Epidemiological characterisation of 1918 pandemic influenza aboard ships

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Contents

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Abstract

Influenza has been the principal cause of pandemic events over the last century. As such, strategies must be implemented to reduce the potential impact of future pandemics. These epidemic control measures should be informed by the epidemiological characteristics of the disease, but our current understanding of influenza is wanting. Here, we study one of the worst pandemics: the *1918 "Spanish flu" pandemic*. Viral descendants of the 1918 influenza strain are still in circulation today, such as the 2009 influenza pandemic virus. Hence, there is significant motivation to study the epidemiological characteristics of the strain responsible for the 1918 pandemic to best inform the development of control measures against future pandemics.

Past epidemiological studies of the 1918 pandemic have been restricted to data and epidemic models that fail to account for important dynamics, or ignore external factors which could potentially bias results. Here, we investigate a previously unstudied data source of contained influenza outbreaks from the 1918 pandemic that alleviates these issues. Data of 15 influenza outbreaks aboard naval and passenger vessels travelling to Australia has been collated. These *on-board epidemics* are natural *pseudo experiments* of influenza transmission; contained outbreaks replicating transmission experiments with a level of recorded detail unprecedented for the 1918 pandemic. To exploit the data, we develop a novel stochastic epidemic model that accounts for features salient to characterising the epidemiology of the 1918 pandemic strain; these include asymptomatic infections, the pre-symptomatic infectious period and prior immunity. To validate our approaches, an extensive investigation of inference methods and parameter identifiability is conducted.

Parallel inference across multiple ship outbreaks is used to characterise the 1918 pandemic influenza strain and enables comparison across pandemic waves. We find that 1918 pandemic was caused by a highly transmissible virus, and the reduced impact between the second and third pandemic waves

was a result of significantly increased population immunity. We find evidence indicating individuals are infectious for a significant period of time (approximately 20 hours) before the development of symptoms. Most importantly, we find transmission from *non-symptomatic* individuals, that is, infectious individuals that are asymptomatic or in the period prior to onset of symptoms, was the dominant cause of infection aboard these ships.