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**CAYETANO HEREDIA**

“ASOCIACIÓN ENTRE  
SEROPREVALENCIA DEL VIRUS  
DE SARAMPIÓN EN MONOS Y LOS  
DIFERENTES CONTEXTOS DE  
CONTACTO CON HUMANOS EN  
BANGLADESH”

TESIS PARA OPTAR EL GRADO DE  
MAESTRO EN CONTROL DE  
ENFERMEDADES INFECCIOSAS Y  
TROPICALES

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# ASOCIACIÓN ENTRE SEROPREVALENCIA DEL VIRUS DE SARAMPIÓN EN MONOS Y LOS DIFERENTES CONTEXTOS DE CONTACTO CON HUMANOS EN BANGLADESH

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## **RESUMEN**

Las infecciones por sarampión pueden causar una morbilidad y mortalidad significativas en poblaciones humanas y de monos. La endemicidad del sarampión en poblaciones humanas y la circulación viral en poblaciones de monos en libertad pueden tener importantes repercusiones en la transmisión zoonótica y para la salud a largo plazo de las poblaciones de monos. Sin embargo, aún no se ha investigado la dinámica de transmisión del sarampión cuando coexisten poblaciones humanas y de monos. En este estudio, para determinar la seroprevalencia del virus del sarampión en distintos contextos de contacto entre humanos y monos, analizamos los datos de suero de 56 monos *Macaca mulatta* aparentemente sanos que ocupaban diversos contextos, con diferentes grados de contacto entre humanos y monos, en Bangladesh. Encontramos asociación entre la seropositividad al virus del sarampión en los monos y el contexto en el que interactúan con humanos. La seroprevalencia más baja fue en las áreas naturales (0,0%) y fue en aumento, en santuarios (4,8%), áreas urbanas (5,9%), y la más alta entre los circos nómades (50,0%), donde los monos son utilizados como animales de actuación. Este trabajo sugiere que es necesario un enfoque de "Una Salud" para explorar el desarrollo de planes de conservación de monos evaluando su interacción con humanos. Asimismo, sugiere la necesidad de plantear programas de vigilancia a largo plazo en las poblaciones de monos y se evite así la propagación del virus de sarampión tanto en las poblaciones de monos, como de humanos.

## **PALABRAS CLAVES**

BANGLADÉS, *MACACA MULATTA*, SARAMPIÓN, SEROPREVALENCIA, 'SPILLBACK', UNA SALUD, ZOOANTROPONOSIS

## **ABSTRACT**

Measles infections can cause significant morbidity and mortality in human and monkey populations. The endemicity of measles in human populations and viral circulation within populations of free-living monkeys may have important repercussions for potential zoonotic transmission events and for the long-term health of monkey populations. Yet, there has not been a rigorous investigation of measles transmission dynamics where human and monkey populations coexist. In this study, to determine the difference in seroprevalence of the measles virus across different contexts of human-monkey contact, we analyzed serum samples collected from 56 apparently healthy *Macaca mulatta* monkeys who occupied diverse contexts, with different degrees of human-monkey contact, in Bangladesh. We found an association between measles virus seropositivity in monkeys and the context in which they interact with humans. Seroprevalence was the lowest in wild areas (0.0%) and increased in shrines (4.8%), urban areas (5.9%), and was highest among monkeys who are used as performance animals (50.0%). This work suggests that a "One Health" approach is necessary to explore the development of monkey conservation plans by evaluating their interaction with humans. Likewise, it suggests the need to propose long-term surveillance programs in monkey populations to prevent the spread of the measles virus in both monkey and human populations.

## **KEY WORDS**

BANGLADESH, *MACACA MULATTA*, MEASLES, ONE HEALTH, SEROPREVALENCE, SPILLBACK, ZOOANTHROPONOSIS

## I. ARTÍCULO PUBLICADO

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### Association between seroprevalence of measles virus in monkeys and degree of human-monkey contact in Bangladesh

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#### ABSTRACT

Measles infections can cause significant morbidity and mortality in human and monkey populations. The endemicity of measles in human populations and viral circulation within populations of free-living monkeys may have important repercussions for potential zoonotic transmission events and for the long-term health of monkey populations. Yet, there has not yet been a rigorous investigation of the dynamics of measles transmission where human and monkey populations coexist. In this study, to determine the difference in seroprevalence of the measles virus across different contexts of human-monkey contact, we analyzed serum samples collected from 56 apparently healthy *Macaca mulatta* monkeys who occupied diverse contexts, with different degrees of human-monkey contact, in Bangladesh. This is the first report of measles virus seroprevalence in monkeys in Bangladesh. We found a clear association between measles virus seropositivity in monkeys and the context in which they interact with humans. Seroprevalence was the lowest in wild areas (0.0%) and increased in shrines (4.8%), urban areas (5.9%), and was highest among monkeys who are used as performance animals (50.0%). This work suggests that a One Health approach informed by local interspecies transmission dynamics is necessary to develop strategies that both improve measles vaccination coverage, achieve long-term surveillance in monkey populations, and prevent measles spillover to monkeys. This approach aims to inform conservation efforts and protect the long-term health of human and monkey populations.

#### 1. Introduction

Measles is a highly contagious febrile disease caused by a virus of the genus *Morbillivirus* in the family *Paramyxoviridae* and is easily spread through respiratory droplets [1,2]. The measles virus has the highest basic reproductive number; an infected person can infect between 12 and 18 other individuals [3]. Despite the development of an effective vaccine in the 1960s, measles infection is associated with over 140,000 measles deaths worldwide [2,4]. While humans are natural hosts of the measles virus, viral circulation occurs in populations of free-living monkeys, likely a result of human-monkey transmission followed by within-population transmission [5]. Currently, more than 90% of deaths related to measles occur in Southeast Asia, a geographic area where,

coincidentally, the human-monkey interface is diverse and has contexts with different degrees of human-monkey contact [5,6].

The research published to date on the prevalence of measles infections in monkeys has not been sufficient to fully understand the transmission dynamics of the virus between human and monkey populations [5]. The World Health Organization considers humans as the only reservoir [4]. However, studies have shown that measles infection can occur among free-ranging populations of macaques [5,7]. Despite the potential impact that this disease can have on human and animal health until now it has not been possible to establish adequate strategies for its surveillance and control of interspecies transmission [1,8]. For example, Bangladesh, a country that has strengthened its surveillance system, still faces challenges in eliminating continuous small-scale

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outbreaks in humans [1,9], which may spill over to local monkey populations [5,10–13].

Bangladesh is characterized by a high human population density, a high level of poverty, and a tropical climate [9,14]. Additionally, it has many areas with human-wildlife contact, turning this place vulnerable to interspecies pathogens transmission [15]. In addition, Bangladesh is home to one of the most widely distributed monkey species, *Macaca mulatta* [16]. These monkeys are often chosen by locals to perform in circuses, are kept as household pets, and participate in various Bangladesh cultural traditions [16]. Given the importance of these monkeys in local communities, there are many contexts in which they come into contact with humans (i.e. natural areas, urban areas, shrines, and performing environments). These contexts of human-monkey contact are created by the characteristics of the associated human population. Additionally, the degree and extent of human contact with the monkeys varies across contexts regarding time of interactions, proximity, and frequency [5,7,17]. Therefore, it is essential to study the presence of measles virus, a pathogen that poses a significant threat to both humans and monkeys, in areas that allow different degrees of contact between humans and monkeys, and where outbreaks occur regularly [1,6,9].

Laboratory monkeys that get infected with the measles virus show a range of clinical signs from asymptomatic, to mild gastrointestinal signs, secondary bacterial infection, pneumonia, encephalitis, abortion, and to death [8,18]. Wild monkeys, which are known to become infected when they are in contact with infected humans, show temporary immunosuppression similar to or often more acute and severe than it presents in humans [18,19], causing mortality of up to 100% [5]. The study of the seroprevalence of the measles virus in populations of monkeys can allow a better understanding of its transmission dynamic and determine the risk that contact with humans represents for the health of local monkey populations and conservation areas [5].

During the last two decades, infection with the measles virus has been studied in wild monkeys from different parts of Asia such as Indonesia, Singapore, and Nepal [5,20]. For example, in Nepal, researchers reported 100% seroprevalence in *Macaca mulatta* individuals sampled in a temple [5]. However, none of these studies included multiple contexts of human-monkey interactions which would have facilitated a stratified analysis across contexts that offer a gradient of

human-monkey contact such as natural areas, urban areas, shrines, and performing environments. Also, the seroprevalence of the measles virus in monkeys in Bangladesh has not yet been determined. Thus, in this study, our objectives were to estimate of seroprevalence of the measles virus in monkeys of the species *Macaca mulatta* in Bangladesh and identify an association between the level of seropositivity and the degree of human-monkey contact.

## 2. Methods

### 2.1. Ethics statement

Ethical approval was obtained from the University of Washington's Institutional Animal Care and Use Committee (approval number: 3143-03).

### 2.2. Study Site

Bangladesh is one of the most densely populated countries in the world. Its geographical location has positioned it for centuries as an important point of Asian and world trade [14,16]. It also has many urban areas located within or near monkey habitats [15,16]. Data collected from seven geographically distinct areas in Bangladesh were included, chosen because they represent areas with defined human-monkey contact [21] (Fig. 1).

### 2.3. Geographical areas

The seven different geographical areas from which the samples were obtained were chosen based on the human and monkey density, the transportation routes, and the degree of human-monkey contact [15,17].

### 2.4. Contexts

This study focuses on 4 different contexts: wild areas, urban areas, shrines, and performing environments:

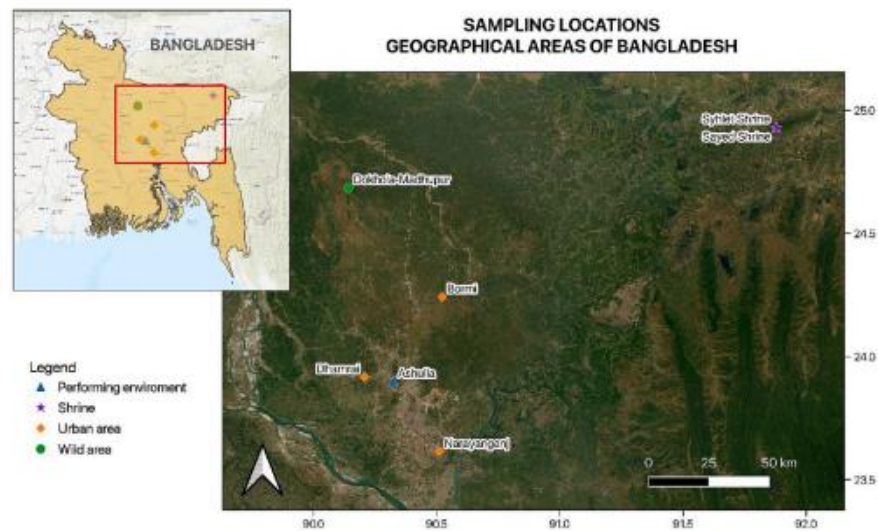


Fig. 1. Geographical areas for monkey sampling according to context in Bangladesh.

- i) *Wild areas* typically contain ecotourism attractions. These areas maintain sporadic and casual human-monkey contact [15].
- ii) *Shrines* have been reported as one of the places where the most diverse human-monkey contact occurs [15]. These areas are refuges for monkeys [21] that come into direct contact with shrine visitors that often offer food to the monkeys [15].
- iii) *Urban areas* contain the highest human population density and the presence of synanthropic monkeys is very common; therefore, they represent areas where the presence of the measles virus in the human population is constant with frequent outbreaks, as measles has not been eliminated from Bangladesh [15].
- iv) *Performing environments* are circuses run by the “Bedey” community [15,22]. Bedey people are nomadic and marginalized; 98% of them live below the poverty and have scant access to healthcare and education [15,22]. In these circuses, Bedey individuals own and train the performing monkeys resulting in frequent and prolonged human-monkey contact [22].

## 2.5. Study population

The study population was chosen by convenience. Study subjects were obtained through capture and/or by agreement with the owners of performing monkeys. A total of 56 (28 females and 28 males) rhesus macaques *Macaca mulatta* were evaluated. All animals were apparently healthy and did not show any signs of disease at the time of capture.

## 2.6. Capture and Sampling

Physical or chemical immobilization methods were used to capture and restrain individuals in all settings. In the case of performing monkeys, physical restraint was achieved with the help of the owners [16,28]. Free-ranging monkeys were restrained using a remote darting system (Telinject -Agua Dolce, CA, USA) and a Tiletamine-Zolazepam protocol (Telazol 3 mg/kg) [16,17,28]. Blood samples (5–10 ml) were obtained from the femoral vein of physically restrained or anesthetized monkeys, following a complete clinical examination and morphometric measurements [16,17,23,28]. Animals were weighed using manual spring scales of 1, 5, and 15 kg. Age category (older juvenile, subadult, and adult) was determined according to the dental formula [24].

To minimize the risk of accidental injuries due to capture, younger animals and pregnant females were excluded, as they are prone to acute stress conditions [5,15,25]. After sampling and examination, animals were placed in portable boxes (the capture boxes of approximately 2.5 m<sup>3</sup>, and the recovery boxes of 0.75 m<sup>3</sup>; manufactured at the National Primate Research Center in Washington), until they were fully recovered from anesthesia to later be released into the area where they were initially trapped [5].

## 2.7. Sample processing and serology

Blood samples were collected in Vacutainer tubes with EDTA and then separated by centrifugation to obtain the plasma [5]. Plasma samples were placed in containers with ice packs and then stored at –80 °C, to be sent to the Laboratory of the University of Washington, United States of America.

Samples were analyzed using the multiplex immunoassay (MIA) technique [26], which have demonstrated its efficiency, validity, and reliability in serological studies of herd immunity against vaccine-preventable infections to measles, mumps, rubella, varicella-zoster virus and hepatitis B [26,27]. Also, this technique is suitable for large-scale surveillance studies because it requires small amounts of serum, and is faster than the enzyme-linked immunosorbent assays (ELISAs) [27–31]. More importantly, they are more sensitive than the ELISAs and have high specificity [26,32]. In addition, this technique has shown low cross-reaction in multiple studies on viral pathogens [33,34].

## 2.8. Statistical analysis

The database was imported into the statistical program R [35]. A descriptive analysis was performed to determine the absolute and relative frequencies of each of the variables. In the bivariate analysis, associations between context, geographic area, categorical age, and sex with measles virus seropositivity were determined using the Chi-square test in variables with 10 or more observations per group, Fisher’s exact test for categorical variables with fewer than 10 observations in any subgroup. The association between seropositivity and the monkeys’ weight was evaluated using a student’s *t*-test. We built logistic models for the multivariate analysis. All statistical tests were 2-sided, and the significance level was 0.05.

## 3. Results

### 3.1. Demographics of *Macaca mulatta* in the Bangladesh study

From a total of 56 samples, 50% were males, with an average weight of 7.3 kg (SD = 3.1), and 50% were females, with an average weight of 6 kg (SD = 1.6). The area from which the largest number of samples was obtained was Syhlet Shrine (21.4%) and the area with the least number of samples was Narayanganj (5.4%). The age distribution of the sampled individuals was 17.9% older juvenile, 16.1% subadult, and 66.1% adult (Table 1).

### 3.2. Measles seroprevalence varies by sex and age

We observed a much higher percentage of seropositivity in the sampled females (21.43%) versus males (3.57%) and this difference was statistically significant ( $\chi^2 = 4.08$ ;  $p = 0.043$ ). The samples of adult individuals resulted in a higher percentage of seropositivity (16.22%) compared to the other categories (older juvenile 0%, subadult 11.11%), however, this difference was not statistically significant (Fisher’s exact test,  $p = 0.513$ ). We did not find an association between weight and seropositivity (Table 2).

### 3.3. Measles seroprevalence across geographical area

Across geographical areas, the highest measure of seroprevalence was observed in monkeys sampled in Ashulia (50%) compared to the other areas (Bormi 0%, Dhamrai 12.5%, Dokhola Modhupur 0%, Narayanganj 0%, Sayed Shrine 11.11%, Syhlet Shrine 0%), and this imbalance distribution was statistically significant (Fisher’s exact test,  $p = 0.009$ ) (Table 2).

### 3.4. Association between seroprevalence and degree of human-monkey contact

The highest percentage of seropositivity was obtained in the performing environments (50%), compared to the urban areas (5.88%), shrines (4.76%), and wild areas (0%). We found a statistical association between the context of human-monkey contact and the seroprevalence of the measles virus in monkeys in the bivariate analysis (Fisher’s exact test,  $p = 0.002$ ) (Table 2) and in the regression models adjusted for other variables (Table 3), providing evidence of higher levels of measles seropositivity in monkeys with increasing degree of human-monkey contact.

## 4. Discussion

We found a highly significant association between the context of human-monkey contact and measles virus seroprevalence in monkeys. There is a clear gradient between the degree of human-monkey contact that each of these contexts offers and the probability of seropositivity in monkeys. Seroprevalence was the lowest in wild areas and increased in

**Table 1**  
Distribution of *Macaca mulatta* monkeys in Bangladesh according to the context of contact with humans, sex, area, and age.

Variable	Levels	Context									
		Performing		Shrine		Urban		Wild		Total	
		N	%	N	%	N	%	N	%	N	%
Sex	Female	9	16.1%	7	12.5%	6	10.7%	6	10.7%	28	50.0%
	Male	1	1.8%	14	25.0%	11	19.6%	2	3.6%	28	50.0%
	Ashulia	10	17.9%	0	0.0%	0	0.0%	0	0.0%	10	17.9%
Geogr. Area	Bormi	0	0.0%	0	0.0%	6	10.7%	0	0.0%	6	10.7%
	Dhamrai	0	0.0%	0	0.0%	8	14.3%	0	0.0%	8	14.3%
	DokholaModhupur	0	0.0%	0	0.0%	0	0.0%	8	14.3%	8	14.3%
	Narayanganj	0	0.0%	0	0.0%	3	5.4%	0	0.0%	3	5.4%
	Sayed Shrine	0	0.0%	9	16.1%	0	0.0%	0	0.0%	9	16.1%
	Syhlet Shrine	0	0.0%	12	21.4%	0	0.0%	0	0.0%	12	21.4%
Weight	Mean in kg (SD)	10	5.7 (1.3)	21	5.4 (2.3)	17	8.5 (2.6)	8	6.6 (1.8)	56	100.0%
	OlderJuv	0	0.0%	8	14.3%	1	1.8%	1	1.8%	10	17.9%
Age	Subadult	2	3.6%	4	7.1%	3	5.4%	0	0.0%	9	16.1%
	Adult	8	14.3%	9	16.1%	13	23.2%	7	12.5%	37	66.1%
Total		10	17.9%	21	37.5%	17	30.4%	8	14.3%	56	100.0%

**Table 2**  
Measles virus seroprevalence in *Macaca mulatta* in Bangladesh by contextual and individual variables.

Variables	Levels (N)	Seropositivity	95% CI	p-value
Context	Performing environment (10)	50.00%	(0.24–0.76)	0.002 <sup>a</sup>
	Urban area (17)	5.88%	(0.01–0.27)	
	Shrine (21)	4.76%	(0.01–0.23)	
	Wild area (8)	0.00%	(0–0.32)	
Geographical areas	Ashulia (10)	50.00%	(0.24–0.76)	0.009 <sup>a</sup>
	Bormi (6)	0.00%	(0–0.39)	
	Dhamrai (8)	12.50%	(0.02–0.47)	
	DokholaModhupur (8)	0.00%	(0–0.32)	
	Narayanganj (3)	0.00%	(0–0.56)	
	Sayed Shrine (9)	11.11%	(0.02–0.43)	
Sex	Syhlet Shrine (12)	0.00%	(0–0.24)	
	Female (28)	21.43%	(0.10–0.4)	0.043 <sup>b</sup>
Weight median (6.3 kg)	Male (28)	3.57%	(0–0.18)	
	Below median (28)	7.1%	(0.04–0.27)	0.760 <sup>c</sup>
	Above median (28)	5.4%	(0.06–0.31)	
Age	Older Juvenile (10)	0.00%	(0–0.28)	0.513 <sup>a</sup>
	Subadult (9)	11.11%	(0.02–0.43)	
	Adult (37)	16.22%	(0.08–0.31)	

CI = Confidence interval; a = Fisher’s exact test; b = Chi-square test; c = t-student test.

**Table 3**  
Association between context and degree of human-monkey contact and measles seroprevalence in *Macaca mulatta* in Bangladesh.

Variables	OR	95% CI	p-value
Context			
Shrine	Ref.	Ref.	Ref.
Urban	0.74	(0.04–13.33)	0.840
Performing	1.16	(1.05–127.35)	0.046
Wild	0.0000003	(0–Inf)	0.996
Age			
Adult	Ref.	Ref.	Ref.
Subadult	0.48	(0.04–5.99)	0.569
OldJuv	0.000003	(0–Inf)	0.996

OR = Odds ratios estimated with multiple logistic regression; CI = Confidence interval.

shrines, urban areas, and was highest in performing environments. These data suggest that seroprevalence (and exposure) is associated with the degree of human-monkey contact permitted by each context.

*Wild areas* maintain sporadic and casual human-monkey contact due

to ecotourism attractions [15], likely limiting the transmission of the measles virus from humans to monkeys and explaining the observed nil seroprevalence. *Shrines* are visited by many people, who frequently come into direct contact with the monkeys [15]. However, the measles vaccination rates among these visitors are expected to be higher than those in the Bangladeshi population. *Urban* areas contain the highest human population density and measles outbreaks are common since measles has not been eliminated in Bangladesh and measles vaccination coverage is suboptimal in multiple areas [36]. These urban areas offer a greater possibility for monkeys to acquire the virus [15]. *Performing environments* are run by the “Bedey” community. This human community is largely marginalized in Bangladesh and has limited access to healthcare, so measles vaccination coverage is very low among them [37]. In addition, performing monkeys have a different ecology than monkeys from wild, urban, or shrines [38–40]. The performing monkeys are in constant proximity to their owners and family members [39] creating optimal conditions for monkeys to acquire human pathogens [38]. The nomadic performing practices of this group also increase the likelihood that the monkeys will come into contact with other villagers in various parts of the country and the world (tourists), and with other domestic or even wild animals [39]. Our performing monkeys were sampled in Ashulia village, a resting point for performing groups, which explains that high seroprevalence reported for that area [39].

We observed greater measles seropositivity in female monkeys than in males and this difference was statistically significant. Similarly, although higher seropositivity was observed in older individuals, the present study could not determine that there is a statistical association between the seroprevalence of the measles virus and age in monkeys from Bangladesh. We observed effect sizes and trends that suggest an association, but we failed to detect statistical associations likely because of our sample size. It will be necessary to carry out a larger study to clarify these associations.

Although a few authors consider the monkey as a possible reservoir of the measles virus [40], many others state that the human being is the only reservoir known to date [5,9,11,41]. Our definition of reservoir, shared by others, is a species or a community of species that can maintain transmission of a pathogen indefinitely [42]. For measles persistence, the extremely high transmissibility of the measles virus among humans requires populations greater than 250,000 individuals to maintain transmission, otherwise, the susceptible host population would be depleted. If the same transmission parameters operate in the monkey population, which cannot reach 250,000 individuals, the endemic or persisting transmission of the measles virus would not be possible [41]. However, isolated measles outbreaks in monkey populations can occur following interspecies viral transmission from humans to monkeys [43].

To better understand transmission within monkey populations and

between monkeys and humans, greater sampling efforts of monkey populations will be required, where longitudinal observational health is integrated with non-invasive sampling methodologies (e.g., urine samples or saliva found in food waste). In addition, it will be necessary to develop new strategies to improve the measles vaccination coverage in endemic areas to prevent transmission from human to monkey populations [9]. This approach would aim to protect the long-term health of both human and monkey populations in Bangladesh and other regions where interspecies measles transmission occurs. Additionally, this One Health approach also emphasizes the importance of establishing a measles prevention and control plan that considers both humans and monkeys, understanding that measles virus infection is a serious threat to both groups [2,11,12,43].

We faced some challenges during the execution of this study. Due to the limited access to these animals, part of the sample was self-selected; for performing monkeys the owners had to agree to participate. Also, in the case of free-living monkeys, samples were obtained from individuals captured by traps; both sample schemes can introduce selection bias. It is possible that there are temporal trends in measles virus exposure at the population and individual level, but our cross-sectional study with limited variation in age was not set up to detect those patterns. The sample size was too small for stratification and identifying other associated variables, however this does not alter our conclusions. This is an initial study, which will inform future research in measles virus in monkeys.

The use of MIA to detect measles antibodies in monkeys was a strength of our study. This technique has proven to be particularly valuable for conducting extensive surveillance studies [30] due to its fast, sensitivity and reproducible characteristics [34]. Also, studies where MIA was used to detect Human Papillomavirus, and Arboviruses show no evidence of cross-reaction with other pathogens [33,34]. However, due to the little attention received by the measles virus in monkeys, no studies have reported evaluation of cross-reactivity using MIA. Although, based on the findings obtained in analogous studies, we expected no or minimal cross reactivity—if any—using MIA to detect measles antibodies in monkeys.

The ability of the measles virus to infect macaques has been proven by others using molecular techniques. In 1999, during an outbreak at a primate facility, the measles virus was detected in *Macaca mulatta* using reverse transcriptase-polymerase chain reaction (RT-PCR) [45]. In another measles outbreak in a different primate facility, the measles virus was detected in urine specimens using virus isolation or RT-PCR [11], and viral detection correlated with measles virus-specific IgG and IgM antibodies [11]. Also, multiple strains of measles virus have been identified and compared in *Macaca fascicularis* using RNA analysis from Vero cells culture [46]. Our serological findings are supported by these molecular studies and most likely represent direct exposure of *Macaca mulatta* to the measles virus and evidence of measles spillback to monkeys.

## 5. Conclusions

We found a clear association between measles virus seropositivity in monkeys and their degree of contact with humans in Bangladesh, which is linked to the context in which these two species interact. Monkeys from wild areas, where interaction between humans and wildlife is minimal, had the lowest measles seroprevalence. Monkeys from urban areas and shrines had relatively similar and intermediate levels of seroprevalence. Performing monkeys had the highest seroprevalence; it is possible that the health status of the Bedey nomad community, which own and train these animals, may be playing a determining role or may help us, at least partially, understand the dynamic of the virus measles in this context. It is recommended to assess the vaccination coverage in the human populations corresponding to the various contexts of human-monkey contact to determine how vaccination coverage influences interspecies transmission. Also, it is recommended to continue

evaluating the measles virus in *Macaca mulatta* monkeys through larger longitudinal studies that include non-invasive methodologies and direct observation of the human-monkey contact rates. This may inform more evidence-based prevention strategies for outbreaks of measles in monkeys, and the greater plan for conservation plans of free-living monkey populations.

## CRedit authorship contribution statement

**Lizzie Ortiz-Cam:** Conceptualization, Methodology, Formal analysis, Writing – original draft. **Lisa Jones-Engel:** Investigation, Resources, Data curation, Validation, Writing – review & editing. **Patricia Mendoza:** Visualization, Writing – review & editing. **Ricardo Castillo-Neyra:** Visualization, Validation, Supervision, Writing – review & editing.

## Declaration of Competing Interest

None.

## Data availability

Data will be made available on request.

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## References

- [1] Catharine I. Paules, Hilary D. Marston, Anthony S. Fauci, Measles in 2019 — going backward, *N. Engl. J. Med.* (380) (2019) 2185–2187, <https://doi.org/10.1056/NEJMp1905099>.
- [2] Melissa M. Coughlin, Andrew S. Beck, Bankamp Bettina, y Rota Paul A., Perspective on global measles epidemiology and control and the role of novel vaccination strategies, *Viruses* (2017), <https://doi.org/10.3390/v9010011>.
- [3] Canals Mario, Gallegos Doris, Avendaño Fidel, Estimación del número reproductivo efectivo del brote de sarampión 2018-2019 en Chile, *Rev. Chil. Infectol.* 37 (3) (2020) 231–236, <https://doi.org/10.4067/s0716-10182020000300231>.
- [4] World Health Organization, Measles, <https://www.who.int/news-room/fact-sheets/detail/measles?gclid=CjwKCAIApveb8lhAvEiwAe7mfHSCJIRkGrr9KcK5Rr0naXW450v4l82xc8-D6dSICEaCq7pNSd-roCbtQQAvD BwE, 2019>.
- [5] Jones-Engel Lisa, Gregory A. Engel, Michael A. Schillaci, Lee Benjamin, Heidrich Jhon, Chalise Mukesh, et al., Considering human – primate transmission of measles virus through the prism of risk analysis, *Am. J. Primatol.* 68 (2006) 868–879, <https://doi.org/10.1002/ajp.20294>.
- [6] A.S. Mahmud, N. Alam, C.J.E. Metcalf, Drivers of measles mortality: the historic fatality burden of famine in Bangladesh, *Epidemiol. Infect.* 145 (16) (2017) 3361–3369, <https://doi.org/10.1017/S0950268817002564>.
- [7] Schillaci Michael, Jones-Engel Lisa, Engel Gregory, Randall Kyes, Short report: exposure to human respiratory viruses among urban performing monkeys in Indonesia, *Am. J. Trop. Med. Hyg.* 75 (4) (2006) 716–719, <https://doi.org/10.4269/ajtmh.2006.75.716>.
- [8] Flor H. Pujol, Virus en primates no humanos: zoonosis, antroponosis y biodiversidad, *Interciencia* 31 (6) (2006) 396–402, <http://www.redalyc.org/a/rticulo.oa?id=33911702>.
- [9] Sultana Sharmin, Elimination of measles from Bangladesh: progression and challenges ahead, *J. Microbiol. Exp.* 5 (7) (2017) 00174, <https://doi.org/10.15406/jmen.2017.05.00174>.
- [10] Murray B. Gardner, Paul A. Luciw, Macaque models of human infectious disease, *ILAR J.* 49 (2) (2008) 220–255, <https://doi.org/10.1093/ilar.49.2.220>.
- [11] M.E. Willy, R.A. Woodward, V.B. Thornton, A.V. Wolff, B.M. Flynn, J.L. Heath, et al., Management of a measles outbreak among Old World nonhuman primates, *Lab. Anim. Sci.* 49 (1999) 42–48, <https://pubmed.ncbi.nlm.nih.gov/10090093/>.
- [12] C.A. Devaux, O. Mediannikov, H. Medkour, D. Raoult, Infectious disease risk across the growing human-non human primate interface: A review of the evidence, *Front. Public Health* 7 (2019) 305, <https://doi.org/10.3389/fpubh.2019.00305>.
- [13] Kondgen Sophie, Kuhl Hjalmar, Paul K. N'Goran, Peter D. Walsh, Schenk Svenja, Ernst Nancy, et al., Pandemic human viruses cause decline of endangered great apes, *Curr. Biol.* 18 (4) (2008), <https://doi.org/10.1016/j.cub.2008.01.012>.
- [14] Gijón Prieto Irene Victoria, Comisión Española de Ayuda al Refugiado (CEAR), Informe General sobre la situación de Derechos Humanos, Bangladesh, 2012, <https://www.cear.es/wp-content/uploads/2013/08/BANGLADESH.-2012.-Informe-general1.pdf>.

- [15] A. Engel Gregory, T. Small Christopher, Soliven Khanh, M. Feeroz Mostafa, Wang Xiaoxing, Hasan M. Kamrul, et al., Zoonotic simian foamy virus in Bangladesh reflects diverse patterns of transmission and co-infection, *Emerg Microb & Infect.* 2 (1) (2013) 1–10, <https://doi.org/10.1038/em.2013.60>.
- [16] Feeroz Mostafa, Soliven Khanh, T. Small Christopher, A. Engel Gregory, Pacheco M. Andreina, L. Yee JoAnn, et al., Population dynamics of rhesus macaques and associated foamy virus in Bangladesh, *Emerg. Microbes Infect.* 2 (2013), e29, <https://doi.org/10.1038/em.2013.23>.
- [17] Jones-Engel Lisa, A. Engel Gregory, Heidrich John, Chalise Mukesh, Poudel Narayan, Viscidi Raphael, et al., Temple monkeys and health implications of commensalism, Kathmandu, Nepal, *Emerg. Infect. Dis.* (2006), <https://doi.org/10.3201/eid1206.060030>.
- [18] G. Contreras, J. Puresz, Possible influence of measles virus infection of cynomolgus monkeys on the outcome of the neurovirulence test for oral poliovirus vaccine, *Biologicals*. 20 (1) (1992) 27–33, [https://doi.org/10.1016/s1045-1056\(05\)80004-1](https://doi.org/10.1016/s1045-1056(05)80004-1).
- [19] J.A. MacArthur, P.G. Mann, V. Oreffo, G.B. Scott, Measles in monkeys: an epidemiological study, *J. Hyg. Camb.* 83 (1979) 207–213, <https://doi.org/10.1017/S09502688790025985>.
- [20] L. Jones-Engel, G.A. Engel, M.A. Schillaci, R. Babo, J. Froehlich, Detection of antibodies to selected human pathogens among wild and pet macaques (*Macaca tonkeana*) in Sulawesi, Indonesia, *Am. J. Primatol.* 54 (2001) 171–178, <https://doi.org/10.1002/ajp.1021>.
- [21] Mtakul Sharif Ahmed, A.Z.M. Rashid Manzoor, Uddin Mohammad Belal, The role of spiritual beliefs in conserving wildlife species in religious shrines of Bangladesh, *Biodiversity* (2012), <https://doi.org/10.1080/14888386.2012.694596>.
- [22] Supravat Halder, in: Northern University Journal of Law (Ed.), Bedey Community in Bangladesh: A Socio-legal Study, 2014, <https://doi.org/10.3329/nujl.v3i0.18396>.
- [23] Feeroz Mohammed, A. Schillaci Michael, Begum Sajeda, Hasan M. Kamrul, Aziz M. Abdul, Rabihul Alam, et al., Morphometric assessment of Rhesus macaques (*Macaca mulatta*) from Bangladesh, *Primate Conserv. on.* 25 (2010) 119–125, <https://doi.org/10.1896/052.025.0105>.
- [24] Jones-Engel Lisa, A. Steinkraus Katherine, M. Murray Shannon, A. Engel Gregory, Grant Richard, Aggimarangsee Nantiya, et al., Sensitive assays for simian foamy viruses reveal a high prevalence of infection in commensal, free-ranging Asian monkeys, *J. Virol.* (2007), <https://doi.org/10.1128/JVI.00343-07>.
- [25] Marco Ignasi, G. Mentaberre, A. Ponjoan, G. Bota, S. Manosa, S. Lavin, Capture myopathy in little bustards after trapping and marking, *J. Wildl. Dis.* 42 (4) (2006) 889–891, <https://doi.org/10.7589/0090-3558-42.4.889>.
- [26] Gabry P. Smits, G. van Gageldonk Pieter, Leo M. Schouls, Fiona R.M. van der Klis, Guy A. Berbers, M., Development of a bead-based multiplex immunoassay for simultaneous quantitative detection of IgG serum antibodies against measles, mumps, rubella, and varicella-zoster virus, *Clin. Vaccine Immunol.* 19 (3) (2012) 396–400, <https://doi.org/10.1128/CVI.05537-11>.
- [27] E.P. Mazzalina, D.A. Kleymenov, V.A. Mamulov, V.A. Gushchin, A.P. Tkachuk, A protocol of development of a screening assay for evaluating immunological memory to vaccine-preventable infections: simultaneous detection of antibodies to measles, mumps, rubella and hepatitis B, *Bulletin of RSMU* 5 (2017) 41–52, <https://doi.org/10.24075/bosmu.2017.05-04>.
- [28] L.H. Khan, S. Mendoza, J. Yee, M. Deane, K. Venkateswaran, S.S. Zhou, P.A. Barry, N.W. Lerche, P.A. Luciw, Simultaneous detection of antibodies to six nonhuman-primate viruses by multiplex microbead immunoassay, *Clin. Vaccine Immunol.* 13 (1) (2006) 45–52, <https://doi.org/10.1128/CVI.13.1.45-52.2006>. PMID: 16425999; PMCID: PMC1356626.
- [29] R.M. Stenger, M. Smits, B. Kulpers, S.F. Kessen, C.J. Boog, C.A. van Els, Fast, antigen-saving multiplex immunoassay to determine levels and avidity of mouse serum antibodies to pertussis, diphtheria, and tetanus antigens, *Clin. Vaccine Immunol.* 18 (4) (2011) 595–603, <https://doi.org/10.1128/CVI.00061-10> (Epub 2011 Feb 16. PMID: 21325488; PMCID: PMC3122557).
- [30] Irina Tcherniaeva, Gerco den Hartog, Guy Berbers, Fiona van der Klis, The development of a bead-based multiplex immunoassay for the detection of IgG antibodies to CMV and EBV, *J. Immunol. Methods* 462 (2018) 1–8, <https://doi.org/10.1016/j.jim.2018.07.003>.
- [31] Evgeniia N. Bykonia, Denis A. Kleymenov, Elena P. Mazunina, Liubov I. Popova, Victor A. Manuylov, Vladimir A. Gushchin, Artem P. Tkachuk, Alexander L. Gintsburg, Development of a bead-based multiplex immunoassay for simultaneous quantitative detection of IgG serum antibodies against seven vaccine-preventable diseases, *J. Immunol. Methods* (2023), <https://doi.org/10.1016/j.jim.2022.113408> v. 512. Available from.
- [32] Alexandria R. Mitchell, Evaluating a Measles and Rubella Laboratory Network, Thesis, Georgia State University, 2018, <https://doi.org/10.57709/12427306>.
- [33] A.J. Basile, K. Horiuchi, A.J. Panella, J. Lavea, O. Kosoy, et al., Multiplex microsphere immunoassays for the detection of IgM and IgG to Arboviral diseases, *PLoS One* 8 (9) (2013), e75670, <https://doi.org/10.1371/journal.pone.0075670>.
- [34] L. Bei, X. Zhang, D. Meng, et al., Immunogenicity correlation in cynomolgus monkeys between Luminex-based total IgG immunoassay and pseudovirus-based neutralization assay for 14-valent recombinant human papillomavirus vaccine, *J. Med. Virol.* 94 (2022) 3946–3955, <https://doi.org/10.1002/jmv.27763>.
- [35] R Core Team, R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria, 2022. <https://www.R-project.org/>.
- [36] A.R. Sarker, R. Akram, N. Ali, et al., Coverage and factors associated with full immunisation among children aged 12–59 months in Bangladesh: insights from the nationwide cross-sectional demographic and health survey, *BMJ Open* 9 (2019), e028020, <https://doi.org/10.1136/bmjopen-2018-028020>.
- [37] M. Hasan Kamrul, M. Feeroz Mostafa, Jones-Engel Lisa, A. Engel Gregory, Ahktar Sharmin, Kanthaswamy Shree, Smith David Glenn, Performing monkeys of Bangladesh: characterizing their source and genetic variation, *Primates*. 57 (2) (2016) 221–230, <https://doi.org/10.1007/s10329-015-0508-9>.
- [38] L. Craig Karen, Hasan M. Kamrul, L. Jackson Dana, A. Engel Gregory, Soliven Khanh, M. Feeroz Mostafa, et al., A seminomadic population in Bangladesh with extensive exposure to macaques does not exhibit high levels of zoonotic simian foamy virus infection, *J. Virol.* 89 (2015) 7414–7416, <https://doi.org/10.1128/JVI.01065-15>.
- [39] Jones-Engel Lisa, Michael Schillaci, Gregory Engel, Papatung Umar, Jeffery Froehlich, Characterizing primate pet ownership in Sulawesi: implications for disease transmission, *Primate Pets Dis. Trans.* 113 (2005) 137. <https://www.researchgate.net/publication/265237633>.
- [40] Wachtman Lynn, y Mansfield Keith., Viral diseases of nonhuman Primates. *Nonhuman Primates, Biomed. Res.* (2012), <https://doi.org/10.1016/B978-0-12-381366-4.00001-8>.
- [41] Rik L. De Swart, Measles: what we have learned from non-human primate models, *Drug Discov. Today Dis. Model.* (2018), <https://doi.org/10.1016/j.ddmod.2018.01.002>.
- [42] Richard W. Ashford, What it takes to be a reservoir host, *Belg. J. Zoo* 127 (1997) 85–90. [https://biblio.naturwissenschaften.be/associated\\_publications/bjz/127-1-supplement/bjz-127-sup-1997.p85-90.pdf](https://biblio.naturwissenschaften.be/associated_publications/bjz/127-1-supplement/bjz-127-sup-1997.p85-90.pdf).
- [43] William J. Moss, Strebel Peter, Biological feasibility of measles eradication, *J. Infect. Dis.* 204 (2011) S47–S53, <https://doi.org/10.1093/infdis/jir065>.
- [44] Paul G. Auwaerter, Paul A. Bota, William R. Elkins, Robert J. Adams, Tracy DeLozier, Yaqing Shi, William J. Bellini, Brian R. Murphy, Diane E. Griffin, Measles virus infection in Rhesus macaques: altered immune responses and comparison of the virulence of six different virus strains, *J. Infect. Dis.* 180 (4) (1999) 950–958, <https://doi.org/10.1086/314993>.
- [45] R.S. van Binnendijk, R.W. van der Heijden, G. van Amerongen, F.G. Uytendaele, A. D. Osterhaus, Viral replication and development of specific immunity in macaques after infection with different measles virus strains, *J. Infect. Dis.* 170 (2) (1994) 443–448, <https://doi.org/10.1093/infdis/170.2.443> (PMID: 8035034).

## II. DISCUSIONES

Nuestro estudio aporta información valiosa sobre la posible transmisión del sarampión entre humanos y monos y los factores que influyen en la seroprevalencia.

Esta investigación demuestra una asociación entre el contexto de contacto entre humanos y monos y la seroprevalencia del virus del sarampión en los monos. Observamos una gradiente en la seroprevalencia basado en el grado de contacto que ofrece cada contexto: las áreas naturales presentan la seroprevalencia más baja, seguidas de los santuarios, las áreas urbanas y los circos nómades (entornos de los monos “actores”), que muestran la seroprevalencia más alta (1,2). Estos resultados sugieren que la intensidad, a nivel individual, de la interacción entre humanos y monos desempeña un papel crucial en la transmisión del virus del sarampión.

El estudio ofrece explicaciones plausibles para estas variaciones. Las *áreas naturales*, donde el contacto entre humanos y monos es esporádico y casual, podrían estar limitando la transmisión del virus (1). Además, estas áreas suelen ser más grandes y la densidad de población humana es menor, lo cual también podría estar afectando el resultado. Por otro lado, estas áreas, al ser turísticas, tienen como requisito la presentación del carnet de vacunación – incluyendo la vacuna contra el sarampión- de los visitantes. Esto quizás, podría explicar también la baja seropositividad en este lugar. En cambio, las *áreas urbanas*, caracterizadas por una alta densidad de población humana, cuentan con innumerables zonas donde se acumulan desperdicios alimenticios, los cuales sirven como fuente de alimento para los monos, favoreciendo así el contacto indirecto y directo de ambas especies (1).

Cabe señalar que los reportes de brotes de sarampión provienen de éstas áreas, indicando además una cobertura de vacunación contra el sarampión subóptima (3).

Todo ello ofrece a los monos una mayor oportunidad de adquirir el virus.

Los *santuarios* funcionan como templos turísticos, y por esta razón, son visitados por miles de personas de todo el mundo, quienes ofrecen comida a los monos para poder tener un contacto más cercano y obtener una fotografía con ellos. Es posible que los visitantes se encuentren protegidos contra el virus a través de la vacuna, y esto explica la baja seropositividad del virus en nuestros monos. Cabe resaltar que en estas áreas, un mono podría, tal vez, entrar en contacto con una persona, luego regresar al bosque o sólo recibir alimento y regresar con su grupo familiar, lo que disminuiría la intensidad y el tiempo de contacto individual: mono y humano.

Por el contrario, los entornos que tienen a los monos como mascotas y como actores de sus espectáculos (*circos nómades*) son habitados por comunidades olvidadas (Bedey) sin acceso a la atención sanitaria y por lo tanto, muy bajas tasas de vacunación. Esta comunidad tiene a los monos como mascotas y como un miembro más de la familia. Los monos permanecen con sus propietarios a tiempo completo, comparten los alimentos, los lugares que utilizan para dormir, realizan viajes juntos y otras diversas actividades. Por ello, el contacto individual es más intenso que los otros tres contextos estudiados, presentando condiciones óptimas para que los monos adquieran patógenos humanos (3-6).

Respecto a la diferencia de la seropositividad en las zonas geográficas, la alta seropositividad encontrada en *Ashulia*, puede deberse a que este lugar es considerado un punto de descanso para las comunidades Bedey, por lo que se

presenta una interacción entre monos y propietarios de diferentes grupos, y permanecen juntos durante varios días.

En cuanto a la diferencia encontrada en la seropositividad según la variable sexo, se obtuvo una seropositividad más alta y estadísticamente significativa en las hembras. Sin embargo, al realizar el análisis de colinealidad, la variable sexo resultó estar correlacionada con la zona geográfica. Las hembras muestreadas estuvieron ubicadas en su mayoría en la zona geográfica Ashulia, lo cual podría indicarnos que la seropositividad en hembras se dio porque se encontraban en una zona de alta transmisión y no porque esta variable sea un factor determinante. Además, no se encontró en la literatura que la variable sexo estuviera relacionada a una mayor seropositividad del virus. Por todo lo mencionado, se decidió eliminar a la variable sexo del modelo final.

No se halló variación según las variables edad, ni peso. Sin embargo, se requerirá de más estudios y de un mayor número de muestra.

La mayoría de los estudios afirman que es ser humano es el único reservorio conocido del virus del sarampión, pero aún se reportan brotes aislados en poblaciones de monos, lo cual sugiere que hay “*Spillback*” (transmisión de patógenos humanos a animales) (7).

El tamaño de la muestra de nuestro estudio, aunque pequeño, proporciona valiosos datos preliminares, pero puede requerir una ampliación en futuras investigaciones, que incluyan observaciones longitudinales, utilizando metodologías de muestreo no invasivas (e.j. muestras de orina). Asimismo, se podría evaluar el potencial de los monos como animal centinela, para monitorear y detectar transmisión del virus de sarampión en zonas de contacto humano-mono.

Cabe señalar que, no hay artículos nuevos relevantes desde la búsqueda que se realizó para la discusión publicada. Por lo que, los hallazgos de esta investigación se hacen más relevantes. Resaltamos la importancia y urgencia de desarrollo de estrategias de prevención eficaces, con intervenciones integradas (8), en contextos específicos y con la necesidad de centrarse en áreas con una elevada interacción entre humanos y monos (9,10) utilizando el enfoque de “Una Salud” (11).

### III. REFERENCIAS BIBLIOGRÁFICAS

1. A. Engel Gregory, T. Small Christopher, Soliven Khanh, M. Feeroz Mostafa, Wang Xiaoxing, Hasan M. Kamrul, *et al.* Zoonotic simian foamy virus in Bangladesh reflects diverse patterns of transmission and co-infection. *Emerg Microb & Infect.*, 2 (1) (2013), pp. 1-10, 10.1038/emi.2013.60
2. A.R. Sarker, R. Akram, N. Ali, *et al.* Coverage and factors associated with full immunisation among children aged 12–59 months in Bangladesh: insights from the nationwide crosssectional demographic and health survey. *BMJ Open*, 9 (2019), Article e028020, 10.1136/bmjopen-2018-028020
3. M. Hasan Kamrul, M. Feeroz Mostafa, Jones-Engel Lisa, A. Engel Gregory, Ahktar Sharmin, Kanthaswamy Shree, Smith David Glenn. Performing monkeys of Bangladesh: characterizing their source and genetic variation. *Primates.*, 57 (2) (2016), pp. 221-230, 10.1007/s10329-015-0508-9
4. L. Craig Karen, Hasan M. Kamrul, L. Jackson Dana, A. Engel Gregory, Soliven Khanh, M. Feeroz Mostafa, *et al.* A seminomadic population in Bangladesh with extensive exposure to macaques does not exhibit high levels of zoonotic simian foamy virus infection. *J. Virol.*, 89 (2015), pp. 7414-7416, 10.1128/JVI.01065-15
5. Jones-Engel Lisa, Michael Schillaci, Gregory Engel, Paputungan Umar, Jeffery Froehlich. Characterizing primate pet

- ownership in Sulawesi: implications for disease transmission. *Primate Pets Dis. Trans.*, 113 (2005), p. 137  
<https://www.researchgate.net/publication/265237633>
6. Wachtman Lynn, y Mansfield Keith. Viral diseases of nonhuman Primates. *Nonhuman Primates. Biomed. Res.* (2012), 10.1016/B978-0-12-381366-4.00001-8
  7. Sparrer McKenzie N, Hodges NF, Sherman T, VandeWoude S, Bosco-Lauth AM, Mayo CE. Role of Spillover and Spillback in SARS-CoV-2 Transmission and the Importance of One Health in Understanding the Dynamics of the COVID-19 Pandemic. *J Clin Microbiol.* 2023 Jul 20;61(7):e0161022. doi: 10.1128/jcm.01610-22. Epub 2023 Apr 26. PMID: 37098970; PMCID: PMC10358177.
  8. Sultana Sharmin. Elimination of measles from Bangladesh: progression and challenges ahead. *J. Microbiol. Exp.*, 5 (7) (2017), p. 00174, 10.15406/jmen.2017.05.00174
  9. William J. Moss, Strebel Peter. Biological feasibility of measles eradication. *J. Infect. Dis.*, 204 (2011), pp. S47-S53, 10.1093/infdis/jir065
  10. Centeno, R.J. Concurrent measles infection of cynomolgus monkey during a Reston Ebola virus outbreak in the Philippines, *International Journal of Infectious Diseases.* 2019. V79, 1. <https://doi.org/10.1016/j.ijid.2018.11.170>.

11. World Health Organization (WHO). “One Health”. 2017.  
<https://www.who.int/news-room/questions-and-answers/item/one-health>