Mathematical modelling helps to control meningococcal meningitis in sub-Saharan Africa

Meningococcal meningitis is endemic in the countries of the African 'meningitis belt' (from Senegal to Ethiopia).

Meningococcal meningitis is a debilitating and deadly disease, causing an estimated 10,000 deaths annually in endemic areas of sub-Saharan Africa. A novel mathematical model developed by Sussex researcher Dr Konstantin Blyuss and colleagues has helped explain the patterns of the dynamics of meningococcal meningitis in endemic areas. This model is now being used by epidemiologists and clinical scientists to design and deliver efficient public-health policies to combat this devastating disease.

Overview

The 'meningitis belt' comprises 26 countries in sub-Saharan Africa and reaches across the continent from Senegal in the West to Ethiopia in the East. Meningococcal meningitis is endemic in this region, and patterns of infection are seasonal, with a higher incidence of disease occurring every dry season. Major outbreaks occur every 6–14 years, causing tens of thousands of deaths with a fatality rate of 5–15 per cent.

A number of environmental factors are believed to be important in explaining the observed seasonality in meningitis in this region, and several alternative hypotheses have been proposed to explain how these factors affect disease transmission. However, the precise causes of observed irregularities in the dynamics of meningococcal meningitis and the relative roles played by different factors have remained poorly understood.

A major challenge to understanding and managing meningococcal meningitis in sub-Saharan Africa has been the contradiction between the available data from this region and the classic Goldschneider paradigm, which asserts an inverse relationship between age-specific disease risk and immunity.

Dr Konstantin Blyuss from the University of Sussex, in collaboration with colleagues Dr Tom Irving (Ministry of Justice), Dr Caroline Colijn (Imperial College London), and Dr Caroline Trotter (University of Cambridge), has developed a new mathematical model of the transmission of meningococcal meningitis that is able to explain the observed patterns of dynamics of this disease. The model explicitly includes temporary immunity and two possible types of seasonality: variation in disease transmission and changes in the rate of progression from carriage to invasive disease. The importance of the model is that it highlights the fundamental role of temporal immunity and its interactions with seasonality in the dynamics of the disease. More specifically, the analysis demonstrated that depending on the duration of a period of temporary immunity and the strength of seasonal variation in the disease transmission rate associated with wet/dry seasons, the model exhibits either periodic oscillations with different periods or irregular chaotic behaviour. Epidemiologically, these types of behaviours correspond to epidemic outbreaks of different periods as observed in the data.

Achieving impact

The primary impact of this work has been its use by epidemiologists and clinical scientists in the practical and optimal design of vaccination programmes and in assessing the effectiveness of a new vaccine for meningitis in the field.

Meningococcal meningitis in the meningitis belt presents a significant healthcare burden to the region, affecting up to 100,000 people with an estimated 10,000 deaths a year. The international Meningitis Vaccine Project, funded by the Bill and Melinda Gates Foundation and the World Health Organization (WHO), was set up in a direct and proactive attempt to tackle this problem. As a result of this concerted international effort, the MenAfricVac™ vaccine has been developed as a cheap and effective means of combating meningitis, and it has completed clinical trials. Following its successful introduction in pilot programmes in Burkina Faso, Mali and Niger in 2010, MenAfricVac™ was introduced into a further seven countries in late 2012 with a view to covering all 26 countries of the meningitis belt by 2016.

Dr Blyuss and his colleagues collaborated closely with the MenAfriCar Consortium to ensure that the academic results of their research are translated into practical recommendations for the design of optimal strategies in vaccine deployment and to assess the efficacy of the new vaccine. Thus, experts from MenAfriCar have been able to use the model, and its subsequent developments, to understand the prevalence, incidence and relative impact of different risk factors in endemic areas and to develop targeted, age-structured vaccination strategies for the deployment of MenAfricVac™.

The Programme Manager of the MenAfriCar Consortium (Professor James Stuart, London School of Hygiene and Tropical Medicine) has confirmed that the model has had a major effect on how epidemiologists on the ground view and interpret the population-level dynamics of meningococcal meningitis and on developing optimal vaccination strategies.

Future impact

This research has been taken up by the MERIT (Meningitis Environment Risk Information Technologies) Project, which is co-ordinated by WHO, for the purposes of disease surveillance. Epidemiologists from GAVI (Global Alliance for Vaccines and Immunisation) are also using the model by Blyuss and colleagues to develop further detailed models for the assessment of the effects of vaccination interventions.

There are two major public health issues associated with the introduction of MenAfricVac™ vaccine. Firstly, in such a large geographical area there are logistical and cost constraints. Thus, effective strategies are needed to optimise vaccination campaigns and enable the treatment of those individuals most at risk. Secondly, in order to determine their true value, there is a need for robust assessment of the population-wide efficiency of such vaccination programmes. The model developed by Blyuss and colleagues will help public-health professionals in the field to address both of these problems.

Funding and partnership

During the project, Dr Blyuss and Dr Tom Irving were supported by the EPSRC grant (EP501214/1), and Dr Caroline Trotter was supported by the MenAfriCar Consortium (Bill and Melinda Gates Foundation/Wellcome Trust).

Epidemiologists from GAVI (Global Alliance for Vaccines and Immunisation) are using the model by Blyuss and colleagues to develop further detailed models for the assessment of the effects of vaccination interventions.

Working with us

If you are interested in working with us, please contact:

Dr Ian Carter
Director of Research and Enterprise
Sussex House
University of Sussex
Falmer, Brighton BN1 9RH

E research@sussex.ac.uk
T +44 (0)1273 877718
www.sussex.ac.uk/research

For further information about research in mathematics applied to biology, visit:
www.sussex.ac.uk/lifesci/mab