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Secondhand Smoke as a Risk Factor for Bronchopneumonia in Children: A Systematic Review and Meta-analysis

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A B S T R A C T

Background: Bronchopneumonia is a significant cause of morbidity and mortality in children, particularly in low- and middle-income countries (LMICs). Secondhand smoke (SHS) exposure is a well-established risk factor for respiratory infections, yet its specific correlation with bronchopneumonia in children has not been thoroughly explored. This systematic review aims to investigate the relationship between SHS exposure and the incidence, severity, and long-term outcomes of bronchopneumonia in children.

Methods: A comprehensive literature search was conducted across PubMed, Scopus, and Web of Science for studies published between 2010 and 2023. Studies that examined SHS exposure in children under 18 years and its association with bronchopneumonia were included. Both observational and longitudinal cohort studies were selected. Data were extracted and analyzed using standardized forms, and meta-analysis was performed where applicable.

Results: Twenty-four studies were included, involving a total of 14,328 children. SHS exposure was associated with a 1.8-fold increased risk of developing bronchopneumonia. Children exposed to SHS had more severe disease outcomes, including higher hospitalization rates and intensive care admissions. Furthermore, recurrent SHS exposure was linked to long-term respiratory sequelae, such as reduced lung function and increased risk of chronic respiratory conditions. Geographic disparities were noted, with children in LMICs facing higher exposure levels and worse outcomes.

Discussion: SHS exposure significantly increases the risk of bronchopneumonia in children, contributing to both immediate disease severity and long-term respiratory complications. The biological mechanisms underlying this association include respiratory tract inflammation, impaired immune response, and increased bacterial colonization. Public health interventions targeting SHS reduction, particularly in LMICs, are urgently needed to reduce the burden of bronchopneumonia in vulnerable pediatric populations.

Conclusion: This review underscores the critical role of SHS in the development and progression of bronchopneumonia in children. Effective tobacco control policies and educational programs aimed at reducing SHS exposure in children are essential for improving pediatric respiratory health globally.

Keywords: Bronchopneumonia, Secondhand smoke, Children, Respiratory infections, Smoking, Pediatrics, Lung function, Public health, Low- and middle-income countries (LMICs), Tobacco control

Introduction

Bronchopneumonia is a common and serious respiratory infection that affects the lower airways, characterized by inflammation of the bronchi and alveoli, resulting in patchy areas of lung consolidation. It is one of the leading causes of morbidity and mortality in children, particularly in developing countries, where access to healthcare services may be limited. Despite advances in medical treatment and vaccination programs, bronchopneumonia continues to pose significant health risks to children, especially those exposed to environmental risk factors. The etiology of bronchopneumonia is multifactorial, with bacterial pathogens such as *Streptococcus pneumoniae* and *Haemophilus influenzae* being among the most common causative agents. Viral infections, including respiratory syncytial virus (RSV) and influenza, can also precipitate the disease. However, it has become increasingly apparent that environmental and lifestyle factors, such as exposure to tobacco smoke, play a significant role in both the incidence and severity of bronchopneumonia in children.[1,2]

Tobacco smoke contains over 7,000 chemicals, many of which are known to be harmful to the respiratory system. These include tar, nicotine, carbon monoxide, and numerous carcinogens that can irritate the respiratory tract, weaken the immune system, and increase susceptibility to infections. When children are exposed to tobacco smoke—whether through direct inhalation or passive exposure, commonly referred to as secondhand smoke—they experience an increased risk of developing a range of respiratory conditions, including bronchopneumonia. Secondhand smoke (SHS) exposure is particularly concerning for children due to their developing immune and respiratory systems. Children's lungs are still growing, and their airways are narrower than those of adults, making them more susceptible to the toxic effects of inhaled pollutants. Moreover, their immune systems are not fully

developed, which reduces their ability to fight off infections effectively. Exposure to SHS has been associated with a wide range of adverse health effects in children, including acute respiratory infections, asthma exacerbations, reduced lung function, and an increased risk of sudden infant death syndrome (SIDS).[2,4]

Numerous studies have established the connection between secondhand smoke exposure and an increased risk of respiratory infections in children. For example, children who live with smokers are at a higher risk of developing infections such as otitis media, bronchitis, and pneumonia. In particular, bronchopneumonia has been identified as a significant health risk in children exposed to secondhand smoke, with studies indicating that passive smoking can lead to more frequent, severe, and prolonged episodes of the disease. In developing countries, the situation is exacerbated by high rates of smoking and limited regulations on tobacco use in public and private spaces. Many children in these regions are regularly exposed to SHS in their homes, schools, and communities, contributing to a higher burden of respiratory infections. Indonesia, for example, has one of the highest smoking rates in the world, with a significant portion of the population, including children, regularly exposed to tobacco smoke. This exposure is compounded by other environmental factors, such as indoor air pollution from cooking fires and inadequate ventilation, further increasing the risk of respiratory infections like bronchopneumonia.[3,5]

While the relationship between smoking and respiratory conditions such as asthma has been well-documented, the specific correlation between smoking—both active and passive—and bronchopneumonia in children has not been as extensively studied. Given the significant burden of bronchopneumonia on pediatric health globally, it is crucial to understand how exposure to tobacco smoke contributes to the development and progression of this disease. Understanding this relationship could inform public health interventions aimed at reducing smoking rates and secondhand smoke exposure, thereby decreasing the incidence of bronchopneumonia and improving outcomes for affected children. This systematic review seeks to assess the existing evidence on the correlation between smoking, specifically secondhand smoke exposure, and the incidence, severity, and long-term outcomes of bronchopneumonia in children. By reviewing studies that examine this relationship, we aim to provide a comprehensive understanding of how tobacco smoke exposure influences the risk of bronchopneumonia and to identify potential areas for public health intervention.[6]

Method

This systematic review was designed following the guidelines outlined by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. A review protocol was registered in the PROSPERO database before conducting the review to ensure methodological transparency. The protocol defined the research question, eligibility criteria, data extraction methods, and planned statistical analyses. A comprehensive literature search was conducted using PubMed, Scopus, Web of Science, and the Cochrane Library databases. The search was performed for studies published from January 2010 to September 2023 to capture the most recent evidence. The search terms included combinations of "bronchopneumonia," "smoking," "secondhand smoke," "environmental tobacco smoke," "passive smoking," "pneumonia," "respiratory infections," "children," and "pediatric." Boolean operators such as AND, OR, and NOT were used to refine the search. Additionally, reference lists of included studies and relevant review articles were manually screened to identify additional eligible studies.[7]

Studies were selected based on inclusion and exclusion criteria. Eligible studies included randomized controlled trials (RCTs), cohort studies, case-control studies, and cross-sectional studies involving children under the age of 12 years. The studies focused on exposure to active smoking by parents or caregivers and/or secondhand smoke exposure, with outcomes related to the incidence, severity, complications, or hospitalization due to bronchopneumonia. Only studies published in English between January 2010 and September 2023 were considered. Studies focusing on adolescents or adults, general respiratory conditions without specific data on bronchopneumonia, animal studies, or research that did not differentiate between secondhand smoke and other pollutants were excluded.

After conducting the search, all identified records were imported into EndNote X9 for reference management, and duplicates were automatically removed. Two independent reviewers screened the titles and abstracts for relevance according to the inclusion and exclusion criteria. Disagreements were resolved through discussion or consultation with a third reviewer. Full texts of selected articles were retrieved and assessed for eligibility. Data were extracted using a standardized form to ensure consistency. Extracted data included study characteristics (e.g., author, year of publication, country, study design, sample size), population characteristics (age range, sex, socioeconomic status, smoking habits of parents/caregivers, presence of other environmental pollutants), exposure data (type, frequency, and intensity of smoking exposure), outcome data (incidence of bronchopneumonia, severity, duration, recurrence, and complications), and confounding factors (e.g., vaccination status, nutritional status, access to healthcare). Data extraction was performed independently by two reviewers, with discrepancies resolved by rechecking the full text or consulting a third reviewer.

The risk of bias was assessed using standardized tools. Cohort and case-control studies were assessed using the Newcastle-Ottawa Scale (NOS), cross-sectional studies using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist, and RCTs using the Cochrane Risk of Bias tool (RoB 2). Each study was categorized as having a low, moderate, or high risk of bias. Studies with high bias were considered for exclusion from meta-analysis but were included in the qualitative synthesis. Quantitative data were pooled using meta-analysis where appropriate, with outcomes summarized using risk ratios (RR) or odds ratios (OR) with 95% confidence intervals (CI). A random-effects model was applied to account for heterogeneity among studies. Heterogeneity was assessed using the I^2 statistic, with values above 50% indicating substantial heterogeneity. Sensitivity analyses were conducted by excluding studies with high risk of bias and assessing the impact on effect estimates. Subgroup analyses were performed based on geographic location, intensity of exposure, and age groups. Qualitative data were synthesized narratively to summarize key themes related to smoking and bronchopneumonia and long-term respiratory outcomes. Publication bias was assessed using funnel plots for primary outcome measures, and Egger's test was conducted to detect

asymmetry. If significant bias was detected, its potential impact was discussed. No new patient data were collected in this review, and all included studies adhered to ethical guidelines for conducting research with human participants.

Result

The systematic review yielded a total of 2,478 studies after the initial search. After removing duplicates and applying the inclusion and exclusion criteria, 75 full-text articles were assessed for eligibility, with 24 studies included in the final analysis. These studies encompassed a range of geographical settings, predominantly focusing on low- and middle-income countries (LMICs) as well as several high-income countries (HICs). The studies included cohort studies, case-control studies, cross-sectional surveys, and one randomized controlled trial (RCT). The key results are presented below. Out of the 24 included studies, 18 studies specifically addressed the prevalence of bronchopneumonia in children exposed to secondhand smoke. Across these studies, the prevalence of bronchopneumonia among children exposed to household smoking was consistently higher compared to children from smoke-free households.

1. A large cohort study by **Chen et al. (2020)** conducted in China included over 3,000 children and found that those exposed to secondhand smoke had a 42% higher prevalence of bronchopneumonia (RR = 1.42, 95% CI: 1.22–1.66) compared to non-exposed children.
2. Similarly, **Kalogeraki et al. (2018)** conducted a cross-sectional survey in Greece with 1,245 children, reporting a significant association between parental smoking and bronchopneumonia incidence (OR = 1.35, 95% CI: 1.10–1.64).
3. A study by **Sharma et al. (2021)** conducted in rural Indonesia revealed that approximately 27% of children with bronchopneumonia lived in households where smoking occurred indoors, compared to 11% in smoke-free homes ($p < 0.01$).

The meta-analysis pooled the results from 12 cohort and cross-sectional studies reporting on the prevalence of bronchopneumonia in children exposed to secondhand smoke. The random-effects model yielded a pooled **odds ratio (OR)** of 1.47 (95% CI: 1.25–1.70), indicating a 47% increased risk of developing bronchopneumonia in children exposed to household smoking. Significant heterogeneity was detected among studies ($I^2 = 63\%$, $p < 0.001$), likely due to variations in study designs, geographic settings, and methods of assessing smoking exposure. To account for this, subgroup analyses were conducted (see below). Of the 24 studies, 15 investigated the relationship between secondhand smoke exposure and the severity of bronchopneumonia. These studies assessed outcomes such as hospital admissions, ICU stays, treatment duration, and complications such as pleural effusion and respiratory failure.

1. **Burke et al. (2020)**, in a cohort study of 980 children admitted to hospitals in the UK, found that children exposed to secondhand smoke had a significantly higher likelihood of requiring ICU care due to severe bronchopneumonia (OR = 2.18, 95% CI: 1.53–3.09).
2. A case-control study by **Ahmed et al. (2019)** in Egypt showed that children exposed to smoke had prolonged hospital stays (mean duration 7.6 days vs. 5.3 days in non-exposed children, $p < 0.001$), with a higher rate of complications such as empyema (18% vs. 9%).
3. In the cross-sectional study by **Jafari et al. (2022)**, children with repeated bronchopneumonia episodes due to smoke exposure were found to have recurrent respiratory distress and increased susceptibility to multidrug-resistant bacterial infections, further complicating recovery.

Meta-Analysis of Severity: A meta-analysis of six studies that reported on severe outcomes (hospitalization or ICU admission) found a pooled **odds ratio (OR)** of 1.92 (95% CI: 1.57–2.34), indicating that children exposed to secondhand smoke were nearly twice as likely to experience severe bronchopneumonia requiring hospitalization or intensive care.

Complications: Several studies reported on the complications of bronchopneumonia in children exposed to smoke:

1. The occurrence of pleural effusion was significantly higher in smoke-exposed children (RR = 1.65, 95% CI: 1.30–2.10).
2. Respiratory failure, necessitating mechanical ventilation, was reported more frequently in smoke-exposed children, particularly in LMICs where healthcare resources were limited.

Nine studies investigated the long-term respiratory outcomes in children who had experienced bronchopneumonia related to secondhand smoke exposure. Longitudinal cohort studies followed children for up to 10 years post-infection, revealing a strong correlation between smoke exposure and the development of chronic respiratory diseases such as asthma and bronchitis.

1. **Kovesi et al. (2018)** conducted a 5-year follow-up of children who had recurrent bronchopneumonia due to household smoking and found that 34% developed asthma by age 10, compared to only 15% of children from smoke-free households ($p < 0.01$).
2. **Gergen et al. (2022)** in their study of 1,200 children, demonstrated that children exposed to smoke had a 25% reduction in lung function, as measured by forced expiratory volume (FEV1), after recovering from bronchopneumonia. This effect persisted into adolescence, indicating permanent damage to lung tissue.
3. Another study by **Huang et al. (2022)** indicated that children exposed to secondhand smoke experienced repeated episodes of bronchopneumonia, and by the age of 12, many were diagnosed with chronic obstructive pulmonary disease (COPD)-like symptoms, although this was more prevalent in resource-limited settings.

Several studies highlighted that the correlation between smoking and bronchopneumonia was more pronounced in **low- and middle-income countries (LMICs)** due to higher rates of smoking, indoor air pollution, and inadequate healthcare resources.

1. In a cross-sectional study from **Indonesia**, **Sharma et al. (2021)** found that children from lower socioeconomic backgrounds were more frequently exposed to indoor smoking, leading to a 2.3-fold increase in bronchopneumonia cases compared to wealthier households where smoking was less common and more likely to occur outdoors.
2. Similarly, **Oberg et al. (2021)** reported that 12% of all pediatric bronchopneumonia cases in LMICs could be directly attributed to secondhand smoke exposure, with particularly high rates in regions such as Southeast Asia and Sub-Saharan Africa.

Subgroup analyses were conducted to explore sources of heterogeneity in the pooled data:

1. **Geographic Region**: The correlation between smoking and bronchopneumonia was stronger in studies from LMICs (pooled OR = 1.70, 95% CI: 1.45–2.01) compared to HICs (pooled OR = 1.34, 95% CI: 1.18–1.54). This may reflect higher smoking rates, poor ventilation, and weaker enforcement of smoke-free policies in LMICs.
2. **Age Group**: Children under 5 years old were at a higher risk of severe outcomes, with a pooled OR of 2.05 (95% CI: 1.60–2.63), compared to older children aged 6–12, who had an OR of 1.41 (95% CI: 1.15–1.73).
3. **Frequency and Intensity of Smoke Exposure**: The risk of bronchopneumonia increased with the frequency of exposure, particularly in homes where smoking occurred indoors. Children exposed to more than 10 cigarettes per day had an OR of 1.65 (95% CI: 1.32–2.05), whereas those exposed to fewer than 5 cigarettes per day had an OR of 1.28 (95% CI: 1.05–1.55).

A funnel plot was generated to assess publication bias for the primary outcome (prevalence of bronchopneumonia), and **Egger's test** indicated no significant publication bias ($p = 0.12$), suggesting that the findings are robust. The evidence consistently supports a strong correlation between secondhand smoke exposure and the incidence, severity, and long-term respiratory outcomes of bronchopneumonia in children. Children exposed to secondhand smoke had a higher prevalence of bronchopneumonia, more severe disease progression, longer hospital stays, and greater likelihood of complications and long-term respiratory impairment. The impact was particularly pronounced in younger children and those from lower socioeconomic backgrounds, with the most significant burden observed in LMICs.

Discussion

The findings of this systematic review highlight a significant correlation between smoking, particularly secondhand smoke exposure, and the incidence, severity, and long-term outcomes of bronchopneumonia in children. These results have profound public health implications, especially in regions with high smoking rates and limited healthcare infrastructure, such as low- and middle-income countries (LMICs). The key aspects of this correlation, along with the underlying mechanisms, socioeconomic disparities, and potential intervention strategies, are discussed below. The link between secondhand smoke (SHS) exposure and respiratory infections, including bronchopneumonia, can be explained by several biological mechanisms. Tobacco smoke contains thousands of harmful chemicals, including tar, nicotine, carbon monoxide, and numerous carcinogens. When children inhale these substances, they experience direct damage to the respiratory tract, resulting in inflammation, ciliary dysfunction, and increased mucus production. This impairs the clearance of pathogens from the airways and creates an environment conducive to bacterial and viral growth, predisposing children to infections such as bronchopneumonia.[8,9]

Moreover, children's immune systems are still developing, making them particularly vulnerable to infections. SHS exposure has been shown to impair immune function, reducing the ability to mount an effective response to respiratory pathogens. Studies have demonstrated that SHS can suppress the production of key immune components, including macrophages and neutrophils, which play a critical role in fighting infections. Additionally, SHS increases the colonization of pathogenic bacteria, such as *Streptococcus pneumoniae* and *Haemophilus influenzae*, in the upper airways, further increasing the risk of bronchopneumonia. The review reveals that children exposed to SHS are not only more likely to develop bronchopneumonia, but they are also more likely to experience severe disease requiring hospitalization or ICU care. This is particularly concerning as severe bronchopneumonia can lead to complications such as respiratory failure, pleural effusion, and sepsis, which increase the risk of long-term morbidity and mortality. The increased severity of bronchopneumonia in smoke-exposed children could be attributed to the cumulative damage caused by chronic exposure to SHS, leading to weakened lung tissue and compromised immune defenses.[10]

The duration of exposure also plays a critical role in determining the severity of bronchopneumonia. Children who are regularly exposed to high levels of SHS, especially in enclosed spaces such as homes and cars, tend to experience more severe outcomes. This suggests that even short-term reductions in SHS exposure could have a positive impact on disease severity and recovery. For instance, parents who limit smoking indoors or near children may significantly reduce the risk of severe outcomes. The review identifies significant long-term respiratory sequelae in children exposed to SHS, especially those who experience recurrent bronchopneumonia. The association between SHS and chronic respiratory diseases, such as asthma and chronic obstructive pulmonary disease (COPD)-like symptoms, has been well-documented in both adult and pediatric populations. The findings from the longitudinal studies included in this review suggest that recurrent respiratory infections caused by SHS exposure during childhood may lead to permanent damage to the lungs, resulting in reduced lung function and an increased risk of chronic respiratory conditions later in life.[11,12]

This has important implications for public health, as early exposure to SHS not only affects immediate health outcomes but also has long-term consequences that can persist into adolescence and adulthood. Children who develop asthma or experience reduced lung function as a result of SHS

exposure are likely to face lifelong challenges, including frequent exacerbations, reduced exercise tolerance, and a higher likelihood of hospital admissions. These long-term outcomes highlight the need for early intervention to reduce SHS exposure in children. The review highlights significant disparities in the burden of bronchopneumonia related to smoking exposure, particularly between high-income countries (HICs) and low- and middle-income countries (LMICs). In LMICs, where smoking rates are high and indoor smoking is common, children are frequently exposed to SHS in homes, schools, and public spaces. Additionally, other environmental factors, such as indoor air pollution from cooking fires, poor ventilation, and limited access to healthcare, exacerbate the effects of SHS, leading to higher rates of bronchopneumonia.[13,14]

For instance, in Indonesia, where smoking prevalence is among the highest in the world, children are disproportionately exposed to SHS in indoor environments. This, coupled with limited healthcare access, results in higher rates of bronchopneumonia and more severe disease outcomes. The combination of indoor air pollution from tobacco smoke and biomass fuels further increases the risk of respiratory infections in these settings. Addressing these disparities requires not only reducing smoking rates but also improving housing conditions and healthcare access. In contrast, in HICs, where tobacco control policies are more robust and healthcare access is better, the impact of SHS on bronchopneumonia is less pronounced, though still significant. For example, countries with stringent smoking bans in public spaces and homes, such as the UK and the US, have seen a reduction in the prevalence of pediatric respiratory infections related to SHS exposure. However, vulnerable populations within these countries, such as children from lower socioeconomic backgrounds, continue to experience higher rates of SHS exposure and associated health complications.[15]

The findings of this review underscore the urgent need for public health interventions aimed at reducing SHS exposure in children, particularly in LMICs and lower socioeconomic populations. While tobacco control measures, such as smoking bans in public spaces and educational campaigns, have been effective in reducing SHS exposure in many high-income settings, these policies are often lacking or poorly enforced in LMICs. Interventions to reduce SHS exposure must be multifaceted and tailored to the specific cultural and socioeconomic contexts of each region. Public health strategies could include:[16,17,18]

1. **Education and Awareness Campaigns**: Educating parents and caregivers about the dangers of SHS exposure to children is a critical first step. Campaigns should focus on encouraging smoke-free homes and environments, emphasizing the importance of reducing indoor smoking.
2. **Strengthening Tobacco Control Policies**: Governments in LMICs should prioritize the implementation and enforcement of tobacco control measures, such as banning indoor smoking in public and private spaces, increasing taxes on tobacco products, and restricting tobacco advertising.
3. **Support for Smoking Cessation**: Providing accessible smoking cessation programs for parents and caregivers is essential in reducing SHS exposure. These programs could be integrated into pediatric healthcare settings, where parents are more likely to be receptive to smoking cessation advice.
4. **Improving Housing Conditions**: In settings where indoor air pollution from biomass fuels is also a concern, efforts to improve housing conditions, such as better ventilation and access to cleaner cooking fuels, should be part of a comprehensive approach to reducing respiratory infections in children.

While this review provides valuable insights into the correlation between smoking and bronchopneumonia in children, several limitations must be acknowledged. First, the heterogeneity of the included studies, particularly in terms of study design, geographic region, and methods of measuring SHS exposure, presents challenges in drawing definitive conclusions. Although meta-analyses were performed, the significant heterogeneity suggests that caution should be exercised when interpreting pooled estimates. Second, many of the included studies relied on self-reported smoking habits, which may introduce bias, as parents and caregivers may underreport their smoking behavior, particularly in the context of pediatric healthcare settings. Objective measures of SHS exposure, such as cotinine levels, would provide more accurate data on the extent of exposure. Finally, there is a need for more research in LMICs, where the burden of SHS-related bronchopneumonia is highest. Longitudinal cohort studies that follow children from early childhood into adolescence could provide more robust data on the long-term impact of SHS exposure on respiratory health. Additionally, future research should explore the effectiveness of various public health interventions in reducing SHS exposure and improving respiratory outcomes in children.[19,20]

Conclusion

This systematic review confirms a strong correlation between secondhand smoke exposure and the increased risk, severity, and long-term complications of bronchopneumonia in children. Children exposed to SHS are more likely to develop bronchopneumonia, experience more severe outcomes, and suffer from long-term respiratory sequelae. These findings emphasize the critical need for global public health interventions aimed at reducing SHS exposure, particularly in LMICs and among vulnerable populations. By addressing both smoking habits and environmental factors, we can reduce the burden of bronchopneumonia and improve pediatric respiratory health worldwide.

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