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## REVIEW ARTICLE OPEN

## Smoke-free legislation and child health

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In this paper, we aim to present an overview of the scientific literature on the link between smoke-free legislation and early-life health outcomes. Exposure to second-hand smoke is responsible for an estimated 166,000 child deaths each year worldwide. To protect people from tobacco smoke, the World Health Organization recommends the implementation of comprehensive smoke-free legislation that prohibits smoking in all public indoor spaces, including workplaces, bars and restaurants. The implementation of such legislation has been found to reduce tobacco smoke exposure, encourage people to quit smoking and improve adult health outcomes. There is an increasing body of evidence that shows that children also experience health benefits after implementation of smoke-free legislation. In addition to protecting children from tobacco smoke in public, the link between smoke-free legislation and improved child health is likely to be mediated via a decline in smoking during pregnancy and reduced exposure in the home environment. Recent studies have found that the implementation of smoke-free legislation is associated with a substantial decrease in the number of perinatal deaths, preterm births and hospital attendance for respiratory tract infections and asthma in children, although such benefits are not found in each study. With over 80% of the world's population currently unprotected by comprehensive smoke-free laws, protecting (unborn) children from the adverse impact of tobacco smoking and SHS exposure holds great potential to benefit public health and should therefore be a key priority for policymakers and health workers alike.

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## INTRODUCTION

Despite the fact that the adverse health effects of tobacco smoking were officially recognised over 50 years ago, smoking continues to be the leading cause of preventable death worldwide.<sup>1</sup> Globally, over one billion people are regular smokers, and annually an estimated six million people die as a consequence of smoking.<sup>2</sup> The prevalence of smoking is highest in the reproductive age range, and approximately 10–20% of women in high-income countries smoke throughout pregnancy.<sup>3</sup> Smoking during pregnancy causes long-lasting epigenetic changes,<sup>4</sup> increases the risk for adverse health outcomes during fetal life and childhood<sup>1</sup> and may have long-term consequences in later life, even for subsequent generations.<sup>5</sup>

Besides active smoking, exposure to second-hand smoke (SHS) is responsible for an estimated 600,000 deaths and almost 11 million disability-adjusted life-years per year worldwide.<sup>6</sup> Maternal SHS exposure during pregnancy is associated with increased risks for stillbirth, low birthweight and paediatric asthma.<sup>1,7–10</sup> After birth, an estimated 40–50% of the world's children are regularly exposed to SHS, primarily by being around smoking parents and/or other household members.<sup>6,11</sup> As a result, children make up over a quarter of all deaths and over half of all disability-adjusted life-years associated with SHS exposure.<sup>6</sup> These estimates are based on the impact of SHS on respiratory tract infections (RTIs) and asthma only, and the estimated burden of death and disease is likely much larger when in addition considering other SHS-associated outcomes including adverse perinatal outcomes, sudden infant death syndrome (SIDS) and invasive meningococcal infections.<sup>6,12–14</sup>

To avoid this preventable burden of death and disease from smoking and exposure to SHS, the World Health Organization (WHO) established the international FCTC (Framework Convention on Tobacco Control) in 2005.<sup>2</sup> Having been ratified by 180 countries, this treaty currently covers more than 90% of the world's population.<sup>15</sup> To support participating countries in implementing the agreements within the FCTC, the WHO introduced a set of six policy measures in 2008 (represented by the MPOWER acronym—Figure 1).<sup>2</sup> As part of the MPOWER measures, the WHO urges all countries to protect their people from exposure to SHS by introducing comprehensive smoke-free legislation to prohibit smoking in all indoor public spaces, including workplaces.<sup>2</sup> Besides reductions in SHS exposure, smoke-free laws have also been associated with decreases in smoking prevalence and in young people taking up smoking.<sup>16,17</sup> There is also consistent evidence for an association between smoke-free legislation and reductions in hospital admissions and deaths owing to tobacco-associated cardiovascular and respiratory diseases among adults.<sup>18,19</sup> As developing humans, children are particularly vulnerable to tobacco smoke and generally cannot control their own exposure to tobacco smoke. It is therefore important to consider the potential benefits of smoke-free legislation to child health via reducing both antenatal and postnatal SHS exposure.

## AIM

The aim of this paper is to present an overview of the scientific literature on the link between smoke-free legislation and perinatal and paediatric health outcomes.

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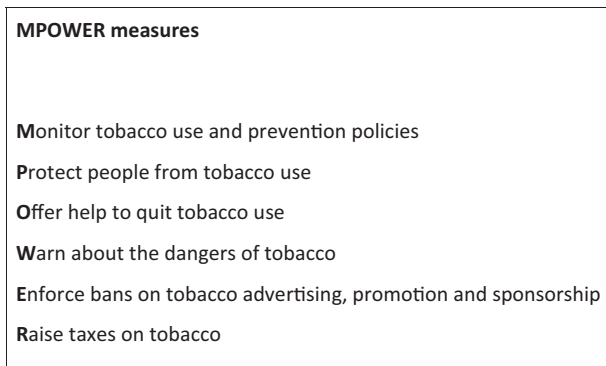
## IDENTIFICATION OF PAPERS

We performed a semi-structured search in PubMed to identify recently published studies from 2005 up to June 2016, using the following search equation: '(smok\* OR tobacco OR cigar\*) AND (legislation\* OR policy OR policies OR ban OR bans OR law OR laws) AND (fetus OR fetal OR stillbirth OR newborn OR neonatal OR baby OR babies OR infant OR child)'. We searched for studies that examined the association between the introduction of smoke-free legislation and health-related outcomes among (unborn) children.

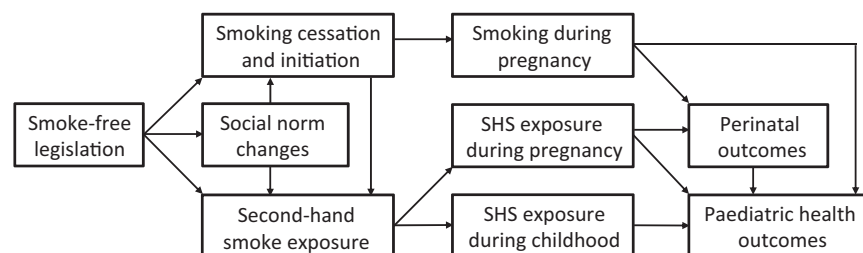
## STUDYING THE LINK BETWEEN SMOKE-FREE LEGISLATION AND CHILD HEALTH

A randomised controlled trial is generally considered the optimal design to study the effectiveness of health interventions. National public health policies such as the implementation of smoke-free legislation are, however, generally not amendable to being implemented in a randomised fashion. In such situations, it is therefore necessary to consider alternative options to make causal inferences regarding the relationship between an intervention and health outcomes.<sup>20,21</sup>

Quasi-experimental studies, such as controlled before–after studies and interrupted time series studies, can provide a robust alternative to randomised controlled trials in such situations and have been used to assess the potential population health benefits of smoke-free legislation.<sup>22</sup> Assessing causality from such studies is, however, difficult owing to the inherent risk of bias and confounding. Studies should therefore be carefully designed, and in attempting to make causal inferences, it is (among other things) important to develop logic models of how the intervention might work and what process measures might help to shed light on the



**Figure 1.** MPOWER measures. MPOWER is an acronym of the six categories of tobacco control measures recommended by the World Health Organisation to combat the death and disease burden caused by smoking and exposure to second-hand smoke. Source: WHO report on the global tobacco epidemic, 2015: raising taxes on tobacco.<sup>2</sup>



**Figure 2.** Likely causal pathways between smoke-free legislation and perinatal and paediatric health outcomes. Source: Adapted from Peelen *et al.*<sup>24</sup>

mechanisms of action, the effect size and consistency of the evidence.<sup>23</sup>

## SMOKE-FREE LEGISLATION AND CHILD HEALTH: LIKELY CAUSAL PATHWAYS

One may argue that children are unlikely to be sensitive to a policy change primarily aimed at reducing SHS exposure in public places such as the workplace, bars and restaurants. Findings from several studies, however, provide support for a number of pathways underlying a potential causal link between smoke-free legislation and improved child health. We have summarised these in a directed acyclic graph (Figure 2), and we discuss the supporting evidence below, by timing of tobacco smoke exposure: antenatal versus postnatal.

### Maternal smoking, SHS exposure and adverse pregnancy outcomes

When a pregnant woman smokes or is exposed to SHS, many constituents of tobacco smoke readily cross the placenta and expose the developing fetus to the associated health risks.<sup>25</sup> Active maternal smoking during pregnancy is a recognised risk factor for a variety of adverse pregnancy outcomes, including stillbirth,<sup>7</sup> low birthweight,<sup>1</sup> preterm birth,<sup>26</sup> small for gestational age (SGA) birth,<sup>27</sup> congenital anomalies<sup>28</sup> and neonatal mortality.<sup>1</sup> It is, in addition, associated with adverse health outcomes during childhood, including SIDS,<sup>14</sup> wheezing/asthma<sup>29,30</sup> and RTIs (Table 1).<sup>32</sup> Smoking cessation during pregnancy has been shown to normalise many of these risks.<sup>34–36</sup>

Similar to active smoking, SHS exposure during pregnancy is associated with increased risks of stillbirth,<sup>8</sup> low birthweight,<sup>9</sup> congenital anomalies<sup>8</sup> and development of childhood wheezing/asthma (Table 1).<sup>30</sup> Although very few studies have evaluated the effectiveness of interventions to reduce SHS exposure during pregnancy,<sup>37</sup> it appears that such interventions have the potential to improve birth outcomes, which include reducing the incidence of very low birthweight and very preterm birth.<sup>38</sup> This suggests that, similar to the perinatal health risks associated with active smoking during pregnancy, those related to SHS exposure are indeed avoidable.

### Smoke-free legislation and maternal smoking and SHS exposure

A number of studies support a link between the implementation of smoke-free laws and a reduction in maternal smoking during pregnancy.<sup>39–44</sup> In Scotland, for example, the prevalence of maternal smoking during pregnancy decreased from 25.4 to 18.8% ( $P < 0.001$ ) after the 2006 implementation of comprehensive legislation prohibiting smoking in public places.<sup>42</sup> Improved perinatal outcomes, namely decrease in low birthweight and preterm delivery, were found among both women who smoked and those who did not smoke during pregnancy.<sup>42</sup> This suggests that reductions in both active smoking and SHS exposure during pregnancy contribute to the observed

**Table 1.** Selected child health outcomes associated with antenatal tobacco smoke exposure

Outcome	Effect size (95% CI)
<i>Maternal smoking during pregnancy</i>	
Perinatal outcomes	
Stillbirth	1.4 (1.27–1.46); ref. 7
Preterm birth	1.27 (1.21–1.33); ref. 26
Birth defects (gastrointestinal)	1.27 (1.18–1.35); ref. 28
Birth defects (cardiovascular)	1.09 (1.02–1.17); ref. 28
Birth defects (musculoskeletal)	1.16 (1.05–1.27); ref. 28
Birth defects (central nervous system)	1.10 (1.01–1.19); ref. 28
Childhood outcomes	
Sudden infant death syndrome	2.25 (2.03–2.50); ref. 14
Early wheezing (age ≤ 2 years)	1.33 (1.03–1.71); ref. 30
Recurrent wheezing	1.49 (1.33–1.67); ref. 31
Wheezing/asthma in ≥ 6-year-olds	1.22 (1.03–1.44); ref. 29
Lower respiratory infections	1.24 (1.11–1.38); ref. 32
Overweight	1.33 (1.23–1.44); ref. 33
Obesity	1.60 (1.37–1.88); ref. 33
<i>Maternal second-hand smoke exposure during pregnancy</i>	
Perinatal outcomes	
Stillbirth	1.23 (1.09–1.38); ref. 8
Low birthweight	1.32 (1.07–1.63); ref. 9
Birth defects	1.13 (1.01–1.26); ref. 8
Childhood outcomes	
Early wheezing (age ≤ 2 years)	1.11 (1.03–1.20); ref. 30

Outcomes with positive associations demonstrated in meta-analyses are shown.  
Abbreviation: CI, confidence interval.

**Table 2.** Selected child health outcomes associated with postnatal tobacco smoke exposure

Outcome	Effect size (95% CI)
Sudden infant death syndrome	1.97 (1.77–2.19); ref. 14
Early wheezing (age ≤ 2 years)	1.29 (1.19–1.40); ref. 30
Wheezing/asthma in ≥ 6-year-olds	1.30 (1.13–1.51); ref. 29
Hospitalisation for asthma exacerbation	1.85 (1.20–2.86); ref. 47
Lower respiratory infections	1.54 (1.40–1.69); ref. 32
Middle ear infection (including otitis media with effusion)	1.32 (1.20–1.45); ref. 48
Meningococcal disease	2.02 (1.52–2.69); ref. 13

Outcomes with positive associations demonstrated in meta-analyses are shown.  
Abbreviation: CI, confidence interval.

mediated via reducing SHS exposure beyond locations primarily targeted.

### SMOKE-FREE LEGISLATION AND EARLY-LIFE HEALTH OUTCOMES

Through the previously described changes in maternal smoking and antenatal and postnatal SHS exposure after the implementation of smoke-free legislation, one might expect to also observe changes in smoking- and SHS-associated perinatal and paediatric health outcomes. Below we discuss evidence from studies assessing the link between smoke-free legislation and perinatal and child health (summarised in Table 3).

#### Perinatal health outcomes

**Perinatal mortality.** Consistent with the recognised link between antenatal smoke exposure and perinatal mortality, the introduction of a comprehensive smoke-free law in England was associated with an immediate –7.8% (95% confidence interval (95% CI): –11.8 to –3.5) reduction in stillbirths and a –7.6% (–11.7 to –3.4) reduction in neonatal deaths.<sup>45</sup> We estimated that, per year, over 240 stillbirths and more than 100 neonatal deaths have been averted across England since the implementation of the legislation.<sup>45</sup> In a smaller study in the Netherlands, we did not observe a significant association between phased introduction of smoke-free legislation, introduced in conjunction with other tobacco control policies, and perinatal mortality.<sup>24</sup> We speculated that lack of enforcement and lower compliance compared with that in England may have attenuated the impact of smoke-free legislation on these outcomes in the Netherlands.<sup>63–67</sup> Other factors including methodological and population differences may also have contributed to the discrepant findings, and additional studies are needed to investigate the impact of comprehensive smoke-free legislation on perinatal mortality.

**Low birthweight.** In a systematic review published in 2014,<sup>58</sup> we identified six studies assessing the association between smoke-free legislation and low birthweight.<sup>41,42,44,68–70</sup> One study demonstrated an immediate reduction in low birthweight,<sup>42</sup> whereas another showed a gradual reduction.<sup>70</sup> In a meta-analysis combining all six studies, however, neither the immediate nor the gradual reduction was statistically significant.<sup>58</sup> Follow-on studies also show mixed evidence.<sup>24,40,45,59,71,72</sup> A closer look at this evidence suggests that reductions in low birthweight are generally observed in countries with the most comprehensive laws.<sup>40,42,45,59</sup>

drop in adverse perinatal outcomes sensitive to tobacco smoke.<sup>41,42,45</sup>

Although we are unaware of studies assessing the association between smoke-free legislation and SHS exposure during pregnancy specifically, significant reductions in SHS exposure among the general adult population were observed in the majority of studies on the topic.<sup>16,18</sup> Much of this effect is likely owing to the actual smoking restrictions in public places. Many studies have, in addition, demonstrated a drop in smoking initiation among the youth,<sup>17,46</sup> a drop in overall smoking prevalence and cigarette consumption and an increase in smoking cessation after the introduction of smoke-free legislation, likely contributing to the overall reduction in SHS exposure (Figure 2).<sup>16</sup>

#### SHS exposure and child health

Children's exposure to SHS is associated with SIDS,<sup>14</sup> wheezing/asthma,<sup>29,30,47</sup> RTIs,<sup>32</sup> otitis media with effusion<sup>48</sup> and meningococcal disease.<sup>13</sup> (Table 2) These risks have been shown to be independent of those associated with maternal smoking during pregnancy.<sup>14,30,32,48</sup>

#### Smoke-free legislation and childhood SHS exposure

Smoke-free legislation has been associated with reductions in SHS exposure among children in various countries.<sup>49–52</sup> Although smoke-free legislation is primarily aimed at reducing SHS exposure in public places, the primary location for children to be exposed is the home environment.<sup>53,54</sup> In this context, it is important to note that, in addition to reducing SHS exposure in public places, implementation of smoke-free legislation is also associated with reductions in smoking at home and with increased adoption of home-smoking bans.<sup>53–57</sup> This illustrates how, through norm spreading, smoke-free legislation may carry additional benefits

**Table 3.** Association between smoke-free legislation and changes in child health outcomes

Outcome	Effect size (95% CI)	Study type	Location(s)	Legislation comprehensive?
<i>Perinatal outcomes</i>				
Stillbirth	−7.8% (−11.8 to −3.5); ref. 45	ITS	England	Yes
	−1% (−9 to 8)/−3% (−12 to 6); ref. 24	ITS	Netherlands	No
Low birthweight	−1.7% (−5.1 to 1.6); ref. 58	MA	Belgium, Norway, Scotland, USA	Mixed
Very low birthweight	−35.4% (−111.1 to 40.3); ref. 58	MA	Norway, USA	No
Preterm birth	−10.4% (−18.8 to −2.0); ref. 58	MA	Belgium, Norway, Scotland, USA	Mixed
Very preterm birth	−17.4% (−26.9 to −6.7); ref. 42	ITS	Scotland	Yes
	−2.3% <sup>a</sup> (−3.7 to −0.9); ref. 59	ITS	Quebec, Canada	Yes
	−6% (−14 to 3)/−11% (−19 to −3); ref. 24	ITS	Netherlands	No
SGA	−1.4% (−3.2 to 0.4); ref. 58	MA	Belgium, Ireland, Scotland	Mixed
Very SGA	−5.3% (−5.4 to −5.2); ref. 58	MA	Ireland, Scotland	Yes
Congenital anomalies	1% (−6 to 8)/−2% (−9 to 6); ref. 24	ITS	Netherlands	No
	−0.03% <sup>a</sup> (−4.0 to 3.9); ref. 41	CITS	Norway	No
Neonatal mortality	−7.6% (−11.7 to −3.4); ref. 45	ITS	England	Yes
	−3% (−16 to 12)/−12% (−24 to 2); ref. 24	ITS	Netherlands	No
<i>Childhood outcomes</i>				
Infant mortality	−6.3% (−9.6 to −2.9); ref. 45	ITS	England	Yes
Sudden infant death syndrome	1.8% (−8.4 to 13.2); ref. 45	ITS	England	Yes
Asthma hospital attendance	−10.1% (−15.2 to −5.0); ref. 58	MA	Canada, England, USA	Mixed
RTI hospital admissions	−3.5% (−4.5 to −2.3); ref. 60	ITS	England	Yes
Lower RTI hospital admissions	−13.8% (−15.6 to −12.0); ref. 60	ITS	England	Yes
	−33.5% (−36.4 to −30.5); ref. 61	ITS	Hong Kong	Yes
Lower RTI emergency department visits	−8% (−13 to −4%); ref. 62	CITS	USA	Mixed

For each outcome, findings from meta-analysis are shown where available; findings from individual studies are shown otherwise. For the study conducted in the Netherlands, figures represent the impact of smoke-free legislation in the workplace, and extension to bars and restaurants, respectively.

Abbreviations: CI, confidence interval; CITS, interrupted time series with control group; ITS, interrupted time series; MA, meta-analysis; RTI, respiratory tract infection; SGA, small for gestational age.

<sup>a</sup>Absolute change (percentage points).

Low birthweight is usually the result of either short gestation (preterm birth) or fetal growth restriction (SGA), and a number of studies have evaluated the association between smoke-free legislation and these outcomes.

**Preterm birth.** In our systematic review on smoke-free legislation and child health, we identified four studies investigating the association with preterm birth.<sup>41,42,44,69</sup> Three demonstrated a statistically significant decrease in preterm birth,<sup>42,44,69</sup> resulting in a pooled reduction of −10.4% (95% CI: −18.8 to −2.0) in meta-analysis.<sup>58</sup> The association between smoke-free legislation and a drop in preterm birth was later confirmed in Quebec.<sup>59</sup> A recent Swiss study provided evidence of a 'dose-response' relationship, with the largest reductions in preterm births observed among pregnancies that were fully protected by smoke-free legislation (versus only from the second or third trimester) and in areas with the most comprehensive legislation.<sup>73</sup> Furthermore, a reduction in very preterm births was observed following extension of the smoke-free workplace law in the Netherlands to include hospitality venues.<sup>24</sup> On the other hand, two large evaluations of local US smoke-free laws failed to demonstrate a link between smoke-free laws and preterm birth.<sup>71,72</sup> A systematic and comprehensive assessment of the strengths and weaknesses of these studies, and the coverage and enforcement of and compliance with the legislation in relation to the reported effect sizes, is ongoing and will help to better understand the discrepant findings.<sup>74</sup>

**Small for gestational age.** Being SGA is a more specific indicator of intrauterine growth restriction than is low birthweight, as it takes into account the gestational age of the baby. Several studies

support a link between smoke-free legislation and a reduction in the risk of babies being born SGA. In a meta-analysis of three studies, although the overall reduction in SGA babies was not statistically significant (−1.40%, 95% CI: −3.20 to 0.40), the number of very SGA babies dropped by −5.30% (95% CI: −5.42 to −5.18).<sup>58</sup> Follow-on work conducted in Quebec and the Netherlands also showed significant reductions in the risk for SGA birth following smoke-free legislation.<sup>24,59</sup> Again, this was mainly owing to a reduction in very SGA births.<sup>24</sup>

#### Child health outcomes

**Infant mortality.** In our analysis of the smoke-free law in England, we observed an immediate reduction in infant mortality (−6.3%, 95% CI: −9.6 to −2.9) following its implementation.<sup>45</sup> This was mainly attributable to the reduction in neonatal deaths described earlier.<sup>45</sup> Despite the strong epidemiological link between SHS exposure and SIDS, we did not, however, observe a significant change in the odds of SIDS in this study. Although an ecological study in the United States did demonstrate an association between strong smoke-free policies and reduced SIDS incidence,<sup>75</sup> this was not confirmed in a multi-country analysis conducted by the same researchers.<sup>76</sup> Thus, although smoke-free legislation appears to be associated with an overall reduction in infant mortality,<sup>45</sup> this cannot be attributed to a reduction in SIDS.

**Asthma.** Asthma remains the most common chronic disease in childhood,<sup>77</sup> and childhood asthma is linked to the development of long-term reduced lung function and chronic obstructive pulmonary disease.<sup>78</sup> Consistent evidence supports an association

between smoke-free legislation and a reduction in childhood hospital attendance for asthma exacerbations. In our systematic review, we identified four studies evaluating this link.<sup>79–82</sup> In a meta-analysis, the implementation of smoke-free legislation was associated with a  $-10.1\%$  (95% CI:  $-15.2$  to  $-5.0$ ) decrease in paediatric emergency department visits and hospital admissions for asthma.<sup>58</sup> This association was confirmed in later studies conducted in the United States,<sup>62,83,84</sup> and is in line with meta-analyses of adult studies demonstrating a link between smoke-free legislation and a reduction in severe respiratory events (i.e., deaths or hospital admissions).<sup>19</sup> Other studies show that smoke-free policies do not affect overall asthma incidence among children, suggesting that the observed reductions in hospital attendance are indeed the result of a drop in asthma exacerbations.<sup>85,86</sup>

**Respiratory tract infections.** RTIs account for the majority of the disease burden associated with SHS exposure among children.<sup>6</sup> In our 2014 systematic review, we did not, however, identify any studies that investigated the association between the implementation of smoke-free legislation and RTIs.<sup>58</sup> We addressed this in an evaluation of the 2007 comprehensive smoke-free law in England, using data of over 1.6 million paediatric hospital admissions for RTIs over a 12-year period. There was an immediate  $-3.5\%$  (95% CI:  $-4.7$  to  $-2.3$ ) decrease in RTI admissions, which was mainly attributable to a reduction in lower RTI admissions ( $-13.8\%$  (95% CI:  $-15.6$  to  $-12.0$ )).<sup>60</sup> This translated into an estimated  $\sim 11,000$  paediatric RTI hospital admissions being averted per year during the first 5 years following the implementation of smoke-free legislation. This link between smoke-free legislation and a reduction in hospital attendance for paediatric lower RTIs was recently confirmed in an evaluation of the 2007 comprehensive smoke-free law in Hong Kong,<sup>61</sup> and a multi-state analysis in the United States.<sup>62</sup> Similar to the studies on asthma, although hospital admissions for RTIs went down after smoke-free legislation,<sup>60–62</sup> there did not appear to have been an overall reduction in RTI incidence.<sup>85</sup> The observed drops in RTI hospitalisations are therefore more likely to represent reductions in disease severity rather than incidence, consistent with epidemiological evidence identifying SHS as a risk factor for severe RTI presentations among children.<sup>87,88</sup>

#### Smoke-free legislation and health inequalities

Tobacco smoking and SHS exposure are important drivers of socio-economic disparities in health outcomes and life expectancy. There are concerns regarding the potential for certain tobacco control policies to have a negative equity impact.<sup>89</sup> In England, the reduction in paediatric RTI admissions following the smoke-free law was largest among children from deprived areas, suggesting that a pro-equity effect may be present.<sup>60</sup> There was, however, no differential association between smoke-free legislation and child health according to socio-economic status in other studies having evaluated this.<sup>59,72,80</sup>

#### INTERPRETING THE EVIDENCE

Clearly over recent years, the evidence base assessing the potential links between smoke-free legislation and population health, including that of children, has grown substantially. Interpretation of the totality of evidence is, however, complicated not only by the fact that it is derived from quasi-experimental evaluations but also by the range of additional potential sources of variation between studies. Examples include geographical location, population demographics, comprehensiveness and enforcement of the legislation, public support for and compliance with the law, degree of associated social norm spreading and methodological aspects of the studies, including choice of

statistical models and approaches to handling sources of bias and potential confounding. Such factors may have contributed to some of the observed inconsistencies between findings of individual studies. Meta-epidemiological evaluations of studies assessing health outcomes following smoke-free legislation among adults have already allowed some of this variation to be taken into account when interpreting the evidence.<sup>19</sup> With the number of studies in the paediatric field continuing to increase, similar opportunities now open up to further increase confidence in the conclusions made according to these studies.<sup>74</sup>

#### IMPLICATIONS FOR POLICY AND PRACTICE

Despite the limitations of the existing evidence base, it provides considerable support for a link between smoke-free legislation and improved perinatal and child health outcomes. Reductions in maternal smoking during pregnancy and in SHS exposure during pregnancy and childhood are likely to be the main drivers behind the observed reductions in adverse early-life health outcomes (Figure 2). The observed associations are in line with the recognised causal links between prenatal and childhood tobacco smoke exposure and adverse perinatal and paediatric health outcomes, as well as the already recognised substantial population health effects of smoke-free policies among adults.<sup>16,18,19,58</sup> Improved compliance with WHO guidelines to address the ongoing global tobacco epidemic and reduce its associated substantial burden of death and disease is clearly needed so that more and more (unborn) children as well as adults can enjoy these health benefits. Over 80% of the world's population, however, currently remains unprotected by comprehensive smoke-free laws, and global compliance with other MPOWER policies is smaller still.<sup>2</sup> Smoke-free laws are generally well supported by the public and appear highly cost-effective.<sup>90,91</sup> It is crucial for policymakers to realise that such policies are most effective in reducing SHS exposure and improving population health when implemented in a comprehensive manner (i.e., covering both workplaces and the hospitality industry).<sup>19,40,92</sup> Smoke-free laws should ideally be part of an integrated tobacco endgame strategy in which, among other aspects, tobacco tax increase is an important element.<sup>93</sup> Tobacco taxes are considered the most effective measure to reduce tobacco use,<sup>2</sup> and have been demonstrated to also benefit perinatal and infant health via reductions in maternal smoking rates during pregnancy.<sup>39,72,76,94,95</sup>

Protecting (unborn) children from the adverse impact of tobacco smoking and SHS exposure should be a key priority for policymakers and health workers alike. Health practitioners have a responsibility to discuss the dangers of active smoking and second- and third-hand smoke exposure (i.e., exposure to toxic tobacco constituents via clothing, curtains, carpets, etc.) in relation to children's health with relevant family members and pre-conceptional and pregnant women. They should be aware of the existing local care pathways to support smoking cessation and be ready to offer cessation advice and pharmacological support when necessary.

#### KNOWLEDGE GAPS AND FUTURE RESEARCH

Now that several health benefits of comprehensive legislation to prohibit smoking in indoor public places have been established, there is a need to evaluate the effectiveness of reducing SHS exposure in other places. An increasing number of countries are now implementing laws to protect children from SHS in outdoor areas (e.g., playgrounds, school grounds, parks, beaches) and private environments, such as cars.<sup>2,96–99</sup> There is a need to evaluate the effectiveness of such policies in reducing SHS exposure, denormalising smoking and improving child health to inform policymakers in other countries that may be considering

implementing similar legislation. There is furthermore a need to identify the effectiveness of additional policy strategies, such as tobacco taxes and mass media campaigns, and combinations of such policies to, in particular, improve child health and reduce smoking initiation among children. Ongoing work to collate existing studies on tobacco control policies and child health via a systematic review will help provide a comprehensive assessment of the available evidence on this topic.<sup>74</sup> Given the shifting burden of smoking and tobacco-related death and disease from high-income to low- and middle-income countries, there is a particular need to assess the impact of tobacco control strategies in such countries and develop tools to support their policymakers in prioritising the most effective policies to improve population health.<sup>58</sup> In parallel to such policy-based evaluations, researchers should continue to develop, evaluate and help implement strategies and interventions to prevent SHS exposure among children at the individual, family and community level.

### Conclusions

Evidence suggests that comprehensive smoke-free legislation is associated with reductions in perinatal mortality, preterm birth and paediatric hospital admissions for RTIs and asthma.<sup>45,58,60,61</sup> There is a clear need for wider implementation of comprehensive smoke-free policies across the globe as a key constituent of tobacco endgame strategies in accordance with FCTC recommendations to improve the population health of (unborn) children and adults alike.<sup>2</sup>

### CONTRIBUTIONS

TF performed literature searches and wrote the first draft. JVB co-wrote the paper, and JVB and AS supervised the writing process. IKR and JPM contributed to the writing.

### COMPETING INTERESTS

AS is joint editor-in-chief of *npjPCRM*. He was not involved in the decision to commission this review and had no role in the handling process or peer review of this work. The remaining authors declare no conflict of interest.

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