Modelling the importation risk of measles during the Hajj

Massad E[1,2], Wilder-Smith AB[3], Wilder-Smith A[4,5], Memish ZA[6,7,8]

[1]School of Applied Mathematics, FundacaoGetulio Vargas, Rio de Janeiro, Brazil

[2]School of Medicine, The University of Sao Paulo, Brazil

[3] University of Edinburgh, United Kingdom

[4] London School of Hygiene and Tropical Medicine, United Kingdom

[5] Heidelberg Institute of Global Health, University of Heidelberg, Germany

[6] Infectious Diseases Division, Department of Medicine & Department of Research, Prince Mohamed Bin Abdulaziz Hospital,

[7]Ministry of Health, College of Medicine, Alfaisal University, Riyadh, Kingdom of Saudi Arabia

[8]Hubert Department of Global Health, Rollins School of Public Health, Emory University, Atlanta, Georgia, USA

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Correspondence:
Prof Annelies Wilder-Smith
London School of Hygiene and Tropical Medicine, UK
Email: annelies.wilder-smith@lshtm.ac.uk

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Dear Editor

Measles has seen a major resurgence in the past two years.[1,2] Measles is one of the most contagious diseases with a reproduction rate of around 20. Although a very effective vaccine against measles it available, vaccine coverage rate is low in an increasing number of countries, including many Muslim

countries.[3] The concern is that measles could be introduced via pilgrims to the Hajj and subsequently spread rapidly as a result of the overcrowded situation of the Hajj rituals.[3]

The 20 leading countries that send Hajj pilgrims are listed in the appendix, and together with Saudi Arabia, they account for more than 80% of all pilgrims. More than 90% of all pilgrims arrive by airplane, eg within 24 hours after departure. The majority of pilgrims are older persons, and those are considered measles immune if born before 1957. Using travel volume data, we attempted to estimate the number of measles importations into Saudi Arabia for the Hajj 2019 (appendix).

Briefly, we obtained data on measles vaccine coverage rates, measles incidence (reported measles cases divided by population size) and number of pilgrims from each of those 20 countries. From data on vaccination coverage, number of measles cases, population size and number of pilgrims from each country, we calculated the expected number of cases exported from these countries to Saudi Arabia. We assumed that 70% of pilgrims were measles immune (born before 1957), and calculated the number of susceptible pilgrims based on the vaccine coverage rates (equation 1 in the appendix).

Next, we calculated the expected number of cases arriving still infected in Saudi Arabia (CA) assuming that 3% of the pilgrims acquire measles at the day of the travel, that an infected individual remains infected for exp(0,1*t) days, and that the trip to Saudi Arabia lasts around 1 day (equation 2 in the appendix).

We then calculated the expected number of susceptible pilgrims arriving in Saudi Arabia by multiplying the number of pilgrims travelling to the Haji times the fraction of susceptible pilgrims (equation 3 in the appendix).

Based on these calculations, we estimated that110 measles importations will occur in the Hajj using data obtained in 2018. This anticipated number may be even higher given that the measles incidence has increased even further in 2019 compared to 2018. The 6 leading countries with the highest number of measles importations into Saudi Arabia will be Yemen, India, Nigeria, Indonesia, Pakistan and Sudan (appendix).

These 110 imported measles cases could potentially lead to many secondary cases. Fortunately, the vaccine coverage rate is very high with 96% in Saudi Arabia. However, at least 100,000 pilgrims may be susceptible to measles out of the approximately 2 million pilgrims. The speed of spread amongthose susceptible Hajj pilgrims will depend on the extent of intermixing between pilgrims during the rituals. Given the high reproduction rate of 20 in susceptible populations, these 110

imported measles cases could trigger a major outbreak towards the end of the Hajj pilgrimage and result in rapid dissemination globally when pilgrims return to their home countries.

Our modelling suggests that measures should be taken to minimize the risk of measles introduction into Saudi Arabia during the Hajj via incoming pilgrims. First, pilgrim-sending countries should offer measles vaccination before departure to all pilgrims without a measles vaccination record and born after 1957. One might even argue that measles vaccination in those countries with suboptimal MCV2 coverage rates should become a Hajj entry requirement. Second, Saudi Arabia may want to consider offering vaccination at arrival in Saudi Arabia to all pilgrims from countries with low measles vaccine coverage rates, although ensuring sufficient vaccine supply and setting up the logistics may be too late for this upcoming Hajj. Third, health care providers during the Hajj need to have a high degree of suspicion to suspect measles and be familiar with the clinical management of measles complications. Lastly, public health measures need to be planned a priori for a rapid response should a measles outbreak occur including stockpiling measles vaccines.

Author contributions: AWS and ZAM had the idea and conceptualized the study, EM did all the mathematical models, ABWS obtained all the data from various public sources and assembled the table. All authors contributed to the final manuscript.

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Appendix

In this appendix we details the calculations carried out in the main text.

The number of cases potentially exported (PEC) to Saudi Arabia was calculated according to to:

$$PEC = ((100 - MCV2)/100) * (MeslCas / PopSize) * NumbPil * 0.3) \quad (1)$$

Next, we calculate the expected number of cases arriving still infected in Saudi Arabia (CA) assuming that 3% of the pilgrims acquire measles at the day of the travel. This is based on the assumption that measles infection lasts 10 days, therefore the probability of acquiring the infection in any of the remaining days of the year is 1/355. In addition we assumed that an infected individual remains infected for exp(0,1*t) days. Finally, assuming that the trip to Saudi Arabia lasts around 1 day we calculated CA according to:

$$CA = 0.03 * EC * \exp(0,1 * 1) \quad (2)$$

We then calculated the expected number of susceptible pilgrims arriving in Saudi Arabia (SP) by multiplying the number of pilgrims travelling to the Haji times the fraction of susceptible, that is:

$$SP = ((100 - MCV2)/100) * NumbPil * 0.3) \quad (3)$$

Finally, we calculated the expected number of secondary measles cases among pilgrims (EMC) by assuming a measles basic reproduction number as equal to 20 ($R_0 = 20$), which, when multiplied by the fraction of susceptible pilgrims gives the effective reproduction number ($R(t)$), that is:

$$R(t) = R_0 /(SP / NumbPil) \quad (4)$$

Table 1 summarizes our findings.

Table 1: Modelled number of imported measles cases via pilgrims to Saudi Arabia from 20 countries taking into account measles incidence and measles vaccine coverage rates in the origin country, and number of pilgrims

Countries	MCV2 (2017)*	Measles cases (2018)**	Population size (000s) (2018)***	Number of Pilgrims (2018)	Susceptible pilgrims	Imported measles
Yemen	46	12617	28915	26710	4327	38
India	77	68841	1354052	183040	12630	19
Nigeria	42	7018	195875	59253	10310	17
Indonesia	63	5412	266795	210984	23419	11
Pakistan	45	33248	2000814	200969	33160	9
Sudan	72	4978	41512	39714	3336	7
Afghanistan	39	1899	36373	31699	5801	5
Syria	59	329	18284	18191	2237	2
Turkey	86	568	81917	116551	4895	1
Iraq	74	484	39340	43075	3360	1
Iran	98	93	82012	86452	519	0
Egypt	94	24	99376	98143	1767	0
Bangladesh	96	2131	166368	133157	1598	0
Morocco	99	7	36192	36764	110	0
Algeria	92	287	42008	39801	955	0
Malaysia	99	2504	32042	25461	76	0
Russia	97	2256	143965	19867	179	0
Jordan	99	0	9904	17391	52	0
Oman	99	0	4830	12422	37	0
Lebanon	68	943	6094	14501	1392	0
				Total	110160	110

* MCV2: http://apps.who.int/gho/data/node.main.MCV2n?lang=en

**https://www.who.int/immunization/monitoring_surveillance/burden/vpd/surveillance_type/active/measles_monthlydata/en

*** Population Size: https://population.un.org/wpp/DataQuery/