Epidemic and intervention modelling – a scientific rationale for policy decisions? Lessons from the 2009 influenza pandemic

Maria D Van Kerkhove[a] & Neil M Ferguson[a]

Problem Outbreak analysis and mathematical modelling are crucial for planning public health responses to infectious disease outbreaks, epidemics and pandemics. This paper describes the data analysis and mathematical modelling undertaken during and following the 2009 influenza pandemic, especially to inform public health planning and decision-making.

Approach Soon after A(H1N1)pdm09 emerged in North America in 2009, the World Health Organization convened an informal mathematical modelling network of public health and academic experts and modelling groups. This network and other modelling groups worked with policy-makers to characterize the dynamics and impact of the pandemic and assess the effectiveness of interventions in different settings.

Setting The 2009 A(H1N1) influenza pandemic.

Relevant changes Modellers provided a quantitative framework for analysing surveillance data and for understanding the dynamics of the epidemic and the impact of interventions. However, what most often informed policy decisions on a day-to-day basis was arguably not sophisticated simulation modelling, but rather, real-time statistical analyses based on mechanistic transmission models relying on available epidemiologic and virologic data.

Lessons learnt A key lesson was that modelling cannot substitute for data; it can only make use of available data and highlight what additional data might best inform policy. Data gaps in 2009, especially from low-resource countries, made it difficult to evaluate severity, the effects of seasonal variation on transmission and the effectiveness of non-pharmaceutical interventions. Better communication between modellers and public health practitioners is needed to manage expectations, facilitate data sharing and interpretation and reduce inconsistency in results.

Abstracts in عربي, 中文, Français, Русский and Español at the end of each article.

Background

Outbreak analysis and mathematical modelling have played an important role in the planning of the public health response to infectious disease outbreaks, epidemics and pandemics. These tools can help quantify the risk to human health posed by a new infectious organism, rapidly analyse and interpret limited data in the early stages of an epidemic, and use such analysis to predict future developments. All of these actions are necessary to evaluate the potential benefits of specific control measures. Statistical and mathematical models integrate and synthesize epidemiological, clinical, virologic, genetic and sociodemographic data to gain quantitative insights into patterns of disease transmission.[1]

Soon after the emergence of A(H1N1)pdm09 in North America in 2009, the World Health Organization (WHO) convened an informal mathematical modelling network of public health experts and mathematical modelling groups in academic institutions. This network worked collaboratively to characterize the dynamics and impact of the pandemic and demonstrate the potential outcome of various interventions in different settings. This work was published in formats suitable for various audiences, including technical experts, policy-makers and the general public. Emphasis was on adapting and interpreting experiences from developed countries for application to low-resource settings.[2]

In this paper we provide an overview of the analysis and mathematical modelling undertaken during and following the 2009 pandemic, with an emphasis on research of relevance to public health planning and decision-making.

Pre-pandemic planning

Mathematical models have been used by ministries of health and governments to inform influenza pandemic planning in many developed countries. Planning assumptions – in which disease severity (e.g. the case-fatality ratio) and the transmission characteristics (e.g. the basic reproductive number, R_0) of the influenza virus are based on past pandemics (e.g. 1918, 1957, 1968) or potential pandemic viral strains (e.g. highly pathogenic avian influenza subtype H5N1) – are modelled to estimate the potential incidence trajectory of infected and fatal cases and the likely impact of control measures. Such information makes it possible to determine the medical and non-medical interventions required, the feasibility of containment and the optimal size of the medication stockpile and best use of pharmaceuticals once a pandemic begins.[3,4]

Modelling during the 2009 pandemic

During the 2009 A(H1N1) pandemic, members of the influenza modelling community worked closely with public health agencies and ministries of health. Efforts focused on rapidly quantifying transmission to provide evidence for WHO pandemic phase changes;[5] assessing severity[6] and seasonality;[7,8] interpreting epidemiologic trends over time; measuring antigenic changes in the virus[9] and assessing the potential impact of interventions.[10,11] Modellers in public health agencies also provided input into study design and helped to identify key data to address public health challenges.[12,13]

Although mathematical modelling was used for planning purposes and to explore mitigation options in many countries of the Americas (e.g. Canada, Mexico and the United States of America), Europe (e.g. France, Germany, the Netherlands and the United Kingdom of Great Britain and Northern Ireland),

[a] Imperial College London, MRC Centre for Outbreak Analysis and Modelling, W2 1PG London, England.
Correspondence to Maria D Van Kerkhove (e-mail: m.vankerkhove@imperial.ac.uk).
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Asia (e.g. China and Japan) and the Pacific (Australia and New Zealand), it was not sophisticated simulation modelling, but rather, real-time statistical analyses based on mechanistic transmission models and the interpretation of emerging epidemiologic and virologic data that most often informed policy decisions on a day-to-day basis. These results were widely disseminated in peer-reviewed publications, yet much of the advice and guidance derived from the modelling was never formally published but was presented instead during face-to-face meetings with national policy-makers, with occasional documentation in meeting minutes or reports.

Early outbreak investigations provided data that proved critical for characterizing the epidemiology of infection with A(H1N1)pdm09 in communities, schools and households. They made it possible to estimate R_0, serial intervals and age-specific clinical attack rates and to track the temporal distribution of secondary infections.[5] These parameters were essential in assessing the burden of infection with A(H1N1)pdm09 and disease severity. Early rapid analyses with limited data performed to inform policy decisions were then followed by more detailed studies that made use of more reliable and complete data. For example, retrospective analyses of publicly available epidemiologic and virologic data from several countries provided a unique opportunity to compare the spread of the same virus in different countries and to determine if differences in latitude, temperature, humidity, population age structure or mixing patterns affected transmission dynamics.[14]

Policy decisions about the optimal use, effectiveness and cost-effectiveness of pharmaceutical (e.g. antivirals or vaccines) and non-pharmaceutical interventions (e.g. school closures, social distancing measures, masks) were heavily influenced by the results of mathematical modelling.[11,15] Since antivirals and vaccines were in short supply or unavailable in many countries at the start of the 2009 pandemic (and, in some countries, throughout the pandemic), modelling provided guidance for the optimal use of such interventions to reduce transmission by targeting school-aged children and other high transmitters, or to reduce morbidity and mortality by targeting high-risk individuals, such as those with chronic underlying conditions or pregnant women.

School closure was a policy option considered in some countries. Although A(H1N1)pdm09 caused milder disease than initially expected, some countries, such as Argentina and Japan, closed all schools early in their epidemic by extension of or overlap with school holidays, while others closed only certain schools. Modelling proved useful in weighing the potential health benefits of school closures against their social and economic costs. During the pandemic, modelling groups in several countries, including Australia, China (Hong Kong Special Administrative Region), France, Japan, the Netherlands, the United Kingdom and the United States, confidentially shared unpublished results with WHO and other WHO Members States via the WHO mathematical modelling network to inform decision-making.[2]

Lessons and challenges

It is difficult to reliably assess the extent to which modelling informed decision-making during the 2009 pandemic. This is because modellers and biostatisticians in most countries provided advice as part of highly interactive multidisciplinary advisory groups, whose contributions often consisted of presenting formal modelling results and a mechanistic dynamic perspective on the unfolding epidemic. Furthermore, policy-makers needed to weigh not only the potential health benefits of different interventions, but also the economic, social, political and ethical costs associated with particular policy options. What is certain, however, is that the insights gained from statistical modelling informed policy in many countries.

Despite good achievements, several challenges remain. To set realistic expectations, improved communication between policy-makers and the public about what modelling can and cannot deliver is essential. It is also important to effectively communicate how prediction differs from scenario modelling. Scenarios are useful in planning for assessing the effectiveness of interventions and various policy options, but they are not predictions. The failure to communicate uncertainty was problematic and led to misunderstanding of modelling results during the 2009 pandemic.

Political pressures during the 2009 pandemic were intense. The data available often failed to match the information needs of policy-makers. Key decisions, such as how much vaccine to purchase, had to be made despite great uncertainty surrounding the likely overall health impact of the pandemic. Analyses conducted in "real time" using limited data are always subject to substantial uncertainty, and central estimates and worst-case assessments are invariably subject to change as more data become available.

As expected, fundamental data gaps early in the pandemic, especially on population infection rates over time, made it very difficult to accurately assess its impact and disease severity. Many countries had reliable and timely data on the demand for primary health care due to influenza-like illness but very limited data on the proportion of individuals who were becoming infected and seeking health care. As a result, the numbers of symptomatic cases who were seeking medical care could not be used to estimate the overall incidence of influenza infection in the community. Real-time serosurveillance data could have filled this gap, but such data were not available in any country before the first peak of pandemic influenza activity.[13] Other data gaps also made it difficult to evaluate the likely impact of seasonal variation on transmission[7,8] or the effectiveness of many non-pharmaceutical interventions, particularly in low-resource settings.

Several important lessons were learnt from the 2009 pandemic (Box 1). Chief among them is that modelling is not a substitute for data. Rather, modelling provides a means for making optimal use of the data available and for determining the type of additional information needed to address policy-relevant questions. We must not, however, take too negative a view of achievements in 2009. Modellers provided a quantitative framework for analysing surveillance data and for understanding both the dynamics of the pandemic and the impact of the interventions. Arguably, it was such timely yet straightforward data analysis and interpretation that most informed the policy decisions made during the first months of the pandemic, rather than sophisticated pandemic simulation modelling of the type used for pre-pandemic planning.

In future, better coordination will be needed not only among modellers and modelling groups, but also with clinicians, epidemiologists, virologists and public health decision-makers. It

Box 1. **Summary of main lessons learnt**

- Better serosurveillance and monitoring of community illness attack rates could have filled data gaps (e.g. not knowing the underlying infection attack rate over time) that made it difficult to estimate disease severity and to predict peak pandemic activity.
- Sharing and analysis of detailed epidemiologic data during the pandemic was crucial for informing decisions, but data from low-resource countries was limited.
- Communication between modelling groups and policy-makers was good in several countries but could be improved further.

will also be important to reduce inconsistencies and build consensus across modelling groups. These goals will be facilitated by the establishment of national and international modelling networks such as those that were created in 2009. ■

ملخص

نمذجة الوباء والتدخل – أساس منطقي علمي للقرارات المتعلقة بالسياسات؟ الدروس المستفادة من جائحة أنفلونزا عام 2009

المشكلة يعتبر تحليل الفاشيات والنمذجة الرياضية في غاية الأهمية لتخطيط الاستجابات الصحية العمومية لفاشيات الأمراض المعدية والأوبئة والجوائح. وتصف هذه الورقة تحليل البيانات والنماذج الرياضية التي تم إجراؤها خلال جائحة أنفلونزا عام 2009 وبعدها، وبالأخص لتوفير معلومات لتخطيط الصحة العمومية وصنع القرار.

الأسلوب بُعيد ظهور الفيروس الوبائي A(H1N1)pdm09 في أمريكا الشمالية في 2009، دعت منظمة الصحة العالمية لعقد اجتماع لشبكة غير رسمية للنمذجة الرياضية من خبراء الصحة العمومية والخبراء الأكاديميين ومجموعات النمذجة. وعملت هذه الشبكة ومجموعات النمذجة الأخرى مع صناع السياسة لوصف الديناميكيات وتأثير الجائحة وتقييم فعالية التدخلات في المواقع المختلفة.

المواقع المحلية جائحة الإنفلونزا A(H1N1) عام 2009.

التغيّرات ذات الصلة قدَّم واضعو النماذج إطارًا كميًا لتحليل بيانات الرصد ولفهم ديناميكيات الوباء وتأثير التدخلات. غير أنه على نحو مثير للجدل لم يكن ما تستنير به القرارات المتعلقة بالسياسات في الغالب على أساس يومي هو نمذجة المحاكاة المتطورة، بل كان التحليلات الإحصائية البسيطة في الوقت الحقيقي القائمة على نماذج الانتقال الميكانيكي بالاعتماد على بيانات الأوبئة والفيروسات المتاحة.

الدروس المستفادة أحدٍ الدروس الرئيسية هو أن النمذجة لا يمكن أن تكون بديلاً عن البيانات؛ بل يمكنها فقط الاستفادة من البيانات المتاحة والتأكيد على ما يمكن أن تستنير به السياسة من بيانات إضافية على النحو الأمثل. لقد جعلت فجوات البيانات في 2009، وبالأخص الواردة من البلدان منخفضة الموارد من الصعب تقييم الشدة وتأثيرات الاختلاف الموسمي على الانتقال وفعالية التدخلات غير الصيدلانية. وثمة حاجة لتحسين الاتصال بين واضعي النماذج وممارسي الصحة العمومية بغية إدارة التوقعات وتسهيل مشاركة البيانات وتفسيرها وتقليل التضارب في النتائج.

摘要

流行病和干预建模 – 政策决策的基本科学原理？ 2009 年流感大流行的经验教训

问题 爆发分析和数?建模对规划传染病爆发、疾病流行和大流行的公共卫生响?至关重要。本文介绍 2009 年流感大流行期间及之后进行的特别用于为公共卫生计划和决策制定提供情报的数据分析和数学建模。

方法 2009 年北美出现 A(H1N1)pdm09 流感病毒之后，世界卫生组?随即召集公共卫生、学术专家和建模团队的非正式数学建模网络。该网络和其他建模团?与决策者协作描述流行病的动?和影响的特征，并评估不同环境中的干预效果。

当地状况 2009 A(H1N1) 流感大流行。

相关变化 建模者提供了分析监测数据和理解流行病动态及干预影响的定量分析框架。然而，日常最经常为?策提供情报的无疑不是复杂的模拟建模，而是基于依赖可用流行病学和病毒学?据的机械传播模型的简单、实?的统?分析。

经验教训 主要的经验教训是：建模替代不了数据；其只能利用可用的数据以及突出可能对?策提供最重要信息的补充数据。2009 年的数据缺口（尤其是财力不足的国家造成的缺口）使评估严重性、季节性变量对?播的影响和非药物干预效果非常困难。要管理预期、促进?据共享以及解释并减少结果中的不一致，需要建模者和公共卫生参与者之间更好的沟通。

Résumé

Épidémie et modélisation d'intervention - une justification scientifique aux décisions politiques? Leçons tirées de la pandémie de grippe de 2009

Problème L'analyse de l'apparition d'une pandémie et sa modélisation mathématique sont cruciales pour la planification des réponses de santé publique à l'apparition de maladies infectieuses, d'épidémies et de pandémies. Ce document décrit l'analyse de données et la modélisation mathématique entreprises pendant et après la pandémie de grippe de 2009, en particulier pour orienter la planification des interventions de santé publique et la prise de décision.

Approche Peu après l'apparition du virus pandémique A(H1N1)pdm09 en Amérique du Nord, en 2009, l'Organisation mondiale de la Santé a rassemblé un réseau informel de modélisation mathématique composé d'experts de la santé publique, de spécialistes universitaires et des groupes de modélisation. Ce réseau et d'autres groupes de modélisation ont travaillé avec les décideurs pour définir la dynamique et l'impact de la pandémie, et évaluer l'efficacité des interventions dans divers environnements.

Environnement local La pandémie de grippe A(H1N1) de 2009.

Changements significatifs Les modélisateurs ont fourni un cadre quantitatif pour l'analyse des données de surveillance et la compréhension de la dynamique de l'épidémie et de l'impact des interventions. Toutefois, au quotidien, les décisions politiques étaient sans doute plus souvent inspirées par des analyses statistiques simples, en temps réel, basées sur des modèles de transmission mécanistes et les données épidémiologiques et virologiques disponibles, que par un modèle de simulation sophistiqué.

Leçons tirées Un des enseignements principaux est que la modélisation ne peut pas remplacer les données. Elle ne fait qu'utiliser les données disponibles et mettre en évidence les données supplémentaires pouvant mieux éclairer les politiques. Le manque de données en 2009, en particulier en provenance des pays à faibles ressources, ont rendu difficile l'évaluation de la gravité, les effets des variations saisonnières sur la transmission et l'efficacité des interventions non pharmaceutiques. Une meilleure communication entre les modélisateurs et les praticiens de la santé publique est nécessaire pour gérer les attentes, faciliter le partage et l'interprétation de données, et réduire les incohérences entre les résultats.

Резюме

Моделирование эпидемий и проведения мероприятий – научное обоснование для принятия решений в отношении проводимых политик? Уроки, извлеченные из пандемии гриппа 2009 года

Проблема Анализ и математическое моделирование вспышек заболеваний играют важную роль в планировании ответных мер органов здравоохранения на вспышки инфекционных заболеваний, эпидемии и пандемии. В этом документе описывается анализ данных и математическое моделирование, осуществленные во время и после пандемии гриппа в 2009 году. Основной целью этих мероприятий было предоставление необходимой информации для осуществления планирования и принятия решений органами здравоохранения.

Подход Вскоре после пандемии вируса гриппа A(H1N1)pdm09 в Северной Америке в 2009 году Всемирная организация здравоохранения создала неформальную сеть математического моделирования из групп академических экспертов и специалистов по моделированию в сфере здравоохранения. Эта сеть и другие группы по моделированию сотрудничали с составителями политик с целью определения характеристик, динамики и влияния пандемий, а также оценки эффективности мероприятий в различных условиях.

Местные условия Пандемия гриппа A(H1N1) в 2009 году.

Осуществленные перемены Составители моделей предоставили количественную основу для анализа данных по эпиднадзору, а также для понимания динамики распространения эпидемий и влияния осуществленных мероприятий. Тем не менее, основная информация для принимающих решения органов поступала на ежедневной основе не по результатам сложного имитационного моделирования, но из простого и проводимого в реальном времени статистического анализа, основывающегося на механистических моделях передачи, использующих доступные эпидемиологические и вирусологические данные.

Выводы Основной вывод заключается в том, что моделирование не может заменить данные. Оно может только служить инструментом для обработки доступных данных и указывать, какие дополнительные сведения могут быть полезны при составлении политик. Пробелы в данных 2009 года, особенно из стран с ограниченными ресурсами, затруднили оценку тяжести пандемии, последствий сезонных изменений при передаче вируса и эффективность нефармацевтических мероприятий. Для достижения ожидаемых результатов, стимулирования обмена данными, а также для улучшения интерпретации результатов и уменьшения количества несоответствий, необходимо повышение качества обмена данными между составителями моделей и сотрудниками здравоохранения.

Resumen

Modelización epidémica e intervencionista – ¿un fundamento científico para la toma de decisiones? Lecciones de la gripe pandémica de 2009

Situación El análisis del brote y la modelización matemática son cruciales para la planificación de respuestas de salud pública a los brotes, epidémicos y pandémicos, de enfermedades infecciosas. Este documento describe los análisis de datos y la modelización matemática utilizados durante y después de la gripe pandémica de 2009. Su objetivo principal era la obtención de información para la planificación y la toma de decisiones en materia de salud pública.

Enfoque Poco después de que surgiera el virus pandémico A(H1N1) pdm09 en Norteamérica en el año 2009, la Organización Mundial de la Salud reunió una red informal de modelización matemática compuesta por expertos académicos, expertos en salud pública y grupos de modelización. Esta red y otros grupos de modelización trabajaron con responsables políticos con el fin de caracterizar las dinámicas y el impacto de la pandemia, así como para evaluar la eficacia de las intervenciones en diversos escenarios.

Marco regional La gripe pandémica A(H1N1) de 2009.

Cambios importantes Los encargados de la modelización proporcionaron un marco cuantitativo para analizar los datos de vigilancia y para entender la dinámica de la epidemia y el impacto de las intervenciones. No obstante, podría decirse que lo que con mayor frecuencia informó a diario a las decisiones políticas no fue la modelización de simulación sofisticada, sino simples análisis estadísticos en tiempo real basados en los modelos mecanicistas de transmisión, que se basan en los datos epidemiológicos y virológicos disponibles.

Lecciones aprendidas Una lección clave fue que la modelización no puede sustituir a los datos, únicamente puede hacer uso de los datos disponibles y destacar aquellos datos adicionales que puedan ser la mejor información para la política. Las lagunas de datos en 2009, especialmente de los países con pocos recursos, dificultaron la evaluación de la gravedad, los efectos de la variación estacional en la transmisión y la eficacia de las intervenciones no farmacéuticas. Es necesario mejorar la comunicación entre los encargados de la modelización y los profesionales de salud pública para gestionar las expectativas, facilitar que se compartan e interpreten datos y reducir las incoherencias en los resultados.

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