influenza

Effectiveness of School Closure for the Control of Influenza

A Review of Recent Evidence

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and Seyed Moghadas, PhD

Prepared for the
National Collaborating Centre
for Infectious Diseases
March 2014

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Introduction

Influenza poses a significant and recurring threat to population health, for which effective, evidence-informed public health responses to prevent and control the spread of infection and serious illness are needed. School closure has been considered as a possible intervention during community outbreaks of communicable diseases, including influenza. Despite continued use of the measure in some countries, particularly during the 2009 influenza H1N1 pandemic, there remains a lack of consensus on the effectiveness of school closure as a mitigation strategy for pandemic or seasonal influenza.

Theoretical support for school closures rests on the knowledge that school-aged children have high contact rates, tend to be more susceptible to influenza infection than other age groups, and have increased viral shedding (1). School closure can reduce influenza transmission among schoolchildren, and is expected to carry secondary benefits for the wider community (1). In practical terms, definitive evidence has been lacking to help guide the use of school closures in public health practice — that is, to help determine when closures may be warranted, for how long, or to what scale in a given community or region. As well, the question of whether school closures have had measurable effects on the severity of influenza outcomes (e.g. lower rate of hospitalization, need for intensive care, death) remains a critical question for consideration.

The implementation of school closure also raises important issues pertaining to high economic and social burden, in addition to difficult ethical considerations. Implementation of this measure requires a clear understanding of community health challenges, and an evaluation of potential health benefits weighed against economic and social costs. The ethical framework of decisions related to school closure is complex; however, explicit quantification of the potential benefits and costs of this strategy will allow public health planners and providers to balance the protection of community health against

Definitions of Key Terms

School closure: refers to cancellation of all classes for a period of time that lasts for at least one full school-day. During this period, students will not attend the school.

Reactive school closure: refers to the closure of school in response to the situation in which a number of students or staff are infected and show symptoms of the disease.

Proactive school closure: refers to the closure of school before any infection transmission among students or staff occurs or is identified.

Targeted closure: refers to the closure of a specific school or all schools in a specific geographic location. As the scale of targeted closures varies considerably, specifics are noted for the particular contexts of studies included in this review.

Attack rate: refers to the cumulative incidence of infection during the entire course of epidemic. Quantitatively, it is the number of individuals who develop disease divided by the total number of exposed individuals (i.e., here assumed to be the total population). The attack rate in this review refers to the incidence of clinical infection (unless otherwise specified), where exposed individuals manifest symptoms of the disease.

Reproduction number: refers to the average number of secondary infectious cases generated by a single primary case during the infectious period of the primary case. This number (denoted by R_0) determines whether the infection will spread ($R_0>1$) or will die out ($R_0<1$).

Triggering threshold: refers to a minimum number (or rate) of identified infectious cases in a school (or a community) required to consider reactive school closures.

the resulting disruption to society, loss of productivity, and absenteeism.

2009 pH1N1, an epidemic that mainly affected children and young adults, saw school closures implemented in several countries which provided added opportunities to assess its effectiveness and relevance for other contexts. This review was undertaken to reexamine the evidence on school closures from recent publications that may draw further lessons from pH1N1, as well as from its application during seasonal outbreaks. The document provides an overview of recent literature and evidence for the potential health benefits, costs, as well as ethical considerations of school closure during influenza outbreaks. It builds on previous reviews and includes a number of epidemiological and modelling studies that have discussed the potential impact of school closure, mainly on reduction of infection transmission and community attack rates that result from reactive and/or proactive strategies. The review also considers important gaps in research and raises questions about how effectiveness is measured in the available literature.

Findings from the literature are summarized below, grouped into three categories of evidence, including summary and systematic reviews, observational studies, and mathematical simulations.

Methods of Review

A review of literature on the effectiveness of school closures for the prevention or control of influenza was conducted, which included observational studies, mathematical modelling studies, and systematic reviews and other secondary or summary analyses. The review covered both academic literature as well as grey literature, such as backgrounders for the consideration of school closure policy. Although the review gave priority to studies of school closures implemented as public health interventions (whether as proactive or reactive closures), studies of the effects of holiday closures were also included. As well, studies related to both pandemic and seasonal influenza were considered for review.

As an update to previous reviews on the subject, the primary focus of this review was literature published from January 1, 2011 through August 31, 2013. The terms school, closure and influenza (or pandemic) were used in a search of titles in PubMed and Google. Only publications written in English were included for review. Additional sources were identified from a manual search of titles in the reference lists of articles selected, as well as from PubMed listings of related articles. In some instances, the preferred date range of publications was relaxed to include earlier, quality studies.

Modelling studies included in this review were selected on the basis of two main criteria: (i) use of existing data sets pertaining to an outbreak scenario (e.g., 2009 influenza A/H1N1 pandemic); (ii) inclusion of comparative scenarios for proactive or reactive strategies, time for initiation of school closure, and its duration. Modelling studies returned by the search criteria were screened by a reviewer with expertise in these methods. Some articles were excluded from the review where the assumptions or model structure and validation were deficient.

The papers reviewed here were examined for their discussion of benefits and costs of school closure strategies in a number of areas including: reduction of community-wide attack rates and transmission among children; severity of influenza outcomes in a population; costs associated with strategy implementation, such as loss of productivity and household financial burden; and cost-savings achieved by lowering healthcare utilization.

Overview of Evidence from Previous Summary Reviews

This review builds on two earlier reviews of research evidence on the effectiveness of school closures for controlling influenza (2, 3). Before proceeding to consider recent evidence, a brief overview of the findings of these preceding reviews will be useful in setting a context.

In March 2011, the United Kingdom Department of Health (UK DOH) released a review of literature that considered the effects of school closure on seasonal and pandemic influenza in a wide variety of settings around the world. The review included 39 epidemiologic and 30 modelling studies published up to the end of May 2010 (2). The epidemiological studies provided evidence that school closures can reduce transmission and incidence of influenza in children, although the effects on other age groups and community-wide benefits were less clear. Some studies also showed a reversal of effect upon re-opening schools, which was interpreted as supportive evidence of the measure's effectiveness. The reviewers noted that although school closures are commonly delivered with other interventions (e.g. antiviral treatment or prophylaxis), some studies showed benefits associated with school closure alone. Despite the evidence suggesting potential benefits of school closures, the authors observed that limited evidence is available to judge the relative benefits of particular closure strategies (e.g. proactive versus reactive closures, local versus national closures, or the optimal timing or duration of closure).

According to the UK DOH review, modelling studies commonly found that school closure can result in greater reductions in peak incidence than in cumulative attack rates, and that early closure may assure the greatest reduction in attack rates. This finding was interpreted as lending support for conservative use of school closures to lessen pressure on health-care services during escalating outbreaks. According to the authors, the evidence also suggested that school closures may be most effective when age-specific attack rates are higher in children than in adults, but that effectiveness diminishes with higher transmissibility of the influenza virus.

The UK review raised several cautions about the epidemiological evidence, including challenges in separating the effects of school closures from natural transmission dynamics of infection, as closures are most often initiated relatively late in the course of an epidemic (i.e. after the epidemic peaks). As well, the authors note that because age-specific attack rates vary among different strains of influenza, the effects of school closures on transmission depend upon the extent to which the dominant strain in a given epidemic affects school-aged children. Thus effectiveness may vary by the demographic makeup of a population. Moreover, the major constraint in

UK Influenza Pandemic Preparedness Strategy (2011)

The UK Department of Health released a pandemic preparedness policy (2), which included guidance on decisions to close schools during influenza outbreaks.

The UK strategy describes school closure as a measure resorted to when the impact of pandemic influenza is very high. It presents a four-phase plan with various interventions scaled to stages of information gathering and outbreak severity. The plan shows school closures considered during a phase signaled by evidence of sustained community transmission of the virus (i.e. cases not linked to any known or previously identified cases). The policy offers two guiding principles for the use of temporary and localized school closures under certain circumstances.

Firstly, precautionary school closures may be enacted by school administrators in the early stages of influenza pandemic to reduce the initial spread of infection locally, while more information on the spread of the virus is gathered.

Secondly, school closures should not be enacted once the virus is more established in the country, unless staff shortages or risks to particularly vulnerable children justify the action (2).

developing evidence for particular closure strategies relates to the heterogeneity of contexts in the epidemiological literature on school closure, which makes it difficult to separate out which factors contribute to effective implementation. The authors also qualified the results of modelling studies in that they are constrained by a lack of suitable data, certain assumptions that must be adopted (e.g. contact patterns in the population), and consequent variability in their results.

The conclusion of this large-scale review was that there was insufficient evidence to support any particular school closure policy (e.g. proactive or reactive approach). The authors recommend that the intervention continue to be considered as a potential component of a mitigation strategy to reduce infection transmission during an influenza pandemic, although the decision to close schools should be responsive to the features of each new epidemic. When a virus appears highly pathogenic, but information is lacking in the early stages of an epidemic, the authors advised that school closures may be used as a precautionary measure. Ideally, decisions to close schools would consider specific information on the influenza strain, that is, distinguish new and previously identified strains, identify sub-populations most at risk (i.e., whether transmission is high among school children compared to adults), assess the pathogenic severity of a strain (mild, moderate or severe), and discern whether antiviral medications are effective for that strain. Finally, acknowledging some of the social, community-level challenges encountered in implementing school closures, the authors emphasized the need to accompany the measure with public health messages advising that children's social contact outside of school also be limited (2). However, the review did not consider the effectiveness of public health messaging in this regard. The authors anticipated that additional evidence from the 2009 pandemic experience, which might provide more clarity on practical considerations for policy, would be forthcoming.

A second evidentiary review from 2011 (3), commissioned by the National Collaborating Centre for Infectious Disease (NCCID), addresses not only school closures, but also evidence for the effectiveness of other common social distancing interventions, including restrictions on travel and mass gatherings. Roth and Henry's review mainly covers publications on pandemic influenza issued since pH1N1 and, with respect to research on school closure outcomes, includes six observational studies and nine modelling studies. The authors point to some evidence from observational studies that school closures may reduce transmission at the community level, as well as among school-aged children, although they also caution that there is a lack of robust empirical evidence that allows comparison between communities with and without school closure interventions. Based on the modelling literature, the authors' analyses were consistent with the conclusions of earlier studies (pre-pH1N1) that generally indicated decreasing effectiveness of school closures with later implementation and with increasing R_0. The authors pointed to the contradiction that school closures may be most effective when social and economic costs are least likely to be accepted — that is, during milder epidemics. The evidence also indicated that school closures of less than two weeks' duration may have limited influence on community transmission and that school closures alone may be ineffective when R_0 is higher than 2.5. For epidemics with this level of transmissibility, the authors cite evidence that school closures used in combination with other social distancing measures or with pharmacological interventions (prophylactic use of antivirals or vaccination), may be more effective than school closures alone. As well, the evidence gave more weight to the use of individual than widespread school closures, for the practical advantage individual schools offered in being able to respond quickly to an outbreak. Roth and Henry concluded, as had the previous review, that there was insufficient evidence on how to best implement school closures (3).

Evidence from Recent Summary & Systematic Reviews

Two recent summary and systematic reviews have contributed to the knowledge base on school closures. An expert review by Chowell and colleagues (4), authors affiliated with the US National Institute of Health, considered evidence from 11 observational and modelling studies (published 2004-2011) on the effects of school closure on influenza transmission. The review included publications based on studies of opportunistic school closures (i.e., for school holidays or teachers' strikes) as well as closures initiated by public health authorities. The studies spanned various jurisdictions and outbreak circumstances, including seasonal influenza epidemics prior to 2009 in Hong Kong, France, Europe and Israel,[1] the 1918 influenza H1N1 pandemic in the US,[2] and the 2009 influenza H1N1 pandemic in Mexico, Japan, Hong Kong, the UK and Peru[3] (4).

Chowell et al. observed that several and nearly all studies covered by the review indicated that school closures were associated with improved influenza outcomes, particularly for influenza transmission (4), although specific outcome measures and case definitions varied. Among the findings reviewed were 16-18% reductions in the incidence of influenza-like illness based 21 years of surveillance data on seasonal influenza in France, as well as a 43% reduction in weekly rates of respiratory disease in Israel ((Cauchemez et al. 2008, and Heymann et al. 2004, cited in Chowell et al.(4)). Also referenced was a populated-based study based on data from eight European countries that modelled changes in social mixing patterns, which concluded that significant reductions (13-40%) in infection transmission in these populations could be achieved with school closures. However, the study was based on holiday closures which the authors assumed could resemble public health closures in pandemic circumstances, and relatively social holiday periods were understood to yield conservative estimates of transmission reductions that might be achieved during closures for influenza outbreaks ((Hens et al. 2009, cited in Chowell et al. (4)). As well, Chowell et al. cited significant reductions in influenza transmission during the 2009 H1N1 pandemic from studies in Japan, Mexico and Hong Kong, which found that school closures were associated with significant reductions in influenza transmission for the population (e.g. reductions of 25% and 29-37% in Hong Kong and Mexico, respectively). In the one study that found no significant effects of school closure (Cowling et al. 2008, cited in Chowell et al(4)) the result was attributed to late implementation of the measure (i.e. closure after the epidemic's peak

Chowell et al. concluded that school closures may be effective in mitigating influenza transmission, particularly when implemented early in the course of an epidemic (4). However, they qualified their finding, cautioning that observed benefits may not be attributable to the intervention, as it is difficult to control for other factors that influence transmission, including seasonal changes in transmission, or the depletion in the number of susceptible hosts. As well, the authors note that there is insufficient evidence to demonstrate lasting benefits of school closures, as observational studies seldom record long-term outcomes, which may be especially important to consider in epidemics that involve several waves of incident cases over months or years. They caution that the total number of cases of influenza may not be affected by school closures, although the peak incidence may be reduced. Chowell et al. suggest that school closure may be most appropriately applied as a short-term mitigation strategy to reduce the peak incidence of influenza and forestall intense demands on healthcare services. This

[1] Cowling et al. 2009; Cauchemez et al. 2008; Hens et al. 2009; Heymann et al. 2004, cited in Chowell et al., 2011(4).

[2] Hatchett, Mecher & Lipsitch, 2008; Bootsma & Ferguson, 2007, cited in Chowell et al., 2011 (4).

[3] Chowell & Echevarría-Zuno et al. 2011; Nishiura et al. 2009; Wu et al. 2010; Jackson et al. 2011; Chowell & Viboud et al. 2011, cited in Chowell et al., 2011 (4).

strategy could also buy time to gather information on the influenza strain, transmission rates, and susceptible populations — information required to plan a longer-term response, such as vaccination or the use of antiviral medication. The authors further recommend a systematic multi-country comparison of 2009 pandemic experiences to explore the effectiveness of school closures in different epidemiological, behavioural and demographic circumstances (4).

In 2013, a large-scale, multi-country review came out of the UK, which went some way toward expanding the analysis of school closures. This systematic review conducted by Jackson et al. (5) — the same authors who contributed to the 2011 UK review — included 79 studies which met the inclusion criteria[4] and were published up to the end of 2011. The review focused on epidemiological and certain modelling studies[5] of the effects of school closure, either planned or unplanned, on the incidence and transmission of seasonal and pandemic influenza. These included studies of influenza experienced in New Zealand, Mexico, Peru, United Kingdom, Israel, Hong Kong, France, Serbia, Japan, China and the United States of America. The results of meta-analyses,[6] which plotted attack rates stratified by the timing of closures, suggested that school closures can reduce transmission of seasonal and pandemic influenza in a population, particularly among children, though many datasets showed no clear effect of the intervention, possibly because closures often occur late in the course of an outbreak (i.e., at or after the peak). Several of the review's conclusions were similar to those drawn from the authors' 2011 review. Reversibility of effect again lent support to closures having an effect on incident infections. There was some evidence of independent effects of school closures, though most studies involved circumstances where more than one strategy was employed, making it difficult to attribute change to any one intervention.

Jackson and colleagues point out that despite general indications that school closures may be beneficial, the evidence for an optimal strategy remains unclear. That is, the research literature cannot serve to guide such practicalities of implementation as when to close a school and for how long. The authors' analysis showed no clear pattern in attack rates (cumulative, peak or normalized peak) plotted by the timing of closures relative to the peak of the epidemic. The review indicated somewhat strong evidence that closures longer than two weeks are associated with reduced incidence and transmission, although inconsistencies in the literature remain. The authors emphasized the difficulty in discerning the relative benefits of targeted versus widespread school closures, proactive or reactive school closures, or various durations of closure because studies typically differed in too many respects (5).

Jackson et al. (5) point to other important gaps and challenges in the school closures research literature. For example, the authors note that long-term impacts of school closures remain unclear because few studies present evidence related to events after schools re-open. They also raise a concern for the generalizability of findings from one pandemic context (e.g. 1918 pandemic) to another, as virulence, population susceptibility, demographic structure of populations, and contact patterns may differ markedly from one context (time/place) to another. As well, the direct applicability of findings from seasonal influenza school closure studies to pandemic influenza were described as problematic, as the former more often involves the holiday school closures when social mixing patterns may differ considerably from closures instituted by public health

[4] Studies were included if they described one or more influenza outbreaks during which schools were initially open and subsequently closed, with or without other interventions. Studies of outbreaks which started during school closure were excluded.

[5] Predictive modelling studies that employed hypothetical outbreak data were excluded.

[6] Meta-analysis involved plotting cumulative and peak attack rates with 95% confidence intervals, calculating a normalized peak (peak attack rate/median attack rate), and stratifying data by the timing of closures (before, during or after the peak). Nineteen and 41 epidemic curves were available on seasonal and pandemic influenza, respectively.

authorities. The authors stress the need for more rigour in this area of research, including consistent and appropriate case definitions. They explain that studies typically do not employ case definitions that are sensitive to school closures. For example, absenteeism may be too general a measure, and laboratory confirmed cases often represent severe illness, frequently in the elderly, and may be insensitive to detecting effects of school closures. Moreover, variation in case finding over the course of an outbreak (e.g. increased surveillance or care seeking after school closure) may obscure evidence of beneficial effects of school closure, and requires a more systematic approach to ascertainment.

Key Points

- School closures may be associated with significant reductions in influenza transmission. These general findings have been observed in different jurisdictions, for opportunistic and purposeful closures, and in various outbreak circumstances.
- Early implementation of school closures in the course of pandemic influenza (prior to the epidemic's peak) may improve the likelihood of substantive effects.
- School closures have a greater effect on peak incidence than on the cumulative attack rate, suggesting that they may have utility as a short-term strategy to forestall the impacts of influenza on healthcare services.
- Some research indicates that school closures have been associated with improved outcomes (i.e. influenza incidence and transmission) in the absence of other concurrent interventions.
- Evidence for an optimal school closure strategy is still insufficient (e.g. particular triggers, appropriate scale of closures) and inconsistent (e.g. duration).
- Closures of two or more weeks' duration may be more effective than shorter closures, but inconsistencies in the evidence remain.
- School closure effectiveness depends upon several variables that remain difficult to control, such as school closures' consequences for contact patterns among children and community members.
- Evidence establishing long-term benefits of school closures is lacking.

Evidence Based on Observational Studies

The information from observational studies is presented by country, with information on the type of strategy employed (e.g. reactive, short/long term, individual school or district-wide closures), as both the strategy and the context in which the strategy is applied may be important to outcomes. All of the observational studies produced by the literature search explored reactive school closures.

United States (USA)

Observational studies of school closures have rarely permitted the inclusion of control groups that provide a baseline for comparison and more reliable evidence of intervention-related effects. A study by Copeland et al. provided such an opportunity in the context of the early stages of 2009 pH1N1 in Texas, USA (6). Two adjacent counties within the Dallas/Fort Worth metropolitan area, with similar demographic and epidemiologic characteristics (i.e., <70 laboratory confirmed cases, two or fewer hospitalizations), provided an opportunity for a natural experiment, with the objective of comparing acute respiratory illness (ARI) in intervention and control communities (IC and CC, respectively) before, during, and after school closures. After a few cases were confirmed in schools, one county implemented a systemic eight-day closure (April 30 to May 7, 2009) in a major school district (80,000 students in kindergarten through grade 12), while schools remained open in the other county (30,000 students). The study compared self-reported ARI in children (ages 0-5, 6-18) and adults (age 19 and older) drawn from surveys with parents in the two school districts , as well as influenza-related visits to emergency departments in the respective counties.

Copeland et al. found evidence that school closure reduced self-reported ARI and emergency visits related to influenza (6). Their analysis demonstrates that, while ARI increased in both intervention and control groups from before to during school closure (IC: 0.6% before to 1.2% during; CC: 0.4% before to 1.5% during), increases were 45% lower in the intervention community. Similarly, respondents in the intervention community were 51% less likely than those in the control community to report ARI in family members during the school closure period (adjusted odds ratio: 0.49, P= .03). No significant differences between the two groups were noted in ARI rates or changes in rates from the time of school closure to after re-opening schools. School closures had greater effects when the analysis focused on families with only school-aged children (ages 6-18 and no children aged 0-5 years), among whom the likelihood of ARI was 72% lower than in the control community.

Emergency department visits showed similar improvements associated with school closure. Prior to school closures, the percentage of daily visits to emergency departments attributed to influenza was similar in the two communities. Rates increased from before to during school closures in both communities (IC: 2.8%- 4.4%; CC: 2.9%- 6.2%), though again the control community saw greater, and more than two-fold increases. Most of the difference between communities was attributed to differences in the school-aged population. For six to eighteen year-olds, influenza-related emergency visits doubled in the control group (5.2%-10.9%), but remained constant where school closures were enacted (~5%).

The strengths of the Copeland et al. study lie in the use of a control group as well as two independent sources of data, including data that demonstrated community-level effects of school closure. Improvements in ARI reports and influenza-related visits to emergency were achieved for closures of only eight days, where closures were initiated early in the outbreak. However, the study is limited by its reliance on self-reported ARI, rather than laboratory confirmed cases of influenza, and emergency department data representing patients' chief complaints, which were not verified by physicians (i.e. may differ from discharge diagnoses).

United Kingdom

An observational study by Awofisayo et al. described a risk-based approach to decision-making developed and implemented during the 2009 influenza H1N1 pandemic in a hard-hit region of West Midlands, England (7). In the absence of definitive guidance on triggers for school closure, the Health Protection Agency (HPA) together with several stakeholders, sought a method to use available evidence to guide a coordinated response during the 'containment phase' of the pandemic, when the greatest priority was to limit the spread of influenza. The study retrospectively outlined features of the approach and provided lessons regarding challenges and opportunities in the management of reactive closures.

A regional, multi-professional and multi-agency team, including representatives of the HPA, National Health Services and Local Authorities for schools, participated in a daily risk assessment process.

[7] Data were available for analysis for 5188 household members in the intervention community and 4842 in the control community. 619 individuals met the ARI case definition; ARI cases were defined by the presence of two or more of the following symptoms: fever, cough, sore throat, or runny nose.

The team considered basic scientific evidence on epidemiological characteristics, clinical presentation and laboratory results for the influenza virus, as well as general physician consultation rates for influenza-like illness and respiratory infection, and information gathered from frontline public health practitioners. More notably, findings from these data were synthesized with information from additional school-based and other local or regional data, including: number of laboratory confirmed cases in a school; reported rates of school absenteeism (influenza-related absences, when possible); date of symptom onset and school attendance information for confirmed cases; records of calls from parents or teachers about rumored cases in a school; and geographic location of schools relative to schools with confirmed cases, among other information. Daily assessments considered the level of risk in a school as well as the likelihood of a threat to the community. Assessment led to one or more recommendation being made, including choices to monitor absenteeism, swab symptomatic students for influenza testing, offer antiviral prophylaxis to contacts and high risk groups, treat presumed or confirmed cases, or close classrooms or school.

During the containment phase, at the height of the pandemic, 344 school assessments were performed, of which 209 (60%) had confirmed cases of influenza. Closures were enacted for 65 schools—23 (35%) for the purpose of controlling the outbreak and 21 (32%) for operational issues, such as staff shortages, and one to protect a medically vulnerable child. No reason was recorded for 20 of the 65 school closures. The average duration of closure was six days, up to a maximum of eleven days. Median weekly absentee rates were higher in schools that were recommended for closure (6.2%; range 3.1-9.2%) than other schools that were assessed but which remained open (3.9%; range 3.0-4.9%) and significantly more elementary than secondary schools were recommended for closure (7).

Although this study was not designed to assess the effectiveness of school closures, the authors observed that the reactive approach employed, usually of short duration, and in a context of a rapidly accelerating outbreak, likely had minimal impact on containing the spread of influenza in the region. As well, anecdotal reports indicated that benefits of closures may have been negated by a compensatory shift in children's social interactions from schools to the community. Focusing their analysis on the decision-making process rather than the outcomes of closures, the authors conclude that the risk-based framework may represent good practice as it offers benefits of an inclusive, consistent and transparent method, which remains adaptable to changing circumstances. They advocate for the use of risk management approaches in pandemic preparedness planning, exercises and training. Among other lessons learned was the value of employing school-based public health information synthesized with information available from established public health sources. As well, the authors emphasized the need for clearly defined authority and roles in risk assessment teams and a stronger evidence-base on the effectiveness of school closure, because a lack of consensus on this point presented challenges to risk assessment (7). Despite somewhat favourable conclusions with respect to the risk-based framework for decision making, the authors describe the process as highly resource and labour intensive. As well, the study does not offer any basis for comparison with alternative decision-making processes.

Australia

A study by McVernon et al. (8) considered the behaviours and attitudes of families affected by school closure as influences on the measure's effectiveness. The authors aimed to assess compliance of family members with quarantine as well as pharmacological interventions that were recommended during school closures, and to identify household characteristics associated with compliance with quarantine (8). The study was based on anonymous telephone and online surveys completed by parents whose children attended schools that had been closed as a public health measure in the early stages of the influenza H1N1 pandemic in the state of Victoria, Australia. Victoria's policies at this time called for closures in schools that had multiple confirmed cases in different classes, where the recommended minimum duration of closure was seven days from the date the last confirmed case attended school. Influenza cases and their family members were asked to remain at home and refrain from contact with others. The recommended time for quarantine ranged from one to fourteen days, with a median of seven days. A total of 314 households representing 1,330 residents responded to the surveys; 496 people were asked to adhere to voluntary quarantine measures. The overall response rate to the survey was 27% of eligible households, which raises concern that sampling bias may affect the results, that is, respondents may be more likely to comply with social distancing measures than non-respondents and the result may not be generalizeable to the population as a whole. Of particular concern to the authors was a disproportionately low level of responses from parents of children who attended less advantaged schools. As well, a considerable difference in reporting of school closure status by government agencies and school principals (82 versus 39) was observed, but could not be explained by the authors (8). The observed discrepancy may raise the question of whether school administrators were compliant with the standard government policy on closures.

McVernon and colleagues found high levels of compliance with quarantine, at both individual and household levels, and particularly high compliance in households with a case of influenza. Of those who were quarantined, household members stayed at home for more than 94 percent (95% CI, 92.8-95.9) of the recommended period. Most respondents (88%) stayed at home for the entire recommended time. Household level compliance was also high, with 84.5% (95% CI, 79.3-88.5) or 250 of the 301 participating households reporting full compliance. Children in 43 households spent time outside the household, and nearly half of these occurrences involved mixing with other children. Although the study provided little opportunity to explore factors influencing differences in compliance, the authors cite possible predictors at the household level being socioeconomic status and parental employment. The authors cite other research that has found parental care to children in the home is associated with higher compliance with social restrictions (Gift et al., 2009, cited in McVernon (8)). However, a less expected finding by McVernon and colleagues was the extent of variability in the quarantine recommendations given to families, which reflected public health system challenges in consistent implementation of closures. The authors suggest that irregular practice rather than public compliance may undermine the effectiveness of school closures. They underscored the importance of communication strategies that use clear messages in the native language of community members to encourage compliance with public health recommendations for social distancing (8). Again, this research has not actually provided evidence of the effectiveness of such messaging strategies.

The authors observed that, compared to similar studies from Australia and the US, compliance with quarantine during school closures was high. In part, this was attributed to Victoria being the first jurisdiction to report cases in the southern hemisphere when the potential severity of the influenza strain was unknown and heightened public awareness and increased vigilance by public health officials may have encouraged compliance among families affected by school closures. As well, the authors note the study's focus was on cases and their close contacts, whereas other studies have considered the behaviour of all peers during closures. The relatively high number of households with confirmed cases in this study population was acknowledged as a possible factor contributing to high compliance, because households with cases are more likely to be concerned and compliant (8).

Key Points

- An observational study from Texas USA, which compared influenza-related outcomes (i.e. self-reported influenza-like illness, emergency department visits) in two counties, one of which closed schools (i.e. non-randomized control), found that short-term school closures (i.e. eight-day duration) may be effective as a mitigating strategy, early in an outbreak.
- Attitudes toward and social behaviours associated with school closures factor in their success and vary by population and outbreak circumstances.
- Evidence for high compliance with recommendations for social distancing during school closures may be context specific and not generalizable.
- Less is known about the practicality of school closures among disadvantaged populations, including the likelihood of compliance with community-level social distancing during school closures.
- Families' childcare needs and the movements of young children during school closures are key factors influencing effective implementation.
- Variable practice and inconsistent directives from public health officials also undercut the effectiveness of school closure.
- Clear and consistent messages and protocols for school closures may be needed.
- Multi-sector, risk-based assessment processes may represent good practice in guiding decisions on local, reactive school closures. Refinement and training in such processes may be beneficial. However, such processes are highly labour and resource intensive.
- Local, school-based information on influenza outbreaks, combined with other public health information, may be useful to school closure decisions.

Evidence Based on Modelling Studies

Mathematical, statistical, and computational models have been recognized as essential tools for addressing major public health concerns about the transmission and control of human diseases. One of the major contributions of these tools has been the ability to assess the risk of disease transmission and its outcomes, and to evaluate the potential impact of different public health intervention strategies. This section of the review provides an overview of such papers in the context of school closure interventions for influenza infection.

Reactive short-duration closure of schools has the potential to reduce pressure on health services in regions where influenza outbreaks challenge service capacity but it is unclear what spatial scale and timelines would need to be used in order to make closure an effective strategy. A team of researchers (9) evaluated the impact of localized (targeted) school closures on reducing the burden of influenza on hospital intensive care units (ICU) that are reaching capacity. Using detailed catchment area data for hospitals in England, the study modelled 600 scenarios for reactive school closure, by considering age-dependent mixing patterns derived from the pan-European POLYMOD survey (10). These scenarios were evaluated for a range of school closures lasting one to four weeks, with different reproduction numbers: R_0=1.1, R_0=1.4, R_0=2.

The study concludes that, based on simulation results, school closures should be coordinated in time (simultaneous) and location (all schools within a school district) in order to become an effective strategy to reduce infection transmission, and consequently relieve capacity pressures of hospital ICU admissions (9). The findings are based on some key assumptions, including the assumption that the optimal timing and duration of school closure can be precisely calculated well in advance of the epidemic peak. Due to the diversity and density of the UK population, and a broad range of assumptions and parameter values considered in their simulations, the investigators suggest that their model and strategies have wide applicability across other developed jurisdictions. However, given the uncertainty about assumptions of transmissibility of the disease and variability in how epidemics unfold in different populations, these findings may not be applicable to other settings, particularly where populations differ substantially in demographic characteristics, contact patterns, and the timing of their interventions. Nevertheless, the study summarizes three main observations: (i) longer school closures have the greatest impact on reducing peak incidence of infection; (ii) school closures are more effective for epidemics with high reproduction numbers (in this case, $R_0=2$); and (iii) school closures are more effective in reducing peak incidence of infection among children than adults (9).

In Canada, school closure was not recommended as a mitigation strategy during the 2009 H1N1 pandemic, but part of the first wave of the outbreak coincided with schools closing for the summer. Using virologic (i.e., laboratory confirmed cases) and epidemiological data in the province of Alberta, Earn et al. analyzed the transmission dynamics of influenza to determine the impact of school closure (11). Model simulations suggested that school closure reduced infection transmission among school-aged children by at least 50%, which lessened the impact of pandemic. By including weather data, the model demonstrated a significant increase in the number of confirmed influenza cases as temperatures dropped in the fall of 2009, during which the second wave unfolded. Since the model used for this study is a simple susceptible-infected framework, an important limitation relates to the assumption of homogeneity in population contacts, where all susceptible individuals are assumed to be equally likely to acquire infection regardless of their contact patterns. Furthermore, a question remains as to whether the reduction in infection transmission was also affected by an increase in the temperature

Modelling Methodologies

The modelling literature that has evaluated health benefits and socio-economic costs associated with school closure is largely based on three methodologies, namely: dynamic modelling; agent-based or network modelling; and statistical analysis.

Dynamic modelling has the advantage of using fewer parameters compared to other methods, but often suffers from unrealistic assumptions (for example, homogeneity in population contacts) with large parameter uncertainties, and lack of detailed population characteristics and individual behavioural responses.

Agent-based modelling is the most advanced methodology to address the conditions of uncertainty and project plausible scenarios under different conditions. This methodology is useful for policymakers due to its fidelity and large-scale capability in capturing a wide range of parameter values and assumptions, by integrating various data sources pertaining to the population, health, disease, and intervention measures. However, the availability and reliability of databases pose key challenges to this type of modelling, as outcomes of the system are extremely sensitive to small changes in input data.

Statistical analysis provides a useful quantification of possible outcomes with measures for their uncertainty. However, for this methodology, as with agent-based models, epidemiological, surveillance, and clinical data are a key source of input.

during the first wave, independent of the effect of closing schools for the summer. Overall, a combination of factors may have contributed to the reduction of disease transmission, but the study provides compelling evidence that school closure and intervention strategies targeted towards school-aged children may be considered as important public health measures in future outbreaks.

More detailed models have been used to evaluate the effect of school closure on reduction of attack rates in the community. These include agent-based modelling (ABM) as a more advanced methodology capable of grasping the dynamic interplay between disease, health, and demographic parameters with the inclusion of social behaviour inherent to human societies (12). ABMs can be developed to act as computer representations of human societies in which independent individuals (i.e., autonomous agents) perceive, make decisions, interact during daily activities, and are bonded by social ties. Such degree of fidelity is necessary in order to make ABMs a useful tool for public health planners and service providers. Through the use of ABM computational systems, it is possible to systematically test different hypotheses related to attributes of individuals, and investigate how population-level phenomena are emerging from individual-level behaviour among a heterogeneous set of interacting populations (12).

A recent study by Halder and colleagues developed an agent-based simulation model of Albany, a small community in Western Australia with a population of approximately 30,000, and used the model to investigate the effectiveness of reactive school closure in reducing the community attack rates for an influenza pandemic with scenarios of R_0=1.5, R0=2, R0=2.5 (13). The study considered two different closure scenarios corresponding to individual school closures (at different times and different triggering thresholds for closure in terms of the number of identified cases per day) and simultaneous closure of all schools. The effectiveness of these strategies was analyzed for 2, 4 and 8 weeks closure duration. The study found that closures of shorter duration (2-4 weeks) had insignificant effects on attack rates and resulted in negligible differences between individual and simultaneous strategies. However, modelling individual school closure of eight weeks' duration for a pandemic strain with R_0=1.5 resulted in a 14% reduction (declined from 33% to 19%) in the overall attack rate. This reduction was 9% (from 33% to 24%) for the same duration of simultaneous school closures, indicating the individual strategy was more effective. These scenarios were considered in the absence of antiviral use, and the closures were triggered when a minimum of 30 cases of influenza infection was confirmed daily in the entire community. Combined with antiviral use, the reduction was increased to 19%. For higher R_0, both school closure scenarios were significantly less effective. The findings suggest that the particular school closure strategy depends critically on the transmissibility of the pandemic strain and the duration of school closure. An important observation from this study is that, due to the difficulty in determining the true degree of epidemic spread and its severity in the early stages of an outbreak, an individual school closure strategy would be more effective than simultaneous school closure. The findings of this modelling strategy are inconsistent with the observations of the UK study (9) which suggested simultaneous school closure over a geographic or school division area, and higher effectiveness of this measure for higher R_0. The difference in outcomes between the two studies could be related to several factors, including different modelling strategies and assumptions; vastly different population demographic variables (urban and highly dense versus small rural community); and the objectives for evaluation of effectiveness (i.e., impact of closure on ICU admissions versus impact of closure on the overall community attack rate). These discrepancies attest to the fact that evaluation of school closure strategy is highly context specific.

Modelling studies of school closure have also explored use of the intervention in the context of seasonal influenza, prior to the 2009 H1N1 pandemic. A statistical modelling study by Cauchemez and colleagues evaluated the impact of school closure on influenza epidemics by analyzing disease surveillance data and information on the timing of school holidays in France (14). The study hypothesized that influenza transmission changed during holiday school closures as a result of the altered mixing patterns of children. The model structured the population into two main settings for transmission (i.e., schools and households) and assumed that random transmission can occur between all members of the population in other settings. The overall reproduction number was estimated to be $R_0=1.7$ (range 1.5–1.8) during school term, and $R_0=1.4$ (range 1.3–1.6) during holidays. The simulation results showed that holidays could result in up to 29% reduction in transmission between children, with no measurable effect on transmission between adults. Fitting the model to seasonal data suggested that holidays prevent 18-21% of influenza cases in children. The findings suggest that prolonged school closure (i.e. 4 weeks or longer) during a seasonal influenza outbreak may reduce the cumulative number of cases by 13–17% and the highest attack rates by up to 45% (14). The estimated reduction is, however, based on the assumption that low contact rates between children can be maintained for a sufficiently long period of time following the onset of school closure. The scale of any reduction in the overall attack rate is generally difficult to attribute to the single strategy of school closure, especially in the presence of other public health interventions and without accurate estimates on age-specific transmissibility of a pandemic strain.

During the first wave of the 2009 H1N1 pandemic in Hong Kong, school closures were systematically implemented. After the identification of the first local (non-imported) case, all primary schools, kindergartens, childcare centers and special schools were closed until the summer vacation (i.e., approximately 1 month prior to summer holidays). Secondary schools were only closed for a period of 14 days if there was more than one case confirmed in the school. Using data for laboratory confirmed cases, a study by Wu et al. evaluated the effect of these closures on transmission reduction and drop in reported cases (15). The study used an age-structured susceptible-infectious-recovered transmission model, and employed an imputation procedure to fit the model to data in three different time periods (May 4 – June 19; June 20 – June 29; and June 29 – August 27, 2009) during the outbreak. The analysis of model fitting provided an estimated reduction of 66% (note: this is reported as 70% reduction in the paper for an R_0 decrease from 1.7 to 1.1) in intra-age group transmission following school closure throughout summer vacation. The estimate of transmission reduction following school closures should not be fully attributed to this intervention, as discussed in the paper, as no data were available to compare the outcomes with the scenario where schools were open. However, the authors conclude that a prolonged school closure (considered in this study as one month closure in addition to summer vacation) would contribute more effectively to transmission reduction. This study does not account for the effect of other factors such as seasonality and weather change, nor differences in contact patterns during holidays and school closure periods, which could have substantial effects on disease transmissibility (15).

Mexican authorities also implemented proactive, system-wide closures in the early stages of the 2009 H1N1 pandemic. Chowell et al. analyzed a large sample of laboratory confirmed and influenza-like illness data from Mexico[8] by age and state of residence across three waves (April 1- May 20, May 21-August 1, August 2-December 31) of the 2009 pandemic to assess the influence of mandatory school closures and other social distancing

[8] The study employed medical system data for private sector workers and their families, which covered 40% of the Mexican population (107 million individuals).

measures on transmission patterns (16). A mathematical model of influenza transmission was applied and associations between school activity periods (closures, school breaks) and transmission patterns were quantified. The study was distinct for its consideration of progressive waves of pandemic as well as its large, national scale.

According to Chowell et al., Mexico's early and aggressive public health intervention was effective in achieving a short-term reduction in disease transmission in the early stage of the influenza H1N1 pandemic (16). The 18-day mandatory school closure (April 24-May 11) and cancelation of public gatherings in the greater Mexico City area was associated with a significant (29%-37%) reduction in transmission in the Spring wave. The authors identified patterns in transmission dynamics that coincided with school cycles, in addition to the Spring school closures. Late May saw resurgence (primarily in Southern Mexico) in incident cases prior to summer break, and the Fall school term prompted a broad pandemic wave 2-5 weeks after classes resumed, which coincided with an increasing average age of incident cases (from 18 to 31 years), indicating a shift toward community transmission during the third wave. The study demonstrates a relationship between school activities (closures and holidays) and highlights the utility of early school closures (16). Nevertheless, because school closures were implemented in conjunction with some additional social distancing measures, the study cannot attribute improvements to school closure alone, nor does it distinguish differences in the dynamics and effects of holiday closures and purposeful school closures.

Key Points

- School closure simulations have, in some cases, predicted substantial reductions in infection transmission (i.e., 29%-50%) among school-aged children.

- School closures are predicted to be more effective in reducing the incidence of infection and infection transmission among children than among adults in the wider community.

- Studies comparing the effectiveness of simultaneous, district-wide closures and individual school closures in reducing infection transmission have arrived at disparate conclusions. If closures are of sufficient duration (8weeks versus 4 or 2 weeks), individual school closures may be more effective.

- It is unclear whether school closures are more effective for epidemics with high or low reproduction numbers (R_0), although most studies suggest that reduction in the overall attack rate is higher for lower R_0.

- Longer school closures have greater influence than shorter closures (e.g. 8 versus 2 or 4 weeks) on reducing the incidence of infection, and have reduced community attack rates by 14% where simultaneous closures were enacted in a region.

- Distinct contact patterns in different populations may limit the generalizability of findings.

- Results are likely to depend on the timing of intervention by stage of epidemic, which also varies by jurisdiction.

- It may be unrealistic to assume that low contact rates can be maintained throughout a long closure.

- It is difficult to attribute all effects (i.e., reduction in attack rates) to school closures alone.

Costs and Cost-effectiveness of School Closures

While not the primary focus of this evidence review, cost-effectiveness is an important consideration for public health decisions. Evaluating the cost-effectiveness of school closure necessitates estimation of their associated costs. Yet accurate estimates have been difficult to achieve, in part, due to a lack of accurate data on the number of confirmed cases of influenza as well as the amount of sick-time taken by labour force participants.

Recent school closures research literature refers to a range of economic and closely tied social consequences of school closures, including not only decreased labour force productivity and lost income, but also decreased capacity in the healthcare system when professionals stay home to care for children, childcare costs, and educational losses to school children. As well, the fear of infection has indirect and perhaps immeasurable costs (17-20). Childcare costs are an important concern for families with younger children who cannot be left on their own if parents continue to work during a school closure, yet these costs may not be adequately accounted for. As many parents with dependent children are also health professionals and healthcare workers, school closure may also negatively impact healthcare services.

A clear understanding of the savings afforded by influenza control measures, including school closures, may also benefit from improved understanding of the costs and burden of influenza itself. According to Xue et al., pandemic influenza cost estimations are overly simplistic and lead to underestimation of the impacts of influenza. The authors have called for more accurate estimates that account for differences in age-specific attack rates, severity of influenza-related disease, and potential costs from disruption of commerce and societal functions (21). Thus, fair estimates of cost-effectiveness of school closure may await improved measurement of the burden of influenza itself, as well as consideration of the costs and benefits of intervention for sub-populations most severely affected by influenza.

Prior to the 2009 pandemic, a study by Sadique and colleagues evaluated the costs associated with school closure policy from a societal perspective based on nationally representative survey data from the UK (22). The study estimated the costs of productivity loss due to parental workplace absenteeism during the period of school closure. The 'human capital method' was used to estimate the value of potential lost production or income. The researchers adjusted for the estimated proportion of working parents who have access to informal care, the elasticity of production (ability of workers or their co-workers to compensate for production lost), and the proportion of parents able to work from home while they care for sick children. It was estimated that, in the context of the UK population, about 16% of the workforce might be absent for childcare responsibilities during a school closure that lasts for 12 weeks (corresponding to estimates for the duration of a pandemic wave). The costs of this absenteeism lie in the range of £0.2 – £1.2 billion per week. This significant financial burden may be balanced by cost-savings that could be achieved through reduction of disease transmission, and consequently, healthcare utilization. However, such costs may not be affordable or justified in many other settings (e.g. disadvantaged, rural or remote communities), especially when the reduction of transmission in school-aged children is offset by increased household transmission in crowded settings (22). The study suggests that for adoption of school closure policy, a full economic analysis that is population specific should be carried out to evaluate the cost-effectiveness of this strategy.

Attesting to the fact that cost-savings of school closure strategy could be significantly outweighed by the costs of strategy implementation, a cost-effectiveness study was conducted in the context of the 2009 pandemic for the state of Pennsylvania, USA (23). Using an agent-based computational simulation, the study compared the net costs of school closure with the net medical savings of influenza cases averted as a result of this strategy. The scenarios for comparison included reactive school closures in the range of 1 to 8 weeks, with $R_0=1.2$, $R_0=1.76$, $R_0=2$, and used hospitalization and case-fatality rates estimated for the pandemic 2009. The computational model included three main locations: households, schools, and workplaces including healthcare settings. School closure strategy was targeted and triggered by the number of symptomatic cases present in the range of 1 to 30 in each school. The cost-benefit analysis indicates that school closure could have incurred substantial costs to society for lost productivity and childcare, which could have far outweighed the cost-savings in preventing influenza cases. The study suggests that prior to implementation, the costs and potential benefits of this strategy should be carefully evaluated, although this may also be subject to substantial uncertainty due to unknown disease-specific parameters. Some of these parameters include age-dependent transmissibility of infection, reproduction number (R_0), infectious period, and the rate of asymptomatic infection, which is largely affected by pre-existing immunity in the population and the immune status of individuals.

Employing modelling methods, Xue et al. projected the cost-effectiveness of school closure as a public health strategy to mitigate the effects of pandemic influenza (24). The study employed a Susceptible-Exposed-Infected-Recovered (SEIR) disease model, and developed an economic model that accounted for the spread of influenza, as well as the costs and benefits of school closure. The disease model was created using population data from Oslo, Norway for case scenarios of varying illness severity and infection rates (100%, 50%, 30% and 15%) during the SEIR stages. Varying assumptions were adopted concerning the behaviours of care-taking parents and of dismissed students during school closure, as well as case fatality rates. Economic costs of school closure were calculated using parents' productivity losses, based on the national wage rate, and students' loss of learning, calculated from average private school cost rates.

The study concludes that school closure has moderate impact on influenza disease but may incur significant economic costs (24). The authors state that although closing secondary schools is a cost-effective means to mitigate the effects of influenza, given that children aged 12 years and older do not require childcare, it is not effective for kindergarten and primary schools. For pandemics similar to H1N1 2009, Xue et al. find that school closure would not be cost-effective as a single intervention, given that other prevention measures, specifically immunization, would cost substantially less than school closures. However, these conclusions may be tempered by factors such as higher transmission rates, longer duration of a pandemic, and the severity of impact (24).

Other studies have considered the cost-effectiveness of school closure in combination or comparison with other interventions. In a modelling study, Halder et al. assessed the cost-effectiveness of various interventions (25). Using Australian data based on the 2009 pandemic influenza experience, their analysis suggested that neither short- nor long-term school closures (nor other social distancing measures) when used alone, are cost-effective compared to antiviral prophylaxsis, although these measures may be necessary when antiviral medications are not available or when risk of antiviral resistance is high (25). Similar conclusions were arrived at by a subsequent modelling study by the same group of authors. Kelso et al. (26) assessed the cost-effectiveness of interventions based on the greatest reductions in attack rates that could be achieved for the lowest cost per person in the modelled community, employing data from the town of Albany, Australia (population = 30,000). The authors determined that non-pharmacological interventions, when implemented alone, were not likely to be cost-effective in a less severe pandemic (CFR < 0.1). However, where case fatality rates exceeded 1.5% and when combined with antiviral treatment and household prophylaxis, strict non-pharmacological interventions were likely to be cost-effective. Notably, these interventions would include school closures as well as workforce contact reduction and/or community contact reduction of 8 weeks' duration (26). While the model represents an optimal simulation, it is difficult to image this extent of restriction on social contact being feasible in actual households and communities.

Key Points

- Challenges assessing cost-effectiveness stem from limited information on confirmed cases of influenza and challenges estimating indirect costs, but may also reflect inadequate measure of the burden of influenza itself.
- Childcare costs are important household and societal costs associated with school closures.
- Population-specific, full economic analyses of school closures are advisable.
- Costs of school closure, delivered as a singular intervention, significantly outweigh savings.
- School closures may be cost-effective for secondary schools, as older children don't require care when out of school, but not for kindergarten and primary schools.
- Cost-effectiveness of school closure improves with higher transmission rates, longer duration of a pandemic, and greater severity.
- Relative to other measures, such as immunization, school closures are much less cost effective.
- Neither short- nor long-term school closures (nor other social distancing measures) when used alone, are cost-effective.
- All non-pharmacological interventions, when implemented alone, are not likely to be cost-effective in a less severe pandemic (case fatality rates lower than 1.5%).
- In a severe pandemic, when combined with antiviral treatment and household prophylaxis, strict non-pharmacological interventions (including school closures, community and workforce contact reduction for 8 weeks) may be cost-effective.

Social and Ethical Issues in School Closure

The studies discussed above highlight the costs and benefits of school closure in both economic and health perspectives. However, none has addressed the ethical considerations underlying the implementation of such measures with potential challenges in different population settings. A number of social issues should be taken into account when evaluating and developing school closure policies, which can have significant effects on the subsequent costs and benefits for disadvantaged segments of the population (27). For example, some schools provide free daily nutritional programs, which could be essential for children from disadvantaged groups with fragile financial status. There may be an added financial burden for low-income households when prolonged school closures force parents to miss work and lose income to care for children home from school. Furthermore, a decrease in quality of education would be expected that could disproportionately affect poor economies less able to afford additional costs to help children attain expected educational standards. Basurto-Davila et al. studied the economic impact of school closure during the 2009 H1N1 pandemic in Argentina and found that closures disproportionately impact low-income households. The authors highlighted the importance of considering socio-economic status in the evaluation of strategy effectiveness (28).

As evidenced from the existing literature, there is a contentious debate over costs and benefits of school closure, potential resource utilization, and cost-savings of this policy. While most studies suggest that school closure could potentially lead to significant transmission reduction, albeit mostly among school-aged children, this conclusion is subject to more uncertainty when considering overall community attack rates. For instance, in communities where households are large in size and often multigenerational, school closure strategies may overlook the fact that exposed older family members are at increased risk of suffering serious complications that may require costly healthcare resources, such as hospitalization and intensive care (29). Closing schools may reduce the interactions among children in a particular location (i.e., school), however, it does not necessarily reduce contacts in other community arenas, and could potentially increase secondary household attack rates. This is particularly relevant to remote and isolated communities in northern latitudes, with strong social ties and crowded households, low quality housing and poor sanitation, and prevalence of predisposing health conditions that increase the risk of severe outcomes. It is clear that understanding the contextual implications of school closure in communities with low average age and large household size is of critical importance.

Key Points

- Social factors have significant influence on the costs borne for school closures. School closure costs disproportionately affect low-income households.

- Socio-demographic characteristics of disadvantaged, minority communities may differ from the general population (e.g. larger household size and more multi-generational households) with consequences for influenza risks and costs (e.g. school closures sparking transmission from children to elders in the home).

Pandemic Preparedness Planning

While pandemic plans are not the main focus of this review, a few publications address aspects of planning as critical considerations for the success of public health measures, including school closures. Since the 2009 H1N1 pandemic, significant resources have been expended to prepare pandemic plans, while also considering lessons learned from other jurisdictions.

In 2011, Australia reviewed its response to the 2009 pandemic and published a summary of the experience that identified lessons learned to improve future strategies (30). Numerous aspects of Australia's national and regional pandemic responses were considered, and of the many recommendations that were articulated, a few that relate to public health measures and school closures may be of interest. Firstly, the report emphasizes the value of a comprehensive and accessible information management system to inform decision making. That is, the lines of communication and feedback must include primary care, public health and all levels of government, at all stages of a pandemic. Coordinated communications serve to facilitate understanding, agreement, and adherence to public health interventions, including school closures as a mitigation strategy. The recommendations relate to observations on challenges that public health officials met with in implementing school closures in Australia. In spite of advance planning with a well-rehearsed pandemic plan, school closures were described as disruptive and challenging, with no certainty as to their effectiveness for reducing disease transmission. There was reported confusion in the general public, and among government partners and school representatives regarding the need for school closures, especially as information emerged that the pandemic was not as severe as anticipated (30). The report recommended policy reviews on closure of childcare and schools, including attention to the interface between disease severity and recommendations to close educational settings (30).

Rosella et al. explored planning and evidence informed decision-making that occurred across Canada during the 2009 pandemic (31). The study was based on semi-structured interviews with key informants after the end of the 2009 pandemic and reviewed 76 pandemic policy documents. The research considered theories to aid in understanding how decisions were made and implemented. The summary analysis documented various factors that influenced decisions related to key policies, including school closure. Rosella et al. found that there was confusion regarding roles and responsibilities of partners and stakeholders (31). This confusion, combined with varied ideological perspectives, led to different decisions and outcomes across the country in the face of the same evidence. Conflict avoidance theory was also employed to understand decisions being made that were contrary to the available evidence. Ultimately, it seemed that public confidence was eroded due to the disparity of decisions across different parts of the country. Rosella et al. concluded that increased transparency, partner/stakeholder inclusion and documentation of processes might facilitate evidence review and policy decisions (31).

Key Points

Lessons from past outbreaks show that planning and decisions regarding school closures benefits from:

- Comprehensive planning and integrated communications
- Inclusiveness and transparency of process
- Consensus building among stakeholders, to facilitate understanding, agreement and adherence
- Responsiveness to disparate ideologies on the effectiveness of school closures and to conflict among parties to decisions
- Clarity on roles and authority in decision making
- Consistent messages to the public
- Responsiveness to evidence of changes in an outbreak, and
- Greater consideration of the severity of an influenza outbreak.

Existing Research Gaps

Since school closure has mostly been implemented as a reactive measure, the reduction of transmission may be affected by the implementation of other intervention strategies (such as antiviral treatment or prophylaxis). It is often unclear how transmission reduction is influenced by school closure in the presence of other intervention measures (5). This may require an assessment of proactive school closure when other measures are not widely implemented. However, opportunities for proactive studies are scarce as there is still considerable debate and no consensus about if, when, and how proactive school closure should be implemented.

Given the existing gaps in evidence concerning the impact of school closure, a number of areas should be prioritized for further research to inform policy effectiveness. These include:

- Determining the sensitivity of outcomes with timing of the onset of school closure and its duration for both reactive and proactive strategies.

- Conducting a comparative study between reactive and proactive strategies.

- Identifying thresholds (i.e., reported cases) for triggering reactive individual and community-wide school closures.

- Evaluating the impact of demographic and socio-economic factors on health benefits, and social and household costs of short-term and prolonged school closures.

- Assessing longer-term effects of school closures, after schools reopen.

- Evaluating the influence of school closures on the severity of influenza outcomes (e.g. hospitalizations, ICU admission, death).

- Determining how the magnitude of benefits and costs of school closure is affected by other intervention measures, including treatment with antiviral medication and vaccination.

In all research priorities, the severity of a pandemic influenza and its disproportionate impact on different age groups should be taken into account. Many modelling studies consider the reproduction number (R_0) as a parameter to indicate the severity of the epidemic. However, R_0 is not the sole factor determining disease outcomes (32). Several other factors affect these outcomes, including socio-economic and demographic variables, healthcare capacity and program delivery, and behavioural responses of the individuals that evolve throughout the epidemic.

Finally, the research should address the relative value of school closure compared to other intervention strategies in different population settings, to assess whether similar benefits could be achieved with less cost and better tolerated interventions.

Discussion & Conclusions

The evidence on the effectiveness of school closures for the control of pandemic (and seasonal) influenza remains inconclusive. In part, this is owing to the complexity of studying highly variable strategies, in distinct outbreak and social contexts. Findings may be highly context specific and not generalizable. Researchers point to a lack of robust empirical evidence that allows comparison between communities with and without school closure interventions. As well, inconsistencies remain in case definitions (influenza-like illness or laboratory confirmed cases) and there is a lack of clarity on which outcomes might be important in signifying effective results (i.e. reduced transmission, or fewer ICU admissions or deaths).

Recent research evidence generally supports findings from earlier reviews, which suggested that, when implemented early in the course of an outbreak, school closures may be useful as a strategy to mitigate infection transmission, particularly if age-specific attack rates show children to be highly susceptible. This strategy would forestall the impacts of influenza and reduce the short-term burden on the healthcare system until other interventions became available (e.g. vaccine). The approach has been supported by research that has found school closures to be associated with reductions in the peak but not cumulative attack rates. Thus, the total number of individuals infected with influenza may not be appreciably affected by the intervention, though the short-term impact of an outbreak may be blunted. This research has not addressed questions on the long-term effects of school closures, nor questions of whether school closures reduce the severity of health outcomes, for children or for populations overall.

Research has indicated that school closures may be associated with significant reductions in influenza transmission, which has been described in several jurisdictions and outbreak circumstances. For example, significant reductions in influenza transmission were described for the 2009 H1N1 pandemic based on studies in Japan, Mexico and Hong Kong, (e.g. reductions of 25% and 29-37%). Based on Canadian data, one modelling study suggested that school closure could result in a 50% reduction in infection transmission among school-aged children. The evidence of school closures' effects on transmission among other age groups and community-level attack rates has been less consistent, though some evidence has been described in this literature.

Some authors have attributed improved outcomes to school closures, independent of other influences, although it is more common to find reports that cite difficulties in separating the effects of school closures from other concurrent interventions, or other causes. As well, the evidence suggests that school closures are more effective in combination with other interventions, particularly when attack rates are higher. An example from modelling studies predicted that combining school closures with antiviral use would achieve significant reductions in community attack rates. Although combination strategies may indeed be effective, such studies do not answer questions on whether to enact school closures.

An important shortcoming of the research on school closures is that it has not resolved questions about when and how to implement these measures. No comparisons were drawn between proactive and reactive closures in the studies reviewed, which may also reflect the greater availability of reactive school closures for study. The review also found no evidence concerning appropriate triggering thresholds that should be met to consider reactive school closures. Although research most often suggests that school closures are more effective for epidemics with low transmissibility (Ro), contradictory findings are also reported. Similarly, recent modelling studies comparing the effectiveness of simultaneous, district-wide closures and individual school closures in reducing infection transmission arrived at disparate conclusions. There appears to be general consensus in the literature that early implementation of school closures, prior to or near the epidemic's peak, improves the likelihood of substantive effects. However, studies also describe challenges in obtaining necessary information on the influenza strain, transmission, susceptible populations and severity early enough to enact timely intervention. Knowledge of an effective duration of school closure is critical, yet evidence on this point remains unclear. There is some evidence indicating that two weeks may represent a sufficient duration of closure to produce effects, yet other variables, such as the timing of initiation and transmissibility also influence outcomes. Beneficial effects have also been reported for shorter closures. Based on recent modelling evidence, longer school closures may have greater influence than shorter closures (e.g. 8 versus 2 or 4 weeks) in reducing peak incidence of infection, and community attack rates. However, prolonged closures are also costly and poorly tolerated.

Even where school closures are demonstrated to be effective, their high costs and associated social disruption make it difficult to justify the measure, particularly in the absence of high fatalities. The research evidence consistently reports that the costs of school closure, when delivered as a singular intervention, significantly outweigh savings. Moreover, neither short-term nor long-term closures achieve cost-effectiveness. Factors that improve the cost-effectiveness of school closure include higher transmission rates, longer duration of a pandemic, and more severe health outcomes. Only in a severe pandemic (e.g. case fatality rate of 1.5% or higher), cost-effectiveness may be attainable when school closures are combined with other social distancing measures, when non-pharmacological interventions are well adhered to, and when the are combined with antiviral treatment and household prophylaxis. Notably, this conclusion relates to a more complex intervention and presupposes good adherence, which may not be achievable.

School closures research has been challenged by the need to adequately account for behavioural and social variables that factor into the measure's success. The research literature reflects a general consensus that the effectiveness of school closures is closely tied to public compliance with recommendations for limiting social contact in other community contexts during school closures. In fact, this complexity of social behaviour also contributes to challenges in evaluating the influence of school closures on outcomes, as studies have also been limited to the consideration of circumstances where closures are combined with other social distancing measures (e.g. cancelation of mass gatherings) or where other measure applied may be unknown. The school closures literature commonly concedes the need for public health authorities to address the challenge of the public's compliance with restrictive social distancing during school closures. The strategy commonly proposed is clear messaging on the importance of these measures, yet the effectiveness of messaging on behaviours and community health outcomes remains to be established.

Although compliance with health authority recommendations is likely to vary according to cultural and social norms and to reflect different barriers to compliance related to the structure of family life, childcare support and labour, this discussion appears absent from the literature. Yet a considerable amount of research on school closure effectiveness comes from societies that would differ considerably in these respects from Canada (e.g. China-Hong Kong, Japan, Peru, and Mexico).

This review included some recent research literature from Australia (i.e. though not presumed to be comparable to Canada) that suggests that compliance with social distancing recommendations during school closures may be good if not excellent. However, the generalizability and quality of the research is questionable. Firstly, this research comes from a context of the earliest appearance of influenza A/H1N1, when uncertainty and concerns over the severity of a novel strain were thought to influence behaviour. Thus, the high compliance documented in this study may not be generalizeable to dissimilar circumstances. Moreover, it must be acknowledged that social desirability may factor large in the results of studies that rely on self-reported (albeit anonymous in the study referenced) compliance with public health authority advice. As well, the study's low response rate (27%) and recognition that disadvantaged households were under-represented raises concerns that the findings may be biased and not representative of the study population. Compliance with social distancing recommendations that accompany school closures may be highly context specific, and it remains unclear how well barriers are addressed.

Despite the limitations of this research, an important lesson drawn from this work is that families' childcare needs and the movements of young children during school closures are important factors influencing the effectiveness of school closures. When schools are closed, the movements of young children to other homes or facilities for care, when a parent cannot provide care in the home, appears to be an important driver of 'non-compliance' with recommendations for social distancing during closures. This can be understood in light of the limited workplace flexibility of many parents, particularly women, and the substantial cost families bear for childcare during school closures.

Given that studies exploring public perceptions on school closure have reported lower participation from disadvantaged communities, more information may be needed on the effects, costs and acceptability of school closures among these populations. This review drew attention to examples of research that has evaluated influenza interventions in remote and disadvantaged Canadian communities and other countries, which has noted that distinct contact patterns in these populations may influence transmission of influenza. As well, costs borne for school closures disproportionately affect low-income households, which reflect the role schools play in the delivery of breakfast/lunch programs that supplement the meals of children and the challenge of affordable childcare for many families. Disadvantaged communities may differ from the general population in having larger household sizes and more multi-generational households in which influenza transmission during school closures could be higher and more detrimental to elders coming into greater with children out of school. These examples raise the importance of weighing not only economic cost, but also ethical implications of the decision to close schools for the control of influenza.

While modelling studies help to define potential 'best case scenarios', models are also limited by the accuracy of their assumptions and access to quality data. In an actual influenza outbreak, data may be scarce and the time necessary to gather and synthesize relevant information may be constrained. Some findings based on models show closures to be most effective when they would be least tolerable. Indeed, the models reviewed here support school closures of several weeks to months as the best way to impede disease transmission, but prolonged closures are not practicable for families or communities. Community members may not be able to maintain low contact rates throughout a prolonged period, as assumed by some modelling studies. As well, assumptions that social mixing patterns during holiday school closures resemble those that apply in pandemic circumstances may not be defensible. An important concern in the Canadian context is that epidemiological and socio-demographic data employed in models may differ significantly from these parameters for remote and rural populations. In general, the financial and socioeconomic costs of school closures are high for households, and the society as a whole, with no guarantee of effective mitigation of the spread of influenza, nor effective prevention of more severe health outcomes that may be of primary concern for the public and for public health professionals.

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