study is held securely in coded form at ICES. While data sharing  
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15 400 agreements prohibit ICES from making the dataset publicly available, access may be granted  
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17 401 to those who meet pre-specified criteria for confidential access, available at  
18  
19 402 [www.ices.on.ca/DAS](http://www.ices.on.ca/DAS). The full dataset creation plan and underlying analytic code are  
20  
21 403 available from the authors upon request, understanding that the computer programs may  
22  
23 404 rely upon coding templates or macros that are unique to ICES and are therefore either  
24  
25 405 inaccessible or may require modification.  
26  
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54 417 (IRCC). The analyses, conclusions, opinions and statements expressed herein are solely  
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3 418 those of the authors and do not reflect those of the funding or data sources; no  
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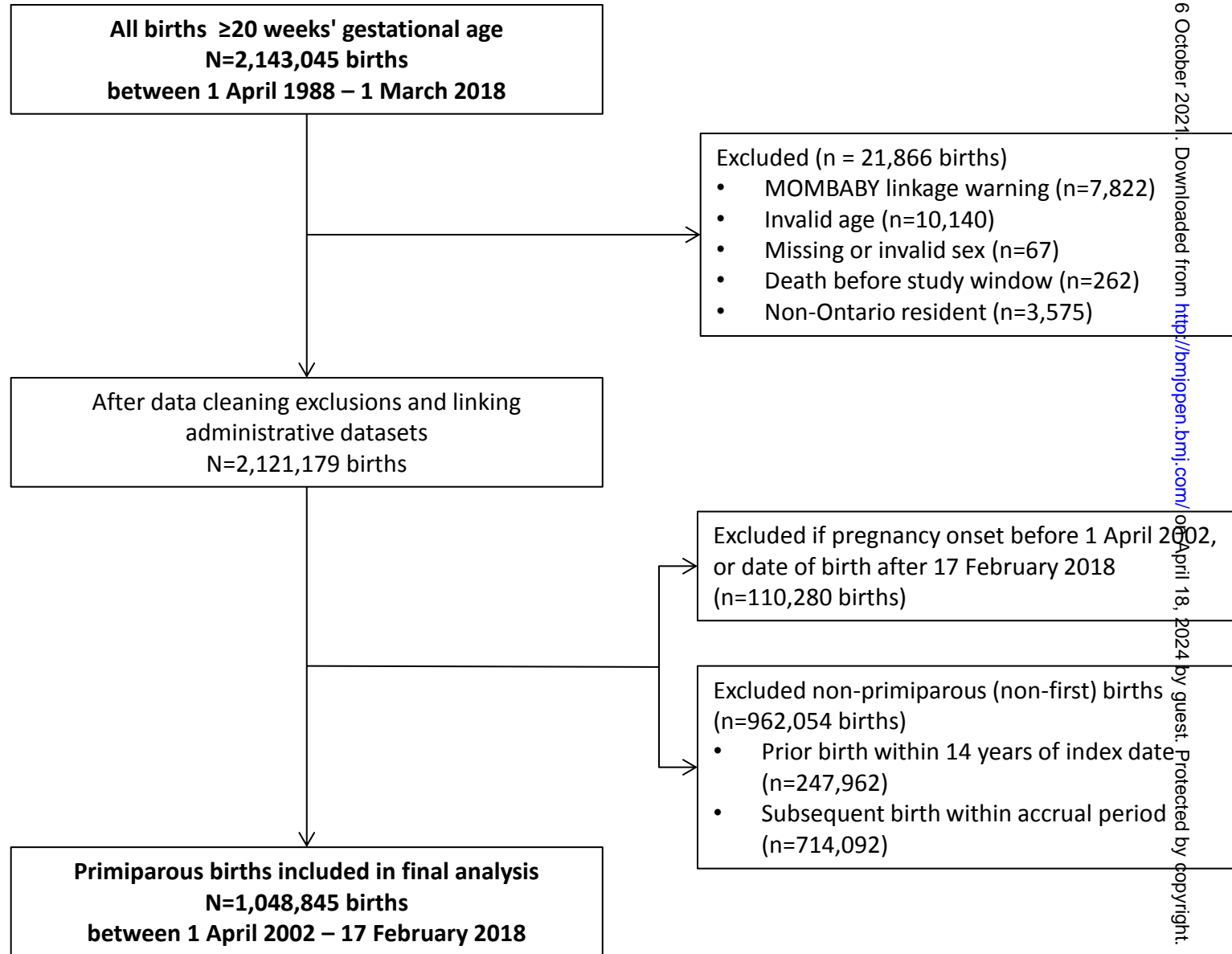
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**Figure 1.** Study inclusion / exclusion flow chart, primiparous births.



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## Supplementary Appendix 1. Data sources for project

### Discharge Abstract Database (DAD)

The DAD is compiled by the Canadian Institute for Health Information and contains administrative, clinical (diagnoses and procedures/interventions), demographic, and administrative information for all admissions to acute care hospitals, rehab, chronic, and day surgery institutions in Ontario. At ICES, consecutive DAD records are linked together to form 'episodes of care' among the hospitals to which patients have been transferred after their initial admission.

### MOMBABY

The ICES MOMBABY Database is an ICES-derived cohort that links the DAD inpatient admission records of delivering mothers and their newborns. From 2002 onward, this linkage is performed deterministically using a maternal-newborn chart matching number. Prior to 2002, mothers were linked to their children by matching on the institutions they were admitted, their postal codes, and their admission/discharge dates.

### Registered Persons Database (RPDB)

The RPDB provides basic demographic information (age, sex, location of residence, date of birth, and date of death for deceased individuals) for those issued an Ontario health insurance number. The RPDB also indicates the time periods for which an individual was eligible to receive publicly funded health insurance benefits and the best known

### Ontario Health Insurance Plan (OHIP)

The OHIP claims database contains information on inpatient and outpatient services provided to Ontario residents eligible for the province's publicly funded health insurance system by fee-for-service health care practitioners (primarily physicians) and "shadow billings" for those paid through non-fee-for-service payment plans. The main data elements include patient and physician identifiers (encrypted), code for service provided, date of service, associated diagnosis, and fee paid.

### Immigration, Refugees, and Citizenship Canada's (IRCC) Permanent Resident Database

The Ontario portion of the IRCC Permanent Resident Database includes immigration application records for people who initially applied to land in Ontario since 1985. The dataset contains permanent residents' demographic information such as country of citizenship, level of education, mother tongue, and landing date. New immigrants who are currently residing in Ontario but originally landed in another province are not captured in this dataset.

### Ontario Marginalization Index (ONMARG)

ONMARG is a geographically (census) based index developed to quantify the degree of marginalization occurring across the province of Ontario. It is comprised of four major dimensions thought to underlie the construct of marginalization: residential instability, material deprivation, dependency, and ethnic concentration. The dataset contains census divisions (CD), census tracts (CT), census subdivisions (CSD), consolidated municipal service manager areas (CMSM), public health units (PHU), local health integration networks (LHIN), sub-LHINs, and dissemination areas (DA).

These datasets were linked using unique encoded identifiers and analyzed at ICES.

The dataset from this study is held securely in coded form at ICES. While data sharing agreements prohibit ICES from making the dataset publicly available, access may be granted to those who meet pre-specified criteria for confidential access, available at [www.ices.on.ca/DAS](http://www.ices.on.ca/DAS). The full dataset creation plan and underlying analytic code are available from the authors upon request, understanding that the computer programs may rely upon coding templates or macros that are unique to ICES and are therefore either inaccessible or may require modification.



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**Inclusion/Exclusion Criteria**

| Concept  | Data Sources | Code Type  | Window                                     | Notes<br>(including Dataset references)   |
|--|--------------|--|--|---|
| <i>Inclusion Criteria</i>  |              |  |  |   |
| Hospital birth (live or stillbirth) at gestational age $\geq 20$ weeks | DAD, MOMBABY | ICD-10 main patient service code for "Obstetrical birth" | Accrual window: 1 April 2002 – 17 Feb 2018 | Canadian Institute for Health Information Discharge Abstract Database (DAD, linked to newborn record in MOMBABY dataset)<br>See:<br><a href="https://datadictionary.ices.on.ca/Applications/DataDictionary/Library.aspx?Library=MOMBABY">https://datadictionary.ices.on.ca/Applications/DataDictionary/Library.aspx?Library=MOMBABY</a> |
| <i>Exclusion Criteria</i>  |              |  |  |   |
| Missing or invalid IKN   | RPDB         |  | Index date                                 | Registered Persons Database<br>See:<br><a href="https://datadictionary.ices.on.ca/Applications/DataDictionary/Library.aspx?Library=RPDB">https://datadictionary.ices.on.ca/Applications/DataDictionary/Library.aspx?Library=RPDB</a>  |
| MOMBABY linkage warning  | MOMBABY      |  | Index date                                 |   |
| Missing or invalid age (<10 or >55)                                    | RPDB         |  | Index date                                 |   |
| Missing or invalid sex   | RPDB         |  | Index date                                 |   |
| Death before the index date  | RPDB         |  | Index date                                 |   |
| Non-Ontario residents / invalid OHIP number                            | RPDB         |  | Index date                                 |   |
| Any births with an index date occurring outside of the accrual period  | MOMBABY      |  | Accrual window                             | Pregnancy onset before 1 April 2002   |
| Any births occurring after accrual end date                            | MOMBABY      |  | Accrual window                             | Births after 17 February 2018   |
| Not first birth  | MOMBABY      |  | 14 years prior to index date               | Prior record in MOMBABY within past 14 years of index date  |
| Not first birth in accrual period                                      | MOMBABY      |  | Accrual window                             | Subsequent records in MOMBABY   |



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**Outcome**

| Concept                         | Data Sources | Code Type     | Window   | Notes<br>(including Dataset references)  |
|---------------------------------|--------------|---------------|--|--|
| Severe maternal morbidity (SMM) | DAD          | ICD 10<br>CCI | Start of lookback period ("pregnancy onset" = index date – gestational age at birth) to end of observation window (42 days following index date) | <p>Patient considered to have outcome IF ANY code in ANY of the following:</p> <ol style="list-style-type: none"> <li>1) Obstetric/ ill-defined or sudden death</li> <li>2) Hypertensive heart/renal disease</li> <li>3) Eclampsia</li> <li>4) Cerebral venous thrombosis</li> <li>5) Complications of anaesthesia – non-cardiac</li> <li>6) Complications of anaesthesia – cardiac</li> <li>7) Cardiac diseases (cardiac arrest, infarction, failure, pulmonary edema)</li> <li>8) Placental abruption c/ coagulation defect</li> <li>9) Antepartum hemorrhage c/ coagulation defect</li> <li>10) Intrapartum hemorrhage c/ coagulation defect</li> <li>11) Uterine rupture – before labour</li> <li>12) Uterine rupture – during labour</li> <li>13) Obstetric shock (including septic shock)</li> <li>14) Septecemia during labour</li> <li>15) Puerperal sepsis</li> <li>16) Pulmonary embolism</li> <li>17) Obstetric embolism</li> <li>18) Cardiomyopathy</li> <li>19) Acute renal failure</li> <li>20) HIV disease</li> <li>21) Cerebrovascular disease</li> <li>22) Acute respiratory distress syndrome</li> <li>23) Acute abdomen</li> <li>24) Hepatic failure</li> <li>25) Acute psychosis</li> <li>26) Cerebral edema, coma</li> <li>27) Disseminated intravascular coagulation</li> <li>28) Sickle cell anemia crisis</li> <li>29) Status asthmaticus</li> <li>30) Status epilepticus</li> <li>31) Assisted ventilation (endotracheal tube or tracheostomy)</li> <li>32) Caesarean hysterectomy</li> <li>33) Postpartum hysterectomy</li> <li>34) Dialysis</li> <li>35) Evacuation of incisional hematoma</li> <li>36) Surgical repair of bladder, urethra, intestine</li> <li>37) Intrapartum hemorrhage with no coagulation defect AND blood transfusion</li> <li>38) Postpartum hemorrhage AND blood</li> </ol> |

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|  |  |  |  | transfusion<br>39) Placenta previa AND blood transfusion<br>40) Embolization/ ligation/ suturing AND postpartum hemorrhage<br><br>See:<br>Joseph KS et al, 2009, <sup>1</sup> Joseph KS et al, 2010, <sup>2</sup> ICD-10CA, 2009, <sup>3</sup> and CCHI, 2012. <sup>4</sup> |
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**Study exposures, covariates**

| Concept                    | Data Sources   | Code Type                 | Window                       | Notes (including Dataset references)  |
|----------------------------|----------------|---------------------------|------------------------------|---|
| Age                        | RPDB           |                           | Index date                   |   |
| Index year                 | DAD            |                           | Index date                   |   |
| Material deprivation index | ONMARG         |                           | Index date                   | Ontario Marginalization Index, Material Deprivation, in quintiles.<br><br>Use version of ONMARG closest to year of index date:<br>2001 for 2002-2003<br>2006 for 2004-2018<br>See:<br><a href="https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=ONMARG">https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=ONMARG</a> |
| Income quintile            | RPDB<br>Census |                           | Index date                   | Ontario Census area profile: income quintile.<br><br>Use Census closest to year of index date:<br>2001 for 2002-2003<br>2006 for 2004-2018<br>See:<br><a href="https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=CENSUS">https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=CENSUS</a>                                 |
| Rurality                   | RPDB           |                           | Index date                   | Rurality Index for Ontario (RIO).<br>Use version of RIO closest to year of index date:<br>RIO2004 for 2002-2006<br>RIO2008 for 2007-2018  |
| Gestational age at birth   | MOMBABY        |                           | Index date                   |   |
| Induction of labour        | DAD            | CCI code                  | Within index hospitalization | Canadian Classification of Health Interventions (CCI)   |
| Epidural                   | DAD<br>OHIP    | CCI code<br>OHIP fee code | Within index hospitalization | Canadian Classification of Health Interventions (CCI); Ontario Health Insurance Plan Claims Database (OHIP)   |
| Delivery mode              | DAD            | CCI code                  | Within index hospitalization |   |
| Multiple gestations        | MOMBABY        |                           | Within index hospitalization |   |
| Stillbirth                 | MOMBABY        |                           | Within index hospitalization |   |
| Immigration status         | IRCC           |                           | Index date                   | Immigration, Refugees and Citizenship   |

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|--|--|--|--|---|
|  |  |  |  | Canada (IRCC)'s Permanent Resident Database<br><br>Number of years since arrived in Ontario.<br>See:<br><a href="https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=CIC">https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=CIC</a> |
|--|--|--|--|---|

**References**

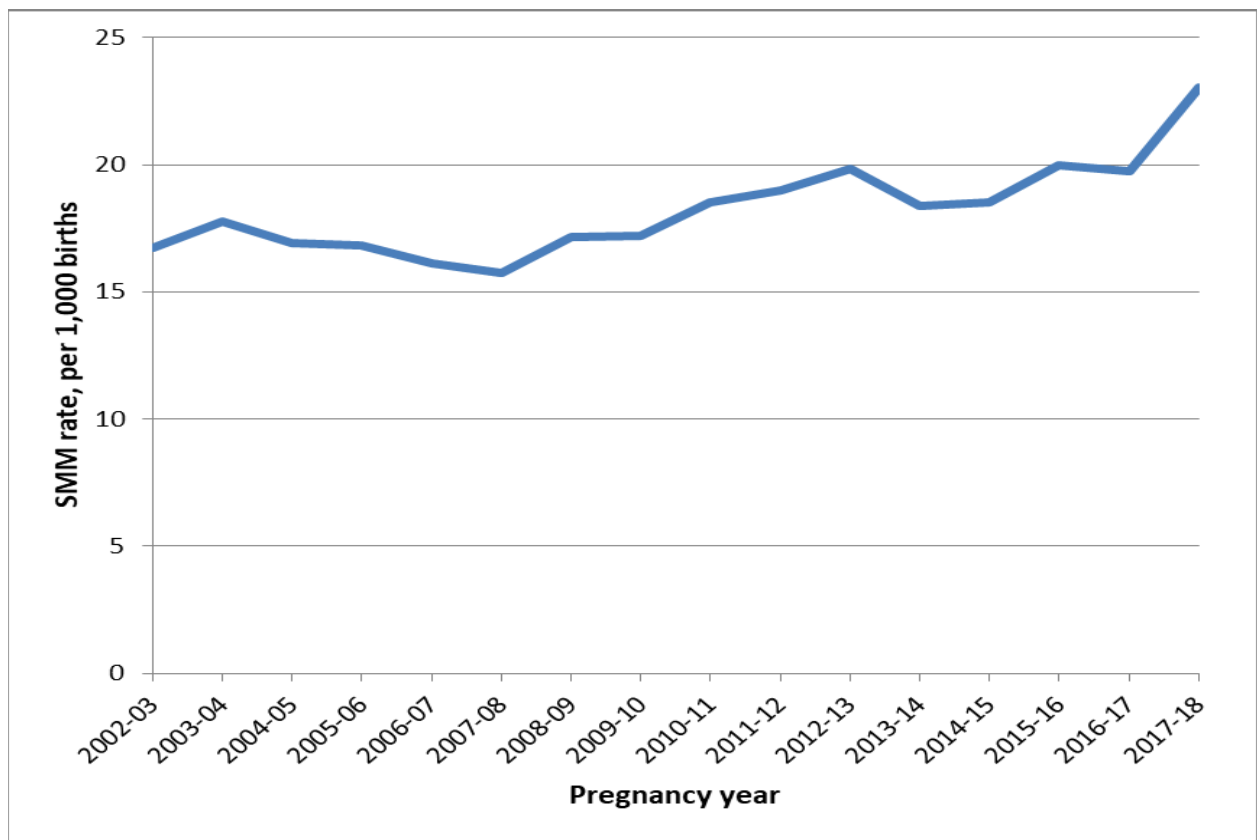
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2. Joseph KS, Liu S, Rouleau J, et al. Severe maternal morbidity in Canada, 2003 to 2007: surveillance using routine hospitalization data and ICD-10CA codes. *Journal of Obstetrics & Gynaecology Canada: JOGC*. 2010;32:837-46.
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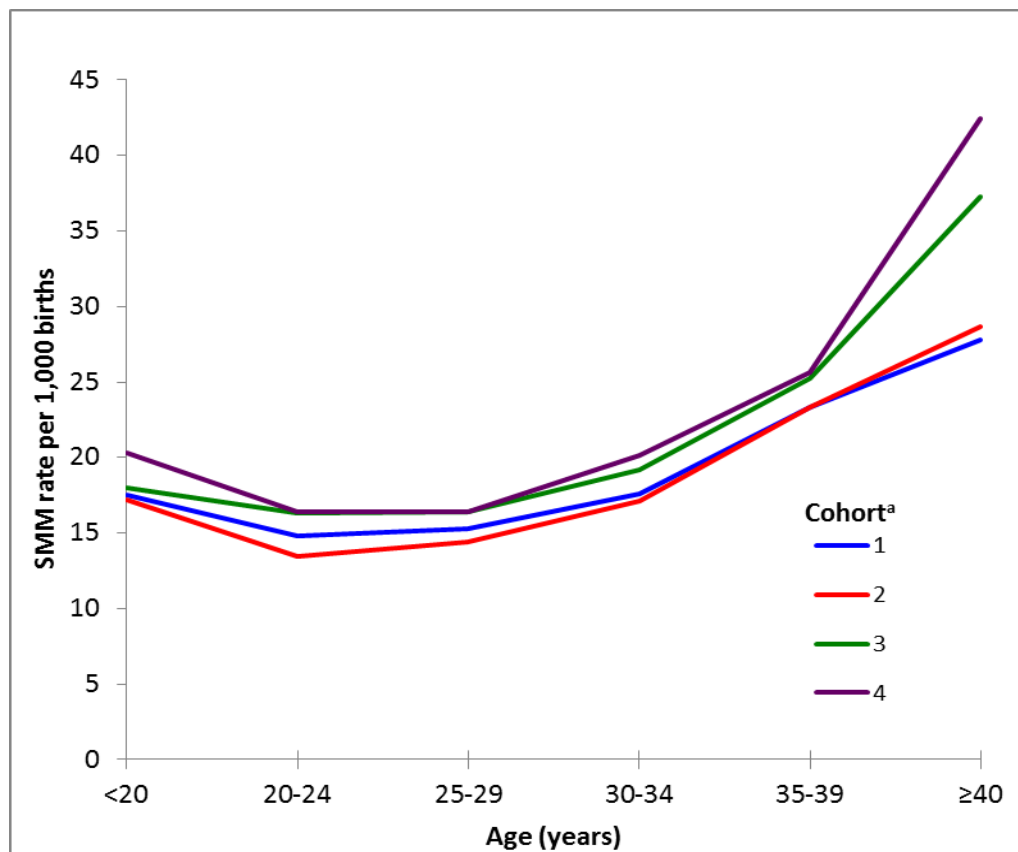
Supplementary Figure 1. Annual crude SMM rate per 1,000 births, 2002-2018.



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Supplementary Figure 2. Average annual SMM rates per 1,000 births by maternal age.



<sup>a</sup>cohort 1: 1 April 2002 to 31 March 2006; cohort 2: 1 April 2006 to 31 March 2010; cohort 3: 1 April 2010 to 31 March 2014; cohort 4: 1 April 2014 to 31 March 2018

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**Supplementary table 1. Four-year average SMM rates per 1,000 births by age and by material deprivation, and rate change over study period.**

| Variable                    | SMM rates by cohort <sup>a</sup> |       |       |       | SMM rate change, cohort 4 vs 1 <sup>a</sup> |                      |
|-----------------------------|----------------------------------|-------|-------|-------|---|----------------------|
|                             | 1                                | 2     | 3     | 4     | Rate difference (95% CI)                    | Rate ratio (95% CI)  |
| Overall study population    | 17.10                            | 16.55 | 18.94 | 19.82 | 2.72 (1.96, 3.49)***                        | 1.16 (1.11, 1.21)*** |
| <i>Maternal age (years)</i> |                                  |       |       |       |   |                      |
| <20                         | 17.54                            | 17.22 | 17.97 | 20.34 | 2.80 (-0.43, 6.04)                          | 1.15 (0.98, 1.37)    |
| 20-24                       | 14.80                            | 13.47 | 16.32 | 16.40 | 1.60 (-0.15, 3.35)                          | 1.11 (0.99, 1.24)    |
| 25-29                       | 15.26                            | 14.40 | 16.37 | 16.42 | 1.15 (-0.77, 2.39)                          | 1.08 (0.99, 1.16)    |
| 30-34                       | 17.58                            | 17.10 | 19.21 | 20.16 | 2.58 (1.18, 3.97)*                          | 1.15 (1.06, 1.23)*   |
| 35-39                       | 23.31                            | 23.35 | 25.23 | 25.67 | 2.36 (-0.16, 4.88)                          | 1.10 (0.99, 1.22)    |
| ≥40                         | 27.78                            | 28.68 | 37.30 | 42.48 | 14.69 (7.96, 21.43)*                        | 1.53 (1.24, 1.89)*   |
| <i>Material deprivation</i> |                                  |       |       |       |   |                      |
| Quintile 1 (least)          | 16.05                            | 16.58 | 19.36 | 18.41 | 2.36 (2.31, 2.41)***                        | 1.15 (1.14, 1.15)*** |
| Quintile 2                  | 16.36                            | 15.97 | 16.17 | 18.52 | 2.16 (2.11, 2.22)***                        | 1.13 (1.13, 1.14)*** |
| Quintile 3                  | 17.46                            | 15.73 | 18.34 | 18.99 | 1.54 (1.48, 1.59)***                        | 1.09 (1.08, 1.09)*** |
| Quintile 4                  | 16.49                            | 16.37 | 19.19 | 20.18 | 3.69 (3.63, 3.74)***                        | 1.22 (1.22, 1.23)*** |
| Quintile 5 (most)           | 18.14                            | 17.32 | 20.78 | 22.32 | 4.19 (4.13, 4.24)***                        | 1.23 (1.22, 1.23)*** |

<sup>a</sup>cohort 1: 1 April 2002 to 31 March 2006; cohort 2: 1 April 2006 to 31 March 2010; cohort 3: 1 April 2010 to 31 March 2014; cohort 4: 1 April 2014 to 31 March 2018

\*p<0.05, \*\*p<0.01, \*\*\*p<0.001

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The RECORD statement – checklist of items that should be reported in observational studies using routinely collected health data.

|                           | Item No. | STROBE items   | Location in manuscript where items are reported                          | RECORD items  | Location in manuscript where items are reported |
|---------------------------|----------|--|--|---|---|
| <b>Title and abstract</b> |          |  |  |   |   |
|                           | 1        | (a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found | Title page (p.1)   | RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included.<br><br>RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract.<br><br>RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract. | Title page, abstract (p. 1-3)                   |
| <b>Introduction</b>       |          |  |  |   |   |
| Background rationale      | 2        | Explain the scientific background and rationale for the investigation being reported   | Background p.4-5   |   |   |
| Objectives                | 3        | State specific objectives, including any prespecified hypotheses   | Background p.4-5   |   |   |
| <b>Methods</b>            |          |  |  |   |   |
| Study Design              | 4        | Present key elements of study design early in the paper  | Methods p.5-9  |   |   |
| Setting                   | 5        | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection  | Methods: <i>Study population and data sources, Main outcome</i> , p. 5-6 |   |   |



Snelgrove JW et al. *Neighbourhood material deprivation and severe maternal morbidity: A population-based cohort study in Ontario, Canada*

|                              |   |  |   |  |  |
|------------------------------|---|--|---|--|--|
| Participants                 | 6 | <p>(a) <i>Cohort study</i> - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up</p> <p><i>Case-control study</i> - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls</p> <p><i>Cross-sectional study</i> - Give the eligibility criteria, and the sources and methods of selection of participants</p> <p>(b) <i>Cohort study</i> - For matched studies, give matching criteria and number of exposed and unexposed</p> <p><i>Case-control study</i> - For matched studies, give matching criteria and the number of controls per case</p> | <p>Cohort study, no matching:</p> <p>Methods: <i>Study population and data sources, Main outcome, Exposures and covariates</i> p. 5-8; Appendix 1</p> | <p>RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided.</p> <p>RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided.</p> <p>RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.</p> | <p>Methods: <i>Study population and data sources, Main outcome, Exposures and covariates</i> p. 5-8<br/>Supplementary Appendix 1</p> |
| Variables                    | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.  | <p>Methods: <i>Study population and data sources, Main outcome, Exposures and covariates</i> p. 5-8; Supplementary Appendix 1</p>                     | <p>RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.</p>   | <p>Methods: <i>Study population and data sources, Main outcome, Exposures and covariates</i> p. 5-8<br/>Supplementary Appendix 1</p> |
| Data sources/<br>measurement | 8 | For each variable of interest, give sources of data and details of methods of assessment (measurement).  | <p>Methods: <i>Study population and data sources, Main outcome, Exposures</i></p>   |  |  |

Snelgrove JW et al. **Neighbourhood material deprivation and severe maternal morbidity: A population-based cohort study in Ontario, Canada**

|                        |    |   |  |  |  |
|------------------------|----|---|--|--|--|
|                        |    | Describe comparability of assessment methods if there is more than one group  | <i>and covariates</i> p. 5-8; Supplementary Appendix 1   |  |  |
| Bias                   | 9  | Describe any efforts to address potential sources of bias   | Methods: <i>Exposures and covariates</i> p. 7-8; Interpretation: <i>Strengths/ limitations</i> p.11-12 |  |  |
| Study size             | 10 | Explain how the study size was arrived at   | Methods: <i>Study population and data sources</i> , p. 5-6; Figure 1                                   |  |  |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why   | Methods: <i>Statistical analysis</i> , p. 8-9  |  |  |
| Statistical methods    | 12 | (a) Describe all statistical methods, including those used to control for confounding<br>(b) Describe any methods used to examine subgroups and interactions<br>(c) Explain how missing data were addressed<br>(d) <i>Cohort study</i> - If applicable, explain how loss to follow-up was addressed<br><i>Case-control study</i> - If applicable, explain how matching of cases and controls was addressed<br><i>Cross-sectional study</i> - If applicable, describe analytical methods taking account of | Methods: <i>Statistical analysis</i> , p. 8-9, Results, p.9-11.  |  |  |

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|                                  |    |  |                                 |  |  |
|----------------------------------|----|--|---------------------------------|--|--|
|                                  |    | sampling strategy<br>(e) Describe any sensitivity analyses   |                                 |  |  |
| Data access and cleaning methods |    | ..   |                                 | RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population.<br><br>RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.   | Methods: <i>Study population and data sources</i> , p. 6; Supplementary Appendix 1; Author contributions, p. 20  |
| Linkage                          |    | ..   |                                 | RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.  | Methods: <i>Study population and data sources</i> , <i>Main outcome</i> , <i>Exposures and covariates</i> p. 5-8<br>Supplementary Appendix 1                               |
| <b>Results</b>                   |    |  |                                 |  |  |
| Participants                     | 13 | (a) Report the numbers of individuals at each stage of the study ( <i>e.g.</i> , numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed)<br>(b) Give reasons for non-participation at each stage.<br>(c) Consider use of a flow diagram | Results p.10; Table 1; Figure 1 | RECORD 13.1: Describe in detail the selection of the persons included in the study ( <i>i.e.</i> , study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram. | Methods: <i>Study population and data sources</i> , <i>Main outcome</i> , <i>Exposures and covariates</i> p. 5-8<br>Results p.10; Table 1; Figure Supplementary Appendix 1 |
| Descriptive data                 | 14 | (a) Give characteristics of study participants ( <i>e.g.</i> , demographic, clinical, social) and information  | Results p.10; Table 1           |  |  |

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|                |    |  |   |  |
|----------------|----|--|---|--|
|                |    | <p>on exposures and potential confounders</p> <p>(b) Indicate the number of participants with missing data for each variable of interest</p> <p>(c) <i>Cohort study</i> - summarise follow-up time (e.g., average and total amount)</p>  |   |  |
| Outcome data   | 15 | <p><i>Cohort study</i> - Report numbers of outcome events or summary measures over time</p> <p><i>Case-control study</i> - Report numbers in each exposure category, or summary measures of exposure</p> <p><i>Cross-sectional study</i> - Report numbers of outcome events or summary measures</p>  | Results p.10; Figure 1; Table 1                 |  |
| Main results   | 16 | <p>(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included</p> <p>(b) Report category boundaries when continuous variables were categorized</p> <p>(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period</p> | Results p.10; Table 1-3; Supplementary Figure 1 |  |
| Other analyses | 17 | Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses  | Results p.10-11                                 |  |

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| Discussion  |    |  |   |  |  |
|---|----|--|---|--|--|
| Key results   | 18 | Summarise key results with reference to study objectives   | Interpretation, <i>Main findings</i> p.11                                       |  |  |
| Limitations   | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias                 | Interpretation, <i>Strengths/limitations</i> p.11-12                            | RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported. | Interpretation, <i>Strengths/limitations</i> p.11-12 |
| Interpretation  | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | Discussion, <i>Main findings</i> p. 11, <i>Strengths / Limitations</i> p. 11-12 |  |  |
| Generalisability  | 21 | Discuss the generalisability (external validity) of the study results  | Discussion, <i>Interpretation</i> p.11-12                                       |  |  |
| Other Information   |    |  |   |  |  |
| Funding   | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based              | Funding, p. 21-22   |  |  |
| Accessibility of protocol, raw data, and programming code |    | ..   |   | RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.   | p. 21; Supplementary Appendix 1                      |

1 Snelgrove JW et al. **Neighbourhood material deprivation and severe maternal morbidity: A population-based cohort study in Ontario, Canada**

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3  
4 \*Reference: Benchimol EI, Smeeth L, Guttman A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langhahn SM, the RECORD Working  
5 Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 201  
6 in press.  
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## Neighbourhood material deprivation and severe maternal morbidity: A population-based cohort study in Ontario, Canada.

|                                 |  |
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|                                 |  |

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1  
2  
3 1 **TITLE PAGE**  
45  
6 2 **Neighbourhood material deprivation and severe maternal morbidity:**  
78 3 **A population-based cohort study in Ontario, Canada**  
910  
11 4  
12  
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3 26 **ABSTRACT**  
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6 27 **Objectives:** Rates of age-associated severe maternal morbidity (SMM) have increased in  
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9 28 Canada, and an association with neighbourhood income is well established. Our aim was to  
10  
11 29 examine SMM trends according to neighbourhood material deprivation quintile, and to  
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13  
14 30 assess whether neighbourhood deprivation effects are moderated by maternal age.  
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16  
17 31 **Design, setting, participants:** A population-based retrospective cohort study using linked  
18  
19 32 administrative databases in Ontario, Canada. We included primiparous women with a live  
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21  
22 33 birth or stillbirth at  $\geq 20$  weeks gestational age.  
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24  
25 34 **Primary outcome:** SMM from pregnancy onset to 42 days postpartum. We calculated SMM  
26  
27 35 rate differences (RD) and rate ratios (RR) by neighbourhood material deprivation quintile for  
28  
29 36 each of four 4-year cohorts from 1 April 2002 to 31 March 2018. Log-binomial multivariable  
30  
31 37 regression adjusted for maternal age, demographic, and pregnancy-related variables.  
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34  
35 38 **Results:** There were 1,048,845 primiparous births during the study period. The overall rate  
36  
37 39 of SMM was 18.0 per 1,000 births. SMM rates were elevated for women living in areas with  
38  
39 40 high material deprivation. In the final 4-year cohort, the RD between women living in high  
40  
41 41 versus low deprivation neighbourhoods was 3.91 SMM cases per 1,000 births (95% CI: 2.12,  
42  
43 42 5.70). This was higher than the difference observed during the first 4-year cohort (RD 2.09,  
44  
45 43 95% CI: 0.62, 3.56). SMM remained associated with neighbourhood material deprivation  
46  
47 44 following multivariable adjustment in the pooled sample (RR 1.16, 95% CI: 1.11, 1.21). There  
48  
49 45 was no evidence of interaction with maternal age.  
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56 46 **Conclusion:** SMM rate increases were more pronounced for primiparous women living in  
57  
58 47 neighbourhoods with high material deprivation compared to those living in low deprivation  
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3 48 areas. This raises concerns of a widening social gap in maternal health disparities and  
4  
5 49 highlights an opportunity to focus risk reduction efforts toward disadvantaged women  
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7  
8 50 during pregnancy and postpartum.  
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11 51

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14 52 **Keywords:** severe maternal morbidity; maternal mortality; maternal health; pregnancy;  
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17 53 perinatal epidemiology; social epidemiology; social inequalities; deprivation  
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21 54

### 22 23 55 **Strengths and Limitations of this Study**

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27 56 • Data were from population linked administrative and health registries that capture  
28  
29 57 all hospital births in Ontario, Canada  
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33 58 • Neighbourhood material deprivation was measured using the Ontario  
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35 59 Marginalization Index, a comprehensive area-level measure based on Census data  
36  
37 60 developed using theoretical frameworks on marginalization and deprivation  
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41 61 • Limiting our study to primiparous women enabled the evaluation of population SMM  
42  
43 62 trends and reduced confounding from previous births  
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47 63 • It was not possible to control for all covariates associated with SMM, including body  
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49 64 mass index, co-morbidities, and the use of assisted reproductive technology  
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## 66 INTRODUCTION

67 Each year, approximately 4,000 Canadian women survive a maternal “near-miss”—a life-  
68 threatening event associated with pregnancy.[1] To characterize maternal near-misses in a  
69 standardized way, the World Health Organization proposed the concept of severe maternal  
70 morbidity (SMM), a composite of conditions that represent end-organ dysfunction or states  
71 of heightened maternal mortality risk associated with pregnancy, birth, or the postpartum  
72 period.[2, 3] Advances in the recognition and management of SMM have resulted in low  
73 maternal mortality rates in economically developed nations. Women living in high income  
74 countries are now more likely to survive a life-threatening pregnancy condition and,  
75 correspondingly, the rates of SMM are 100-fold higher than the rates of maternal mortality  
76 in Canada.[1] However, recent trends in Canada and other high income countries show an  
77 increase in SMM rates coinciding with advancing maternal age and corresponding increases  
78 in pre-existing co-morbidities and the use of assisted reproductive technology.[4-9]

79 The literature also shows persistent though complex associations between SMM and the  
80 social determinants of health. Low occupational class, Black ethnicity,[10] and non-private  
81 health insurance[11] are all associated with higher risk of SMM in the US. Canadian women  
82 who experience SMM are more likely to come from a low-income background, and to  
83 originate from an African or Caribbean country.[4, 6, 12] A systematic review found  
84 evidence for effects of material dimensions of inequality on SMM risk, though it pointed out  
85 the need for further work on other dimensions and in elucidating effect mechanisms.[13]

86 Women of advanced maternal age may be more likely to come from more advantaged  
87 socioeconomic backgrounds and to have planned pregnancies.[14-16] This suggests the  
88 possibility for effect modification, whereby the negative effects of advanced maternal age

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3 89 may be attenuated for women who come from more advantaged backgrounds, and  
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6 90 exacerbated for women from disadvantaged backgrounds. The effects of maternal age and  
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8 91 neighbourhood-level material deprivation may therefore interact, with the highest SMM risk  
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10 92 among older women living in neighbourhoods with higher deprivation.

13  
14 93 In this study, our first objective was to evaluate trends in SMM rates among primiparous  
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16 94 women in Ontario by neighbourhood material deprivation quintile between 1 April 2002  
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18 95 and 31 March 2018. Our second objective was to determine if maternal age moderates the  
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20 96 effect of neighbourhood material deprivation. We hypothesized that SMM rates would  
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22 97 increase disproportionately over time among women living in neighbourhoods with high  
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24 98 material deprivation. We further hypothesized that the highest risk of SMM would be  
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26 99 among women of advanced maternal age living in neighbourhoods with the highest material  
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31 100 deprivation.

## 32 33 34 101 **METHODS**

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37 102 This population-based retrospective cohort study used linked administrative datasets for  
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39 103 Ontario, held at ICES (formerly, the Institute for Clinical Evaluative Sciences). ICES is an  
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41 104 independent, non-profit research institute funded by an annual grant from the Ontario  
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43 105 Ministry of Health (MOH) and the Ministry of Long-Term Care (MLTC). As a prescribed entity  
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45 106 under Ontario's privacy legislation, ICES is authorized to collect and use health care data for  
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47 107 the purposes of health system analysis, evaluation and decision support. Secure access to  
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49 108 these data is governed by policies and procedures that are approved by the Information and  
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51 109 Privacy Commissioner of Ontario. The use of data in this project was authorized under  
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53 110 section 45 of Ontario's Personal Health Information Protection Act, which does not require  
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3 111 review by a Research Ethics Board. We followed the RECORD guidelines (REporting of  
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5 112 studies Conducted using Observational Routinely-collected Data) for reporting this  
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8 113 study.[17]  
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#### 10 11 114 **Patient and public involvement** 12

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15 115 There was no direct patient or public involvement in this study.  
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#### 17 18 116 **Study population and data sources** 19

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21 117 The Canadian Institute for Health Information Discharge Abstract Database (DAD) was used  
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23 118 to capture all hospital admissions for birth and link to newborn records using the ICES-  
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25 119 derived MOMBABY dataset. We included primiparous women aged 10-55 years who had a  
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27 120 hospital birth in Ontario and were enrolled in the province's universal health insurance  
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29 121 program (OHIP). We identified the first live birth or stillbirth delivery at a gestational age of  
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31 122  $\geq 20$  weeks. We used gestational age at birth to calculate pregnancy onset. Women were  
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33 123 included if the onset of their first pregnancy was on or after 1 April 2002 and the  
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35 124 corresponding birth occurred on or before 17 February 2018—allowing 42 days of  
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37 125 postpartum follow-up through the study end date of 31 March 2018. Women who had a  
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39 126 previous birth within 14 years prior to the index date were excluded. We linked these data  
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41 127 with the Registered Persons Database (RPDB), DAD, and OHIP Claims Database to identify  
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43 128 exposures and outcomes of interest. To identify women who had recently immigrated to  
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45 129 Ontario, we used the Ontario portion of the federal Immigration, Refugees and Citizenship  
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47 130 Canada (IRCC) Permanent Resident Database. For neighbourhood material deprivation, we  
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49 131 used the 2001 and 2006 Canadian Census, and Ontario Marginalization Index (ON-  
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3 132 MARG).[18] These datasets were linked using unique encoded identifiers and analyzed at  
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6 133 ICES and are shown in **Appendix 1**.

### 9 134 **Main outcome**

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12 135 The main outcome was a composite of medical conditions and interventions that comprise  
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14 136 SMM. Cases of SMM were identified using diagnosis and procedural codes (International  
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17 137 Statistical Classification of Diseases and Related Health Problems, 10<sup>th</sup> revision [ICD-10] and  
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19 138 Canadian Classification of Health Interventions, respectively) within the DAD database.[15,  
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22 139 19-21] The DAD data have been validated and shown to accurately reflect the information in  
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24 140 medical records.[21, 22] The composite SMM outcome included: 1) causes of direct  
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27 141 obstetric death and conditions related to these (ante-partum, in-partum, and post-partum  
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29 142 hemorrhage; hypertensive disorders of pregnancy and eclampsia; puerperal sepsis; uterine  
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32 143 rupture; obstetric embolus); 2) severe organ system dysfunction (cardiac arrest, failure, or  
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34 144 arrhythmia; renal or hepatic failure; coagulation defect; thromboembolism; respiratory  
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36 145 failure; coma or non-eclamptic seizure; psychosis); 3) procedures or interventions  
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38  
39 146 accompanying life-threatening conditions or health states (cesarean or post-partum  
40  
41  
42 147 hysterectomy; pelvic vessel ligation; surgical repair of bowel, bladder, or urethra;  
43  
44 148 endotracheal or tracheostomy ventilation; dialysis; blood transfusion in the context of  
45  
46 149 severe blood loss); and 4) deaths that were ill-defined or sudden, as these could not reliably  
47  
48  
49 150 be classified as non-obstetric deaths. **Appendix 1** shows the list of SMM indicators for this  
50  
51 151 study. We specified a binary SMM outcome variable for the presence of one or more  
52  
53  
54 152 indicators occurring from the onset of pregnancy up to and including 42 days after birth.

### 57 153 **Exposures and covariates**

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3 154 Our main exposure of interest was neighbourhood material deprivation quintile from the  
4  
5  
6 155 Ontario Marginalization Index (ON-MARG). ON-MARG is the Ontario-specific version of the  
7  
8 156 Canadian marginalization index (CAN-MARG).[23] The index was developed based on  
9  
10 157 theoretical frameworks of marginalization and deprivation, and derived empirically using  
11  
12  
13 158 principal component analysis of Canadian Census variables.[18, 23]The material deprivation  
14  
15 159 dimension is comprised of the following Census measures, each expressed as a proportion:  
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17  
18 160 population aged  $\geq 20$  without secondary school graduation, single parent families,  
19  
20 161 households receiving government transfer payments, population aged  $\geq 15$  who are  
21  
22  
23 162 unemployed, population living below the low income cut-off (adjusted for community size,  
24  
25 163 household size, and inflation).[18] The geographical unit of aggregation is Dissemination  
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27  
28 164 Areas, which average 400-700 people and cover the entirety of Canadian territory.[24] ON-  
29  
30 165 MARG can be operationalized as a standardized interval scale based on factor loadings from  
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32  
33 166 the principal component analysis, or as quintiles each representing 20% of Dissemination  
34  
35 167 Areas.[18, 23] We modelled this exposure as quintiles, with quintile 1 representing  
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38 168 neighbourhoods with the lowest material deprivation, and quintile 5 representing  
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40 169 neighbourhoods with the highest deprivation.[18, 23] ON-MARG has been used to  
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42  
43 170 demonstrate inequalities in various health measures and is stable over time.[25-27] We  
44  
45 171 used the 2001 material deprivation index for births between years 2002-2003, and the 2006  
46  
47 172 index for years 2004-2018. The change from mandatory Census reporting to the voluntary  
48  
49  
50 173 National Household Survey and resulting data quality concerns meant that the 2011 index  
51  
52 174 was comprised from alternate data sources.[28] We used the 2006 version for all years after  
53  
54 175 2004 to avoid operationalizing this variable differently between study years.  
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3 176 We included maternal age at birth, categorized in 5-year bands. We adjusted for rural  
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6 177 setting using the 2004 and 2008 Rurality Index of Ontario (RIO).[29] We used the 2004 RIO  
7  
8 178 index for pregnancies between years 2002 and 2006, and the 2008 index for years 2007 to  
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10 179 2018. We adjusted for number of years since immigration using data from the IRCC.  
11  
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13 180 Additional demographic and pregnancy related variables included delivery mode and  
14  
15 181 multiple gestations. For multiple gestation pregnancies, delivery mode was specified based  
16  
17 182 on highest level of intervention: unassisted vaginal birth of all fetuses (lowest), forceps or  
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19 183 vacuum assisted vaginal birth of one or more fetuses, vaginal breech birth of one or more  
20  
21 184 fetuses, and caesarean birth of one or more fetuses (highest). We examined SMM rates by  
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23 185 gestational age at birth, induction of labour, and the use of epidural analgesia, however  
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25 186 these variables were not adjusted-for in the multivariable models.  
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### 31 **Statistical analysis**

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34 188 We summarized baseline characteristics and SMM rates overall for the study population.  
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36 189 Due to low birth counts for ages 10-14 years, we collapsed these into an age <20 years  
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38 190 group for analysis. We plotted SMM rates by year for the whole study population, and then  
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40 191 to evaluate changes over time, we divided the population into four, 4-year cohorts based on  
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42 192 pregnancy onset: 1 April 2002 to 31 March 2006 (cohort 1); 1 April 2006 to 31 March 2010  
43  
44 193 (cohort 2); 1 April 2010 to 31 March 2014 (cohort 3); and 1 April 2014 to 31 March 2018  
45  
46 194 (cohort 4). To address our first objective, we calculated average annual SMM rates for each  
47  
48 195 4-year cohort by neighbourhood material deprivation quintile. Within each cohort, we  
49  
50 196 estimated unadjusted absolute rate differences (RD) and rate ratios (RR) with 95%  
51  
52 197 confidence intervals (CI) comparing women in quintile 5 (highest deprivation) with women  
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54 198 in quintile 1 (lowest deprivation).  
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3 199 Our second objective was to evaluate the effect of neighbourhood material deprivation,  
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6 200 adjusting for covariates and testing for interaction with maternal age for the overall study  
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8 201 population. We constructed multivariable log-binomial regression models. We initially fit a  
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10 202 model with neighbourhood material deprivation, adjusting only for year of pregnancy onset  
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12  
13 203 (model 1). We then added maternal age (model 2), followed by demographic and  
14  
15 204 pregnancy-related covariates, immigration status, and rurality (model 3). We tested for  
16  
17 205 interaction between material deprivation and maternal age using a cross product term. We  
18  
19 206 did not adjust for stillbirth or gestational age at birth, as these variables are considered  
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21 207 colliders rather than true confounders of outcomes associated with SMM.[30] We did not  
22  
23 208 include induction of labour or epidural analgesia, as these interventions are associated with  
24  
25 209 clinical decisions surrounding birth rather than SMM risk factors. We excluded women with  
26  
27 210 missing information for neighbourhood material deprivation from the multivariable analysis,  
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29 211 as these women represented less than 2 percent of the study population (n=17,130).  
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35 212 We performed two additional analyses evaluating SMM rate trends (RD and RR) over the  
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37 213 study period, comparing the 4-year average annual rates during cohort 4 to cohort 1  
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39 214 separately by maternal age and by neighbourhood material deprivation quintile. We also  
40  
41 215 examined the 4-year average rates of SMM excluding cases defined by HIV disease. This was  
42  
43 216 done in reference to recently proposed changes to the Canadian SMM composite indicator  
44  
45 217 excluding chronic, asymptomatic HIV disease.[12, 31] Statistical analyses were performed  
46  
47 218 using SAS (version 7.15, SAS Institute Inc., Cary, NC) and STATA (version 13, StataCorp.,  
48  
49 219 College Station, TX).

## 220 **RESULTS**

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3 221 There were 2,143,045 hospital-based births in Ontario between 1 April 2002 and 17  
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6 222 February 2018, of which 1,048,845 were primiparous births and included in the study  
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8 223 (**Figure 1**). The overall SMM rate across the study period was 18.0 per 1,000 births, and  
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10 224 increased from 16.7 per 1,000 births in 2002-03 (95% CI: 15.6, 17.9) to 23.0 per 1,000 births  
11  
12  
13 225 in 2017-18 (95% CI: 21.2, 25.0, **Supplementary Figure 1**). Baseline characteristics and SMM  
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15 226 case number and rate for each characteristic are presented in **Table 1**. SMM rates were  
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17 227 higher at the extremes of maternal age, and among women living in neighbourhoods with  
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20 228 the highest material deprivation.

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23 229 **Table 2** presents SMM rates by material deprivation quintile for the pooled study sample  
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26 230 (2002-2018) and each of the four 4-year cohorts. The RD was 2.09 cases per 1,000 births  
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28 231 (95% CI: 0.62, 3.56), corresponding with a RR of 1.13 (95% CI: 1.04, 1.23) comparing women  
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31 232 in quintile 5 with women in quintile 1 during the first 4-year cohort. This increased to a RD  
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33 233 of 3.91 cases per 1,000 births (95% CI: 2.12, 5.70) and RR of 1.21 (95% CI: 1.11, 1.32) in the  
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35  
36 234 final 4-year cohort of the study period. Average annual SMM rates increased between  
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38 235 cohort 1 and cohort 4 for women aged 30-34, and  $\geq 40$  years (**Supplementary Table 1**,  
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40 236 **Supplementary Figure 2**). For the latter group, the absolute increase was 14.69 cases per  
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43 237 1,000 births (95% CI: 7.96-21.43, **Supplementary Table 1**). SMM rates increased over time  
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46 238 for women in each quintile of neighbourhood deprivation, and this increase was most  
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48 239 pronounced for women in the highest quintile of neighbourhood deprivation (RD 4.19 cases  
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50 240 per 1,000 births 95% CI: 4.13-4.24, **Supplementary Table 1**).

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53 241 In the multivariable regression analysis for the overall study population, women living in  
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56 242 neighbourhoods with the highest material deprivation had higher rates of SMM compared  
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58 243 to those in neighbourhoods with the lowest after adjusting for pregnancy year (RR: 1.11,

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3 244 95% CI: 1.06, 1.16, **Table 3**). Full adjustment for age, demographics, pregnancy-related  
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6 245 variables, and rurality had minimal effect on the association between material deprivation  
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8 246 and SMM rates (adjusted RR: 1.16, 95% CI: 1.11, 1.21, **Table 3**). The association between age  
9  
10 247 and SMM persisted in the fully adjusted model, with higher risk for women <20 and ≥30  
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12  
13 248 years of age. We did not find evidence of statistical interaction between maternal age and  
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15 249 neighbourhood material deprivation quintile.

## 250 **DISCUSSION**

### 251 **Main findings**

252 This study demonstrated an association between neighbourhood material deprivation and  
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28 253 severe maternal morbidity among primiparous women in Ontario from 2002-2018. Rates of  
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30 254 SMM increased across all material deprivation quintiles, and we found some evidence that  
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32 255 women in the highest deprivation quintile experienced a higher magnitude SMM rate  
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35 256 increase over the 16-year study period compared with women in the lowest deprivation  
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38 257 quintile. This finding suggests a possible widening of the gap between women living in the  
39  
40 258 most and least deprived neighbourhoods.

### 259 **Strengths/ limitations**

260 The current study was a population-based analysis of all primiparous hospital births at ≥20  
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48 261 weeks' gestational age in Ontario. Hospital births account for over 98% of births in the  
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51 262 province. We used a measure of neighbourhood marginalization that includes income along  
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54 263 with other measures of material resources, and that is stable across time and different  
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56 264 health outcomes.[23, 25] Our study nonetheless had some limitations. We were unable to  
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59 265 account for births prior to 20 weeks' gestation or births that occurred outside of the

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3 266 province. Our measure of SMM was based on validated perinatal health data for  
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6 267 Canada.[15, 21] A revision of the Canadian SMM composite was recently developed which  
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8 268 resolves issues surrounding the inclusion of some pre-eclampsia and HELLP syndrome  
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10 269 measures, as well as the exclusion of HIV infection—a condition that is unlikely to represent  
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12  
13 270 SMM when asymptomatic [12, 31]. We elected to use the former SMM composite for  
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15 271 comparison with previous literature, recognizing this may complicate direct comparison  
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17 272 with recent Canadian studies [4, 6, 12, 31]. The proportion of women with SMM defined by  
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19 273 HIV disease was around 2 percent for each of the 4-year cohorts, and thus we do not believe  
20  
21 274 these cases substantively altered the results of this study. Information on immigrants  
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23 275 arriving prior to 1985 is not captured in the IRCC Permanent Resident Database, and the  
24  
25 276 database does not identify immigrants who landed in other provinces and subsequently  
26  
27 277 moved to Ontario. Although we used a measure of neighbourhood material deprivation  
28  
29 278 developed for Ontario using Canadian Census elements,[28] the ON-MARG index does not  
30  
31 279 include individual-level indicators of marginalization or socioeconomic status. Important  
32  
33 280 social determinants may differ among individuals living in areas characterized by similar  
34  
35 281 measures of neighbourhood deprivation, and it is not possible to elucidate the causal  
36  
37 282 pathways that link social disadvantage to poor health outcomes without incorporating such  
38  
39 283 factors.[32, 33] Finally, pre-pregnancy co-morbidities, obesity, and the use of assisted  
40  
41 284 reproductive technology, contribute to higher SMM rates and may partially explain SMM  
42  
43 285 trends.[8, 9, 34] We were unable to account for these factors. Obstetric comorbidity indices  
44  
45 286 have been developed for risk prediction and adjustment in clinical research. [35, 36] We did  
46  
47 287 not use an obstetric comorbidity index in our adjusted analysis as some index indicators  
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3 288 represent SMM outcomes themselves, or are mediators of SMM outcomes. In addition, our  
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5 289 aim was to examine population SMM trends rather than individual clinical risk factors.  
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8

9 290 **Interpretation**

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11  
12 291 The present study contributes to our understanding of the association between  
13  
14 292 neighbourhood marginalization and SMM and provides preliminary evidence of a possible  
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16  
17 293 widening of this health disparity over time in Ontario. The association between  
18  
19 294 neighbourhood-level measures of inequality and risk of SMM has been demonstrated  
20  
21  
22 295 previously in several high-income countries.[6, 9, 11, 13, 37-41] Notably in Canada, Aoyama  
23  
24 296 and colleagues reported a rise in SMM linked to the relative increase in maternal age and  
25  
26  
27 297 found a significant association between SMM and neighbourhood income quintile.[4]. Our  
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29 298 study confirms this finding using a measure that encompasses income along with additional  
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32 299 measures of neighbourhood material deprivation. Moreover, we extend the current  
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35 300 understanding of this association by providing evidence for a possible disproportionate rise  
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37 301 in SMM risk experienced by women living in marginalized neighbourhoods over time. We  
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39 302 interpret this last finding with caution, as our study showed significant rate differences by  
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42 303 neighbourhood marginalization only during the first and final 4-year cohorts of the 16-year  
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44 304 study period. SMM risks have been demonstrated among other social determinants of  
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47 305 health; for example, lower occupational class, Black ethnicity,[10] and non-private health  
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49 306 insurance[11] are associated with higher risk of SMM in the US. Interaction between  
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52 307 socioeconomic indicators—including ethnicity, education, and poverty—likely contribute to  
53  
54 308 the social gradient of risk such that the protective effects afforded by higher education and  
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56  
57 309 income do not fully ameliorate racial disparities in SMM.[38] Our study showed an  
58  
59 310 association between neighbourhood deprivation and SMM suggesting the effects of  
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3 311 marginalization persist even in the context of universal healthcare. This is a consistent  
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5  
6 312 finding across countries that have similar publicly funded healthcare systems.[41-43] The  
7  
8 313 factors contributing to social inequality are myriad; ethnicity and country of origin, rurality  
9  
10 314 and access to care, income, material resources, education, and psychosocial supports all  
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12  
13 315 have worrisome associations with maternal reproductive health risks.[6, 10-12, 38, 41-47]  
14  
15 316 How these factors contribute to widening health gaps, and what interventions may  
16  
17 317 attenuate their effects will be imperative lines of inquiry going forward as the global  
18  
19  
20 318 challenge to lower SMM continues.

## 23 319 **Conclusion**

26  
27 320 Ontario women living in areas with higher neighbourhood material deprivation experienced  
28  
29 321 the highest risk of SMM, and this association was not fully explained by maternal age.  
30  
31 322 Additionally, women living in high-deprivation neighbourhoods may have experienced a  
32  
33 323 disproportionate increase in the risk of SMM over time. Future work must focus on  
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35 324 addressing the widening social gap in maternal health disparities.  
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## 336 TABLES

337 **Table 1.** Baseline characteristics of the study population, 2002-2018. N=1,048,845 births.

| Variable                        | Number of births | Percent | Number of SMM cases | SMM rate per 1,000 births |
|---------------------------------|------------------|---------|---------------------|---------------------------|
| Overall study population        | 1,048,845        | 100     | 18,880              | 18.00                     |
| Maternal age at birth, years    |                  |         |                     |                           |
| 10-14                           | 1,330            | 0.1     | 35                  | 26.32                     |
| 15-19                           | 72,579           | 6.9     | 1,291               | 17.79                     |
| 20-24                           | 178,074          | 17.0    | 2,684               | 15.07                     |
| 25-29                           | 342,003          | 32.6    | 5,324               | 15.57                     |
| 30-34                           | 305,898          | 29.2    | 5,653               | 18.48                     |
| 35-39                           | 123,698          | 11.8    | 3,017               | 24.39                     |
| ≥40                             | 25,263           | 2.4     | 876                 | 34.68                     |
| Gestational age at birth, weeks |                  |         |                     |                           |
| 20-23                           | 2,751            | 0.3     | 147                 | 53.44                     |
| 24-27                           | 4,158            | 0.4     | 306                 | 73.59                     |
| 28-33                           | 17,688           | 1.7     | 1,104               | 62.42                     |
| 34-36                           | 59,040           | 5.6     | 1,966               | 33.30                     |
| 37-41                           | 961,322          | 91.7    | 15,278              | 15.89                     |
| ≥42                             | 3,886            | 0.4     | 79                  | 20.33                     |
| Induced labour                  | 275,262          | 26.2    | 5,836               | 21.20                     |
| Epidural                        | 655,107          | 62.5    | 10,713              | 16.35                     |
| Delivery mode                   |                  |         |                     |                           |
| Vaginal unassisted              | 579,814          | 55.3    | 6,386               | 11.01                     |
| Vaginal assisted                | 156,383          | 14.9    | 2,724               | 17.42                     |
| Vaginal breech                  | 2,328            | 0.2     | 95                  | 40.81                     |
| Caesarean                       | 310,320          | 29.6    | 9,675               | 31.18                     |
| Multiple gestations             | 20,850           | 2.0     | 1,137               | 54.53                     |
| Stillbirth                      | 3,645            | 0.3     | 199                 | 54.60                     |
| Rurality                        |                  |         |                     |                           |
| Urban                           | 993,282          | 94.7    | 17,814              | 17.93                     |
| Rural                           | 55,563           | 5.3     | 1,066               | 19.19                     |
| Immigration Status              |                  |         |                     |                           |
| Non-immigrant / before 1985     | 739,252          | 70.5    | 13,222              | 17.89                     |
| Immigrated >10 years            | 62,381           | 5.9     | 1,165               | 18.68                     |
| Immigrated 5-10 years           | 62,090           | 5.9     | 1,249               | 20.12                     |
| Immigrated <5 years             | 185,122          | 17.7    | 3,244               | 17.52                     |
| Neighbourhood marginalization   |                  |         |                     |                           |
| Material deprivation            |                  |         |                     |                           |
| Quintile 1 (least deprived)     | 237,877          | 22.7    | 4,183               | 17.58                     |
| Quintile 2                      | 186,550          | 17.8    | 3,112               | 16.68                     |
| Quintile 3                      | 189,575          | 18.1    | 3,327               | 17.55                     |

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|----------------------------|---------|------|-------|-------|
| Quintile 4                 | 191,376 | 18.2 | 3,423 | 17.89 |
| Quintile 5 (most deprived) | 226,337 | 21.6 | 4,397 | 19.43 |
| Missing                    | 17,130  | 1.6  | 438   | 25.57 |

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340 **Table 2.** Four-year average SMM rates per 1,000 births for neighbourhood material  
 341 deprivation quintiles, by pooled sample (2002-2018) and by study period cohort.

| Cohort <sup>a</sup> | <i>SMM rates by material deprivation quintile</i> |       |       |       |              | <i>Q5 vs Q1</i>                  |                                  |
|---------------------|---|-------|-------|-------|--------------|----------------------------------|----------------------------------|
|                     | Q1<br>(least)                                     | Q2    | Q3    | Q4    | Q5<br>(most) | Rate difference (95%<br>CI)      | Rate ratio (95% CI)              |
| Pooled              | 17.58   | 16.68 | 17.55 | 17.89 | 19.43        | 1.84 (1.82,1.87) <sup>***</sup>  | 1.10 (1.10-1.11) <sup>***</sup>  |
| 1                   | 16.05   | 16.36 | 17.46 | 16.49 | 18.14        | 2.09 (0.62, 3.56) <sup>**</sup>  | 1.13 (1.04, 1.23) <sup>**</sup>  |
| 2                   | 16.58   | 15.97 | 15.73 | 16.37 | 17.32        | 0.75 (-0.70, 2.20)               | 1.05 (0.96, 1.14)                |
| 3                   | 19.36   | 16.17 | 18.34 | 19.19 | 20.78        | 1.41 (-0.20, 3.02)               | 1.07 (0.99, 1.16)                |
| 4                   | 18.41   | 18.52 | 18.99 | 20.18 | 22.32        | 3.91 (2.12, 5.70) <sup>***</sup> | 1.21 (1.11, 1.32) <sup>***</sup> |

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343 <sup>a</sup>cohort 1: 1 April 2002 to 31 March 2006; cohort 2: 1 April 2006 to 31 March 2010; cohort 3:  
 344 1 April 2010 to 31 March 2014; cohort 4: 1 April 2014 to 31 March 2018

345 \*p<0.05, \*\*p<0.01, \*\*\*p<0.001

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350 **Table 3.** Neighbourhood material deprivation and risk of SMM: Adjusted multivariable  
 351 models, RR (95% CI). N=1,031,715 births.

| Variable             | Model 1 <sup>a</sup> | Model 2 <sup>b</sup> | Model <sup>c</sup> |
|----------------------|----------------------|----------------------|--------------------|
| Maternal age (years) |                      |                      |                    |
| <20                  |                      | 1.05 (0.99, 1.12)    | 1.20 (1.13, 1.28)  |
| 20-24                |                      | 0.95 (0.90, 0.99)    | 1.01 (0.96, 1.06)  |
| 25-29                |                      | 1 (ref)              | 1 (ref)            |
| 30-34                |                      | 1.19 (1.14, 1.23)    | 1.10 (1.06, 1.15)  |
| 35-39                |                      | 1.56 (1.49, 1.63)    | 1.34 (1.28, 1.40)  |
| ≥40                  |                      | 2.21 (2.06, 2.37)    | 1.73 (1.61, 1.86)  |
| Material deprivation |                      |                      |                    |
| Quintile 1 (least)   | 1 (ref)              | 1 (ref)              | 1 (ref)            |
| Quintile 2           | 0.95 (0.91, 0.99)    | 0.97 (0.93, 1.02)    | 0.97 (0.92, 1.01)  |
| Quintile 3           | 1.00 (0.96, 1.05)    | 1.04 (0.99, 1.08)    | 1.03 (0.98, 1.07)  |
| Quintile 4           | 1.02 (0.98, 1.07)    | 1.07 (1.02, 1.12)    | 1.06 (1.01, 1.11)  |
| Quintile 5 (most)    | 1.11 (1.06, 1.16)    | 1.17 (1.12, 1.22)    | 1.16 (1.11, 1.21)  |

<sup>a</sup>adjusted for pregnancy year

<sup>b</sup>adjusted for pregnancy year, age

<sup>c</sup>adjusted for pregnancy year, age, delivery mode, multiple gestations, immigration status, rurality

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3 361 **FIGURE CAPTIONS**  
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6 362 **Figure 1.** Study inclusion / exclusion flow chart, primiparous births.  
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13 364 **SUPPLEMENTARY MATERIAL CAPTIONS**  
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16 365 **Supplementary Appendix 1.** Data sources for the project.  
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19 366 **Supplementary Figure 1.** Annual crude SMM rate per 1,000 births, 2002-2018.  
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22 367 **Supplementary Figure 2.** Average annual SMM rates per 1,000 births by maternal age.  
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25 368 **Supplementary Table 1.** Four-year average SMM rates per 1,000 births by age and by  
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27  
28 369 material deprivation, and rate change over study period.  
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15 **383 Declaration of competing interests**  
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18 384 The authors declare no conflicts of interest.  
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21 **385 Author contributions**  
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24 386 JWS, DF, KEM, and LCR contributed to the overall conception of the study. JWS, ML, LR, DF,  
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27 387 and LCR contributed to study design and protocol. TW had full access to data used in the  
28  
29 388 study. JWS, TW, and LCR take responsibility for the integrity of the data analysis. JWS wrote  
30  
31 389 the manuscript. All authors made substantial contributions to the data analysis  
32  
33 390 interpretation, and manuscript editing and revising for this project. All authors approve the  
34  
35 391 final submitted version and agree to be accountable for all aspects of the work.  
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40 **392 Ethical approval**  
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43 393 ICES is a prescribed entity under section 45 of Ontario's Personal Health Information  
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45 394 Protection Act. Section 45 authorizes ICES to collect personal health information, without  
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47 395 consent, for the purpose of analysis or compiling statistical information with respect to the  
48  
49 396 management of, evaluation or monitoring of, the allocation of resources to or planning for  
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51 397 all or part of the health system. Projects conducted under section 45, by definition, do not  
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53 398 require review by a Research Ethics Board. This project was conducted under section 45,  
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55 399 and approved by ICES' Privacy and Legal Office.  
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3 400 **Patient consent for publication**  
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6 401 None required.  
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10 402 **Data availability statement**  
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13 403 The dataset from this study is held securely in coded form at ICES. While data sharing  
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15 404 agreements prohibit ICES from making the dataset publicly available, access may be granted  
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17 405 to those who meet pre-specified criteria for confidential access, available at  
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20 406 [www.ices.on.ca/DAS](http://www.ices.on.ca/DAS). The full dataset creation plan and underlying analytic code are  
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22 407 available from the authors upon request, understanding that the computer programs may  
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24 408 rely upon coding templates or macros that are unique to ICES and are therefore either  
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26 409 inaccessible or may require modification.  
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421 and statements expressed herein are solely those of the authors and do not reflect those of  
422 the funding or data sources; no endorsement is intended or should be inferred.  
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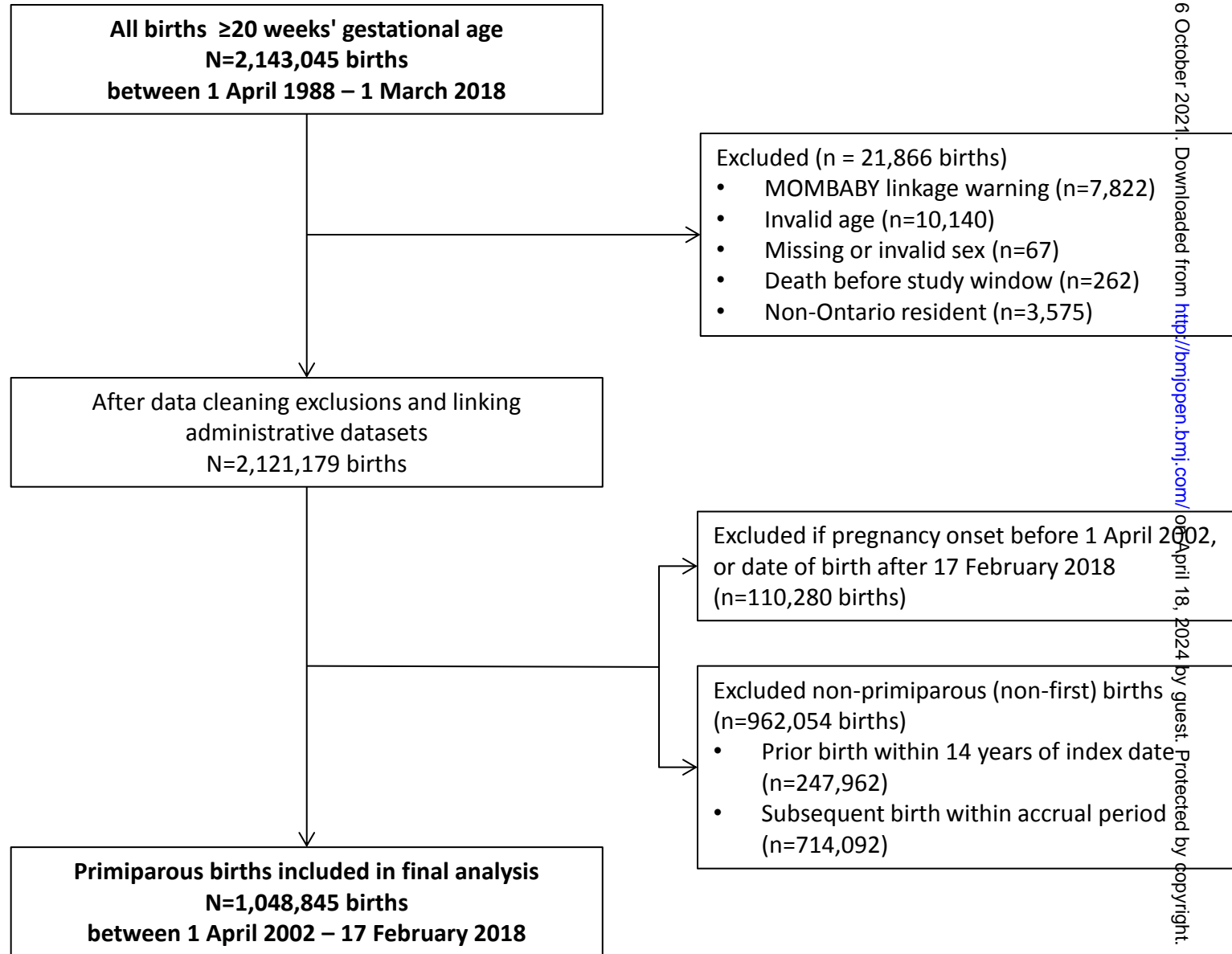
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Figure 1. Study inclusion / exclusion flow chart, primiparous births.



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## Supplementary Appendix 1. Data sources for project

### Discharge Abstract Database (DAD)

The DAD is compiled by the Canadian Institute for Health Information and contains administrative, clinical (diagnoses and procedures/interventions), demographic, and administrative information for all admissions to acute care hospitals, rehab, chronic, and day surgery institutions in Ontario. At ICES, consecutive DAD records are linked together to form 'episodes of care' among the hospitals to which patients have been transferred after their initial admission.

### MOMBABY

The ICES MOMBABY Database is an ICES-derived cohort that links the DAD inpatient admission records of delivering mothers and their newborns. From 2002 onward, this linkage is performed deterministically using a maternal-newborn chart matching number. Prior to 2002, mothers were linked to their children by matching on the institutions they were admitted, their postal codes, and their admission/discharge dates.

### Registered Persons Database (RPDB)

The RPDB provides basic demographic information (age, sex, location of residence, date of birth, and date of death for deceased individuals) for those issued an Ontario health insurance number. The RPDB also indicates the time periods for which an individual was eligible to receive publicly funded health insurance benefits and the best known

### Ontario Health Insurance Plan (OHIP)

The OHIP claims database contains information on inpatient and outpatient services provided to Ontario residents eligible for the province's publicly funded health insurance system by fee-for-service health care practitioners (primarily physicians) and "shadow billings" for those paid through non-fee-for-service payment plans. The main data elements include patient and physician identifiers (encrypted), code for service provided, date of service, associated diagnosis, and fee paid.

### Immigration, Refugees, and Citizenship Canada's (IRCC) Permanent Resident Database

The Ontario portion of the IRCC Permanent Resident Database includes immigration application records for people who initially applied to land in Ontario since 1985. The dataset contains permanent residents' demographic information such as country of citizenship, level of education, mother tongue, and landing date. New immigrants who are currently residing in Ontario but originally landed in another province are not captured in this dataset.

### Ontario Marginalization Index (ONMARG)

ONMARG is a geographically (census) based index developed to quantify the degree of marginalization occurring across the province of Ontario. It is comprised of four major dimensions thought to underlie the construct of marginalization: residential instability, material deprivation, dependency, and ethnic concentration. The dataset contains census divisions (CD), census tracts (CT), census subdivisions (CSD), consolidated municipal service manager areas (CMSM), public health units (PHU), local health integration networks (LHIN), sub-LHINs, and dissemination areas (DA).

These datasets were linked using unique encoded identifiers and analyzed at ICES.

The dataset from this study is held securely in coded form at ICES. While data sharing agreements prohibit ICES from making the dataset publicly available, access may be granted to those who meet pre-specified criteria for confidential access, available at [www.ices.on.ca/DAS](http://www.ices.on.ca/DAS). The full dataset creation plan and underlying analytic code are available from the authors upon request, understanding that the computer programs may rely upon coding templates or macros that are unique to ICES and are therefore either inaccessible or may require modification.

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**Inclusion/Exclusion Criteria**

| Concept  | Data Sources | Code Type  | Window                                     | Notes (including Dataset references)  |
|--|--------------|--|--|---|
| <i>Inclusion Criteria</i>  |              |  |  |   |
| Hospital birth (live or stillbirth) at gestational age $\geq 20$ weeks | DAD, MOMBABY | ICD-10 main patient service code for "Obstetrical birth" | Accrual window: 1 April 2002 – 17 Feb 2018 | Canadian Institute for Health Information Discharge Abstract Database (DAD, linked to newborn record in MOMBABY dataset)<br>See:<br><a href="https://datadictionary.ices.on.ca/Applications/DataDictionary/Library.aspx?Library=MOMBABY">https://datadictionary.ices.on.ca/Applications/DataDictionary/Library.aspx?Library=MOMBABY</a> |
| <i>Exclusion Criteria</i>  |              |  |  |   |
| Missing or invalid IKN   | RPDB         |  | Index date                                 | Registered Persons Database<br>See:<br><a href="https://datadictionary.ices.on.ca/Applications/DataDictionary/Library.aspx?Library=RPDB">https://datadictionary.ices.on.ca/Applications/DataDictionary/Library.aspx?Library=RPDB</a>  |
| MOMBABY linkage warning  | MOMBABY      |  | Index date                                 |   |
| Missing or invalid age (<10 or >55)                                    | RPDB         |  | Index date                                 |   |
| Missing or invalid sex   | RPDB         |  | Index date                                 |   |
| Death before the index date  | RPDB         |  | Index date                                 |   |
| Non-Ontario residents / invalid OHIP number                            | RPDB         |  | Index date                                 |   |
| Any births with an index date occurring outside of the accrual period  | MOMBABY      |  | Accrual window                             | Pregnancy onset before 1 April 2002   |
| Any births occurring after accrual end date                            | MOMBABY      |  | Accrual window                             | Births after 17 February 2018   |
| Not first birth  | MOMBABY      |  | 14 years prior to index date               | Prior record in MOMBABY within past 14 years of index date  |
| Not first birth in accrual period                                      | MOMBABY      |  | Accrual window                             | Subsequent records in MOMBABY   |



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**Outcome**

| Concept                         | Data Sources | Code Type     | Window   | Notes<br>(including Dataset references)  |
|---------------------------------|--------------|---------------|--|--|
| Severe maternal morbidity (SMM) | DAD          | ICD 10<br>CCI | Start of lookback period ("pregnancy onset" = index date – gestational age at birth) to end of observation window (42 days following index date) | <p>Patient considered to have outcome IF ANY code in ANY of the following:</p> <ol style="list-style-type: none"> <li>1) Obstetric/ ill-defined or sudden death</li> <li>2) Hypertensive heart/renal disease</li> <li>3) Eclampsia</li> <li>4) Cerebral venous thrombosis</li> <li>5) Complications of anaesthesia – non-cardiac</li> <li>6) Complications of anaesthesia – cardiac</li> <li>7) Cardiac diseases (cardiac arrest, infarction, failure, pulmonary edema)</li> <li>8) Placental abruption c/ coagulation defect</li> <li>9) Antepartum hemorrhage c/ coagulation defect</li> <li>10) Intrapartum hemorrhage c/ coagulation defect</li> <li>11) Uterine rupture – before labour</li> <li>12) Uterine rupture – during labour</li> <li>13) Obstetric shock (including septic shock)</li> <li>14) Septecemia during labour</li> <li>15) Puerperal sepsis</li> <li>16) Pulmonary embolism</li> <li>17) Obstetric embolism</li> <li>18) Cardiomyopathy</li> <li>19) Acute renal failure</li> <li>20) HIV disease</li> <li>21) Cerebrovascular disease</li> <li>22) Acute respiratory distress syndrome</li> <li>23) Acute abdomen</li> <li>24) Hepatic failure</li> <li>25) Acute psychosis</li> <li>26) Cerebral edema, coma</li> <li>27) Disseminated intravascular coagulation</li> <li>28) Sickle cell anemia crisis</li> <li>29) Status asthmaticus</li> <li>30) Status epilepticus</li> <li>31) Assisted ventilation (endotracheal tube or tracheostomy)</li> <li>32) Caesarean hysterectomy</li> <li>33) Postpartum hysterectomy</li> <li>34) Dialysis</li> <li>35) Evacuation of incisional hematoma</li> <li>36) Surgical repair of bladder, urethra, intestine</li> <li>37) Intrapartum hemorrhage with no coagulation defect AND blood transfusion</li> <li>38) Postpartum hemorrhage AND blood</li> </ol> |

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|  |  |  |  | transfusion<br>39) Placenta previa AND blood transfusion<br>40) Embolization/ ligation/ suturing AND postpartum hemorrhage<br><br>See:<br>Joseph KS et al, 2009, <sup>1</sup> Joseph KS et al, 2010, <sup>2</sup> ICD-10CA, 2009, <sup>3</sup> and CCHI, 2012. <sup>4</sup> |
|--|--|--|--|---|

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**Study exposures, covariates**

| Concept                    | Data Sources   | Code Type                 | Window                       | Notes<br>(including Dataset references)   |
|----------------------------|----------------|---------------------------|------------------------------|---|
| Age                        | RPDB           |                           | Index date                   |   |
| Index year                 | DAD            |                           | Index date                   |   |
| Material deprivation index | ONMARG         |                           | Index date                   | Ontario Marginalization Index, Material Deprivation, in quintiles.<br><br>Use version of ONMARG closest to year of index date:<br>2001 for 2002-2003<br>2006 for 2004-2018<br>See:<br><a href="https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=ONMARG">https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=ONMARG</a> |
| Income quintile            | RPDB<br>Census |                           | Index date                   | Ontario Census area profile: income quintile.<br><br>Use Census closest to year of index date:<br>2001 for 2002-2003<br>2006 for 2004-2018<br>See:<br><a href="https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=CENSUS">https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=CENSUS</a>                                 |
| Rurality                   | RPDB           |                           | Index date                   | Rurality Index for Ontario (RIO).<br>Use version of RIO closest to year of index date:<br>RIO2004 for 2002-2006<br>RIO2008 for 2007-2018  |
| Gestational age at birth   | MOMBABY        |                           | Index date                   |   |
| Induction of labour        | DAD            | CCI code                  | Within index hospitalization | Canadian Classification of Health Interventions (CCI)   |
| Epidural                   | DAD<br>OHIP    | CCI code<br>OHIP fee code | Within index hospitalization | Canadian Classification of Health Interventions (CCI); Ontario Health Insurance Plan Claims Database (OHIP)   |
| Delivery mode              | DAD            | CCI code                  | Within index hospitalization |   |
| Multiple gestations        | MOMBABY        |                           | Within index hospitalization |   |
| Stillbirth                 | MOMBABY        |                           | Within index hospitalization |   |
| Immigration status         | IRCC           |                           | Index date                   | Immigration, Refugees and Citizenship   |

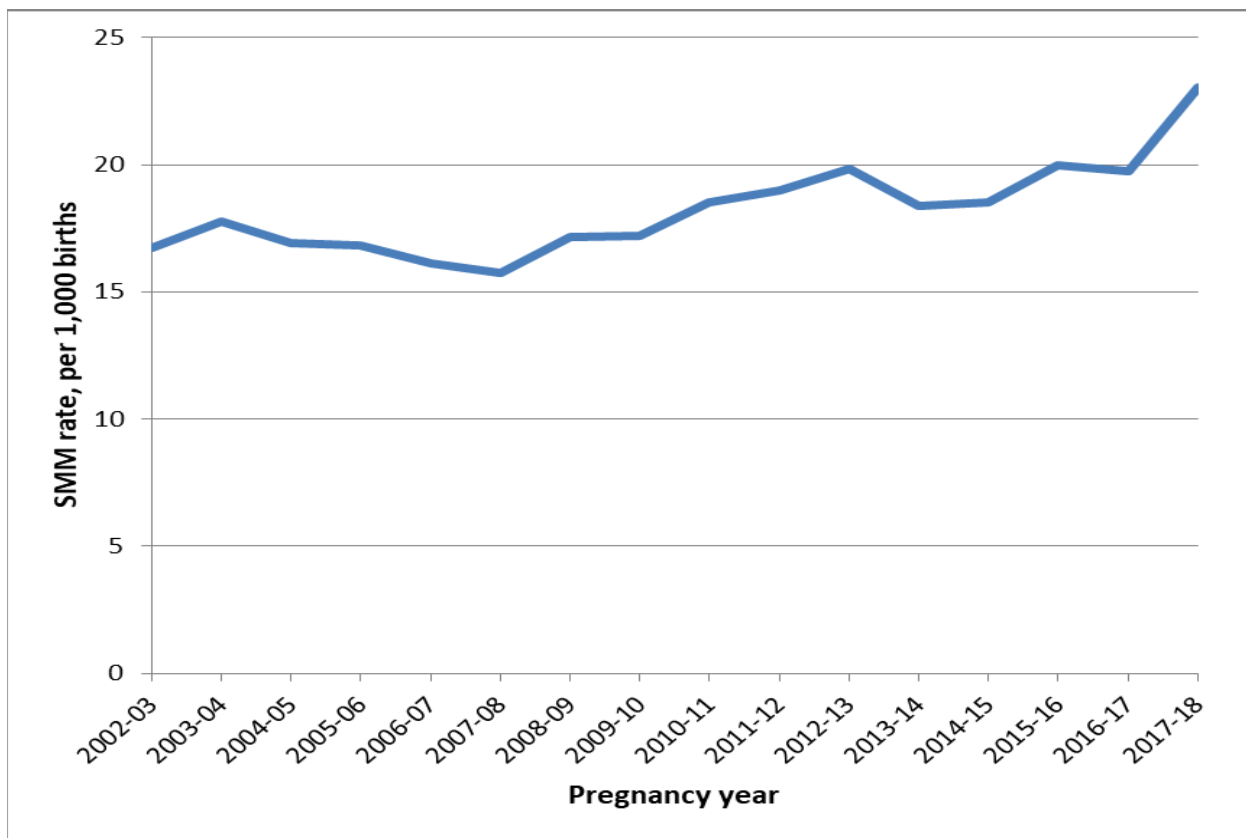
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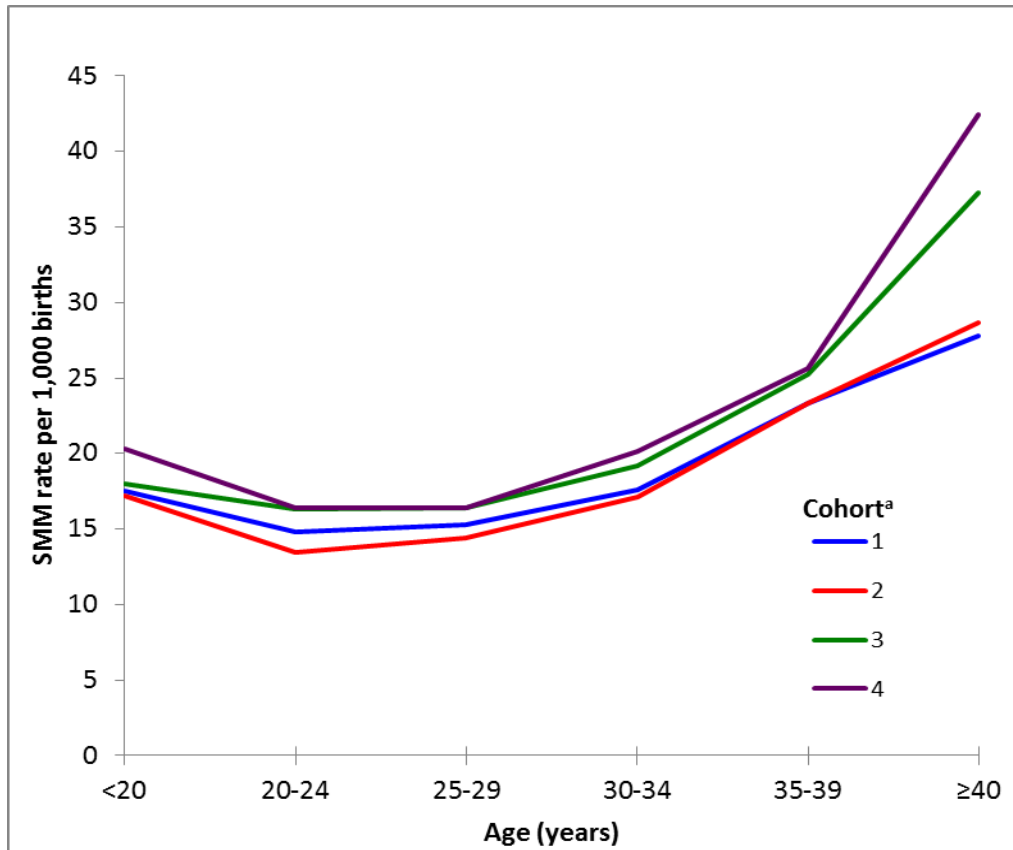
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|  |  |  |  | Canada (IRCC)'s Permanent Resident Database<br><br>Number of years since arrived in Ontario.<br>See:<br><a href="https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=CIC">https://datadictionary.ices.on.ca/Application/DataDictionary/Library.aspx?Library=CIC</a> |
|--|--|--|--|---|

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2. Joseph KS, Liu S, Rouleau J, et al. Severe maternal morbidity in Canada, 2003 to 2007: surveillance using routine hospitalization data and ICD-10CA codes. *Journal of Obstetrics & Gynaecology Canada: JOGC*. 2010;32:837-46.
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Supplementary Figure 1. Annual crude SMM rate per 1,000 births, 2002-2018.



**Supplementary Figure 2.** Average annual SMM rates per 1,000 births by maternal age.

<sup>a</sup>cohort 1: 1 April 2002 to 31 March 2006; cohort 2: 1 April 2006 to 31 March 2010; cohort 3: 1 April 2010 to 31 March 2014; cohort 4: 1 April 2014 to 31 March 2018

**Supplementary table 1. Four-year average SMM rates per 1,000 births by age and by material deprivation, and rate change over study period.**

| Variable                    | SMM rates by cohort <sup>a</sup> |       |       |       | SMM rate change, cohort 4 vs 1 <sup>a</sup> |                      |
|-----------------------------|----------------------------------|-------|-------|-------|---|----------------------|
|                             | 1                                | 2     | 3     | 4     | Rate difference (95% CI)                    | Rate ratio (95% CI)  |
| Overall study population    | 17.10                            | 16.55 | 18.94 | 19.82 | 2.72 (1.96, 3.49)***                        | 1.16 (1.11, 1.21)*** |
| <i>Maternal age (years)</i> |                                  |       |       |       |   |                      |
| <20                         | 17.54                            | 17.22 | 17.97 | 20.34 | 2.80 (-0.43, 6.04)                          | 1.15 (0.98, 1.37)    |
| 20-24                       | 14.80                            | 13.47 | 16.32 | 16.40 | 1.60 (-0.15, 3.35)                          | 1.11 (0.99, 1.24)    |
| 25-29                       | 15.26                            | 14.40 | 16.37 | 16.42 | 1.15 (-0.77, 2.39)                          | 1.08 (0.99, 1.16)    |
| 30-34                       | 17.58                            | 17.10 | 19.21 | 20.16 | 2.58 (1.18, 3.97)*                          | 1.15 (1.06, 1.23)*   |
| 35-39                       | 23.31                            | 23.35 | 25.23 | 25.67 | 2.36 (-0.16, 4.88)                          | 1.10 (0.99, 1.22)    |
| ≥40                         | 27.78                            | 28.68 | 37.30 | 42.48 | 14.69 (7.96, 21.43)*                        | 1.53 (1.24, 1.89)*   |
| <i>Material deprivation</i> |                                  |       |       |       |   |                      |
| Quintile 1 (least)          | 16.05                            | 16.58 | 19.36 | 18.41 | 2.36 (2.31, 2.41)***                        | 1.15 (1.14, 1.15)*** |
| Quintile 2                  | 16.36                            | 15.97 | 16.17 | 18.52 | 2.16 (2.11, 2.22)***                        | 1.13 (1.13, 1.14)*** |
| Quintile 3                  | 17.46                            | 15.73 | 18.34 | 18.99 | 1.54 (1.48, 1.59)***                        | 1.09 (1.08, 1.09)*** |
| Quintile 4                  | 16.49                            | 16.37 | 19.19 | 20.18 | 3.69 (3.63, 3.74)***                        | 1.22 (1.22, 1.23)*** |
| Quintile 5 (most)           | 18.14                            | 17.32 | 20.78 | 22.32 | 4.19 (4.13, 4.24)***                        | 1.23 (1.22, 1.23)*** |

<sup>a</sup>cohort 1: 1 April 2002 to 31 March 2006; cohort 2: 1 April 2006 to 31 March 2010; cohort 3: 1 April 2010 to 31 March 2014; cohort 4: 1 April 2014 to 31 March 2018

\*p<0.05, \*\*p<0.01, \*\*\*p<0.001

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The RECORD statement – checklist of items that should be reported in observational studies using routinely collected health data.

|                           | Item No. | STROBE items   | Location in manuscript where items are reported                          | RECORD items  | Location in manuscript where items are reported |
|---------------------------|----------|--|--|---|---|
| <b>Title and abstract</b> |          |  |  |   |   |
|                           | 1        | (a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found | Title page (p.1)   | RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included.<br><br>RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract.<br><br>RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract. | Title page, abstract (p. 1-3)                   |
| <b>Introduction</b>       |          |  |  |   |   |
| Background rationale      | 2        | Explain the scientific background and rationale for the investigation being reported   | Background p.4-5   |   |   |
| Objectives                | 3        | State specific objectives, including any prespecified hypotheses   | Background p.4-5   |   |   |
| <b>Methods</b>            |          |  |  |   |   |
| Study Design              | 4        | Present key elements of study design early in the paper  | Methods p.5-9  |   |   |
| Setting                   | 5        | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection  | Methods: <i>Study population and data sources, Main outcome</i> , p. 5-6 |   |   |

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|                                      |          |   |  |  |   |
|--------------------------------------|----------|---|--|--|---|
| <p>Participants</p>                  | <p>6</p> | <p>(a) <i>Cohort study</i> - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up<br/> <i>Case-control study</i> - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls<br/> <i>Cross-sectional study</i> - Give the eligibility criteria, and the sources and methods of selection of participants<br/><br/>                 (b) <i>Cohort study</i> - For matched studies, give matching criteria and number of exposed and unexposed<br/> <i>Case-control study</i> - For matched studies, give matching criteria and the number of controls per case</p> | <p>Cohort study, no matching:<br/><br/>                 Methods: <i>Study population and data sources, Main outcome, Exposures and covariates</i> p. 5-8; Appendix 1</p> | <p>RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided.<br/><br/>                 RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided.<br/><br/>                 RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.</p> | <p>Methods: <i>Study population and data sources, Main outcome, Exposures and covariates</i> p. 5-8<br/>                 Supplementary Appendix 1</p> |
| <p>Variables</p>                     | <p>7</p> | <p>Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.</p>  | <p>Methods: <i>Study population and data sources, Main outcome, Exposures and covariates</i> p. 5-8; Supplementary Appendix 1</p>  | <p>RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.</p>   | <p>Methods: <i>Study population and data sources, Main outcome, Exposures and covariates</i> p. 5-8<br/>                 Supplementary Appendix 1</p> |
| <p>Data sources/<br/>measurement</p> | <p>8</p> | <p>For each variable of interest, give sources of data and details of methods of assessment (measurement).</p>  | <p>Methods: <i>Study population and data sources, Main outcome, Exposures</i></p>  |  |   |

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|                        |    |   |  |  |  |
|------------------------|----|---|--|--|--|
|                        |    | Describe comparability of assessment methods if there is more than one group  | <i>and covariates</i> p. 5-8; Supplementary Appendix 1   |  |  |
| Bias                   | 9  | Describe any efforts to address potential sources of bias   | Methods: <i>Exposures and covariates</i> p. 7-8; Interpretation: <i>Strengths/ limitations</i> p.11-12 |  |  |
| Study size             | 10 | Explain how the study size was arrived at   | Methods: <i>Study population and data sources</i> , p. 5-6; Figure 1                                   |  |  |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why   | Methods: <i>Statistical analysis</i> , p. 8-9  |  |  |
| Statistical methods    | 12 | (a) Describe all statistical methods, including those used to control for confounding<br>(b) Describe any methods used to examine subgroups and interactions<br>(c) Explain how missing data were addressed<br>(d) <i>Cohort study</i> - If applicable, explain how loss to follow-up was addressed<br><i>Case-control study</i> - If applicable, explain how matching of cases and controls was addressed<br><i>Cross-sectional study</i> - If applicable, describe analytical methods taking account of | Methods: <i>Statistical analysis</i> , p. 8-9, Results, p.9-11.  |  |  |

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|                                  |    |   |                                 |   |   |
|----------------------------------|----|---|---------------------------------|---|---|
|                                  |    | sampling strategy<br>(e) Describe any sensitivity analyses  |                                 |   |   |
| Data access and cleaning methods |    | ..  |                                 | <p>RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population.</p> <p>RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.</p>   | <p>Methods: <i>Study population and data sources</i>, p. 6; <i>Supplementar Appendix 1</i>; <i>Author contributions</i>, p. 20</p>  |
| Linkage                          |    | ..  |                                 | <p>RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.</p>  | <p>Methods: <i>Study population and data sources</i>, <i>Main outcome</i>, <i>Exposures and covariates</i> p. 5-8<br/><i>Supplementary Appendix 1</i></p>                                   |
| <b>Results</b>                   |    |   |                                 |   |   |
| Participants                     | 13 | <p>(a) Report the numbers of individuals at each stage of the study (<i>e.g.</i>, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed)</p> <p>(b) Give reasons for non-participation at each stage.</p> <p>(c) Consider use of a flow diagram</p> | Results p.10; Table 1; Figure 1 | <p>RECORD 13.1: Describe in detail the selection of the persons included in the study (<i>i.e.</i>, study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.</p> | <p>Methods: <i>Study population and data sources</i>, <i>Main outcome</i>, <i>Exposures and covariates</i> p. 5-8<br/>Results p.10; Table 1; Figure<br/><i>Supplementary Appendix 1</i></p> |
| Descriptive data                 | 14 | (a) Give characteristics of study participants ( <i>e.g.</i> , demographic, clinical, social) and information   | Results p.10; Table 1           |   |   |

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|                |    | on exposures and potential confounders<br>(b) Indicate the number of participants with missing data for each variable of interest<br>(c) <i>Cohort study</i> - summarise follow-up time (e.g., average and total amount)  |   |  |
| Outcome data   | 15 | <i>Cohort study</i> - Report numbers of outcome events or summary measures over time<br><i>Case-control study</i> - Report numbers in each exposure category, or summary measures of exposure<br><i>Cross-sectional study</i> - Report numbers of outcome events or summary measures  | Results p.10; Figure 1; Table 1                 |  |
| Main results   | 16 | (a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included<br>(b) Report category boundaries when continuous variables were categorized<br>(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period | Results p.10; Table 1-3; Supplementary Figure 1 |  |
| Other analyses | 17 | Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses   | Results p.10-11                                 |  |

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| Discussion  |    |  |   |  |  |
|---|----|--|---|--|--|
| Key results   | 18 | Summarise key results with reference to study objectives   | Interpretation, <i>Main findings</i> p.11                                       |  |  |
| Limitations   | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias                 | Interpretation, <i>Strengths/limitations</i> p.11-12                            | RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported. | Interpretation, <i>Strengths/limitations</i> p.11-12 |
| Interpretation  | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | Discussion, <i>Main findings</i> p. 11, <i>Strengths / Limitations</i> p. 11-12 |  |  |
| Generalisability  | 21 | Discuss the generalisability (external validity) of the study results  | Discussion, <i>Interpretation</i> p.11-12                                       |  |  |
| Other Information   |    |  |   |  |  |
| Funding   | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based              | Funding, p. 21-22   |  |  |
| Accessibility of protocol, raw data, and programming code |    | ..   |   | RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.   | p. 21; Supplementary Appendix 1                      |

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