Evidence of neutralizing antibodies against SARS-CoV-2 in domestic cats living with owners with a history of COVID-19 in Lima – Peru

Luis M. Jara a,*, Cusi Ferradas b, Francesca Schiaffino a, Camila Sánchez-Carrión c, Ana Martínez-Vela d, Alexandra Ulloa c, Gisela Isasi-Rivas e, Angela Montalván e, Luis Guevara Sarmiento e, Manolo Fernández e, Mirko Zimic e, f

a Facultad de Medicina Veterinaria y Zootecnia, Universidad Peruana Cayetano Heredia, Lima, Peru
b Unidad de Investigación en Enfermedades Emergentes y Cambio Climático (Emerge), Facultad de Salud Pública y Administración, Universidad Peruana Cayetano Heredia, Lima, Peru
c Clínica Veterinaria Gatuario, Lima, Peru
d Clínica Veterinaria Los Dominicos, Lima, Peru
e Farmacológicos Veterinarios (FARVET), Chinchay, Peru
f Laboratorio de Bioinformática, Biología Molecular y Desarrollos Tecnológicos, Universidad Peruana Cayetano Heredia, Lima, Peru

ARTICLE INFO

Keywords:
COVID-19
SARS-CoV-2
Cats
Serology
Neutralizing antibodies
One health

ABSTRACT

SARS-CoV-2 can infect a variety of wild and domestic animals worldwide. Of these, domestic cats are highly susceptible species and potential viral reservoirs. As such, it is important to investigate disease exposure in domestic cats in areas with active community transmission and high disease prevalence. In this report we demonstrate the presence of serum neutralizing antibodies against the receptor binding-domain (RBD) of the SARS-CoV-2 in cats whose owners had been infected with SARS-CoV-2 in Lima, Peru, using a commercial competitive ELISA SARS-CoV-2 Surrogate Virus Neutralization Test. Out of 41 samples, 17.1% (7/41) and 31.7% (13/41) were positive, using the cut-off inhibition value of 30% and 20%, respectively. Not all cats living in a single house had detectable neutralizing antibodies showing heterogenous exposure and immunity among cohabiting animals. This is the first report of SARS-COV-2 exposure of domestic cats in Lima, Peru. Further studies are required to ascertain the prevalence of SARS-COV-2 exposure among domestic cats.

1. Introduction

The new human coronavirus, SARS-CoV-2, has been shown to mainly infect humans. However, SARS-CoV-2 infection has also been detected in a variety of animals, including wild cats, minks, ferrets, domestic dogs and cats [1–6]. Cats and minks may be considered the most susceptible species because of the higher similarity of the angiotensin-converting enzyme 2 (ACE2) between these species and humans [7]. Although the majority of infected cats are asymptomatic, some animals may develop clinical disease, and the virus can be experimentally transmitted between individuals [8]. Therefore, SARS-CoV-2 could have a direct impact on animal health, while the possibility of cats becoming zoonotic reservoirs has not been totally discarded.

Serological testing is a valuable tool for screening antibody levels associated with pathogen exposure. As with other viral infections, host neutralizing serum antibodies may block the binding of viral proteins to cell surface receptors. In humans, SARS-CoV-2 neutralizing antibodies have been determined to inversely correlate with disease severity and can predict the probability of re-infections [9]. In animals, reported prevalence of neutralizing serum antibodies against SARS-CoV-2 in cats varies, with as low as 0.002% in Germany, 0.2% in Brazil, 5.8% in Italy, and 10.8% in Wuhan, China [10–13]. In Peru, one of the most affected countries by the COVID-19 pandemic, no previous studies have been conducted investigating the seroprevalence or prevalence of SARS-CoV-2 among domestic cats. In this report we demonstrate the presence of serum neutralizing antibodies against the receptor binding-domain (RBD) of the SARS-CoV-2 viral spike protein in cats whose owners confirmed previous infection with SARS-CoV-2.

* Corresponding author at: Facultad de Medicina Veterinaria y Zootecnia, Universidad Peruana Cayetano Heredia, Av. Honorio Delgado 430, San Martín de Porres, Lima, Peru.
E-mail address: luis.jara.s@upch.pe (L.M. Jara).

https://doi.org/10.1016/j.onehlt.2021.100318
Received 26 May 2021; Received in revised form 23 August 2021; Accepted 25 August 2021
Available online 26 August 2021
2352-7714/© 2021 Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
2. Materials and methods

Blood samples of cats seeking routine veterinary care were collected between August 2020 and April 2021 from three veterinary clinics in Lima, Peru. All cat owners signed an informed consent authorizing the use of the samples for research purposes. Samples were centrifuged at 3500 rpm for 5 min and the serum supernatant was stored at -20 °C. Samples from cats whose owners confirmed previous COVID-19 disease (clinical signs with positive IgG/IgM rapid test or qRT-PCR) during veterinary anamnesis were conveniently selected. To test the serum samples for the presence of neutralizing antibodies against the RBD of the viral spike protein, a commercial competitive ELISA cPass™ SARS-CoV-2 Neutralization Antibody Detection Kit also known as SARS-CoV-2 Surrogate Virus Neutralization Test (sVNT) Kit was used according to the manufacturer’s instructions (Genscript, New Jersey, USA). Percent serum neutralization was calculated as follows: – (1 - OD value of sample / OD value of negative control) × 100%. A cut-off value of 20% and an updated 30% of inhibition were used to establish positivity. This study was approved by the Universidad Peruana Cayetano Heredia Animal Care and Use Ethical Committee (N° 027-08-20).

3. Results and discussion

A total of 41 samples from a serum bank of 700 were selected for screening of serum neutralizing antibodies. The median age of the animals was 12 months (IQR: 8 months – 46 months), 53.7% were female (22/41), and 87.8% (36/41) were classified as domestic shorthair. 53.7% (22/41) came from the district of Comas while the remainder 46.3% came from Miraflores (5/41), Surco (5/41), San Juan de Miraflores (3/41), Independencia (2/41), San Juan de Lurigancho (1/41), San Luis (1/41), and San Martín de Porres (1/41). Out of the 41 cat samples, 22 cats (53.7%) lived in a single household (household C), and 2 cats lived in household D. Age, sex, breed, neuter status and district of all animals are shown in Table 1. Animals living in households C and D attended the veterinary clinic for neutering. The rest of the animals attended the veterinary clinics seeking care for based on unspecific clinical signs. Out of the 41 samples, 17.1% (7/41) and 31.7% (13/41) were positive for the presence of serum neutralizing antibodies, using the cut-off value of 30% and 20%, respectively (Fig. 1).

Out of 13 positive samples, 38.4% (5/13) showed clinical signs including sneezing and dyspnea, cough, vomit, or depression. Interestingly, one of the animals with the highest percent neutralization (73.06%) showed all the symptoms described. A subclinical infection, with a prolonged period of oral and nasal viral shedding that is generally not accompanied by symptomatology has been reported in cats [14]. Only 8 out 22 cats in household C had evidence of serum neutralizing antibodies. This suggests that infection may not be homogenous among cohabiting animals, and this could be associated with other factors such as health state, immunity, proximity to the infected owner(s), among others.

Our results show compelling evidence of SARS-CoV-2 exposure in domestic cats and it is the first report of such an event in Peru. Percent seropositivity in this population of cats is high compared to other studies published, such as that of Italy and Wuhan, China, in which 5.8% of 191 cats 10.8% of 102 cats had neutralizing antibodies, respectively [12,13]. However, these studies were not exclusively done on a pet population living with COVID-19 infected owners. In a longitudinal cohort study of pets living with COVID-19 owners conducted in Texas, USA, 43.8% of 16 cats developed neutralizing antibodies against SARS-CoV-2 [15], percentage that is closer to the results obtained in this study.

Limited sample size and a convenience sample do not permit prevalence estimation and seroconversion dynamics. Another limitation is the prolonged time between the onset of COVID-19 in owners and sampling of animals, which could have affected the sensitivity of the test. The immunity duration in pets is currently unknown. Experimentally infected cats develop neutralizing activity by seven days post-viral infection, but seroconversion is evident by 14 days with a plateaued stage at day 42 [16].

Serum neutralization activity is commonly tested using plaque reduction neutralization tests (PRNT) as gold standard. However, the commercial assay utilized in this preliminary study has shown a high correlation with serum neutralization activity using PRNT and has shown robust internal validity parameters for both humans, cats, dogs and hamster sera [17,18]. Additionally, this test has already been used in a large-scale serological survey in cats in Thailand using 20% of inhibition as the cut-off value [19]. Our study reports results based on both a 20% and a 30% inhibition cut-off value, based on the manufacturer’s recommendation. Moreover, moderate to high sensitivity and specificity of the sVNT has been reported using this cut-off value correction (30%) in samples from multiple animal species (ferrets, cats, minks, hamster).

Specifically, the specificity was 99% and 100% using 20% and 30% cut-off values, respectively [20]. The sensitivity of the sVNT using a cut-off value of 20% was 98.9% and 97% when compared to PRNTs0 and PRNTs0, respectively, yet sensitivity decreased to 93.9% when using a 30% of cut-off value (compared to PRNTs0) [17]. Additionally, this commercial assay offers logistical and biosafety advantages for researchers working in resource-limited settings that do not have access to a BSL-3 containment required for SARS-CoV-2 manipulation.

The animals evaluated in our study sought routine veterinary care that was not associated with symptomatic respiratory disease in most of the cases, demonstrating potential asymptomatic infection in cats, and consequently, potential viral reservoirs. In some studies, over 21% and 25% of infected households sampled had pets with neutralizing antibodies [15,21]. Few case studies of natural infection in cats document severe clinical outcomes, and those that have revealed that co-morbidities likely played a contributing factor in illness or death [15]. Seroprevalence studies should be conducted in affected regions to monitor SARS-CoV-2 asymptomatic infections in pets such as cats, ferrets, or dogs, especially in companion animals living with COVID-19 patients [22].

4. Conclusions

It is crucial to monitor SARS-CoV-2 exposure and infection in domestic animals using rapid and affordable point-of-care serological and molecular assays that can be used by veterinarians serving low-income communities. Cats have the potential to serve as sentinels for unidentified community transmission, and in this scenario, veterinarians play a key role as first-line responders.

Ethics statement

The authors confirm that the ethical policies of the journal, as noted on the journal’s author guidelines page, have been adhered to and the appropriate ethical review committee approval has been received.

Conflict of interests

None noted.

CRediT authorship contribution statement

Luis M. Jara: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. Cusi Ferradas: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. Methodology. Francesca Schiaffino: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. Methodology. Camila Sánchez-Carrion: Investigation, Writing – review & editing. Martínez-Vela: Investigation, Writing – review & editing. Alexandra Ulloa: Investigation, Writing – review & editing. Gisela Isasi-Rivas: Investigation, Writing – review & editing.
## Table 1
Data of cats with serum neutralizing antibodies against SARS-COV-2 in Lima (2020–2021).

| Household | Sample Date (MM/DD/YY) | Age (months) | Sex | Breed | Neuter status | District          | Time since onset of clinical symptoms of COVID-19 in owners (weeks) | Percent Inhibition (%) |
|-----------|-------------------------|--------------|-----|-------|---------------|-------------------|---------------------------------------------------------------|------------------------|
| A         | 1/20/2021               | 7            | Male| Domestic Shorthair | Intact | San Juan de Miraflores | Not available                                                   | 73.06                  |
| A         | 1/21/2021               | 28           | Female| Domestic Shorthair | Intact | San Juan de Miraflores | Not available                                                   | 66.69                  |
| B         | 4/01/2021               | 8            | Female| Domestic Shorthair | Spayed | San Juan de Miraflores | Not available                                                   | 3.2                    |
| C         | 10/9/2020               | 8            | Female| Domestic Shorthair | Intact | Comas             | 12                                                            | 29.15                  |
| C         | 10/9/2020               | 12           | Female| Domestic Shorthair | Intact | Comas             | 12                                                            | 25.59                  |
| C         | 10/9/2020               | 11           | Female| Domestic Shorthair | Intact | Comas             | 12                                                            | 23.81                  |
| C         | 10/9/2020               | 36           | Male| Domestic Shorthair | Intact | Comas             | 12                                                            | 22.88                  |
| C         | 10/9/2020               | 10           | Female| Domestic Shorthair | Intact | Comas             | 12                                                            | 20.24                  |
| C         | 10/9/2020               | 5            | Male| Domestic Shorthair | Intact | Comas             | 12                                                            | 10.69                  |
| C         | 10/9/2020               | 5            | Male| Domestic Shorthair | Intact | Comas             | 12                                                            | 4.92                   |
| C         | 10/9/2020               | 24           | Male| Domestic Shorthair | Intact | Comas             | 12                                                            | 9.27                   |
| C         | 10/9/2020               | 12           | Female| Domestic Shorthair | Intact | Comas             | 12                                                            | –3.14                  |
| C         | 10/9/2020               | 12           | Female| Domestic Shorthair | Intact | Comas             | 12                                                            | –0.64                  |
| C         | 10/9/2020               | 24           | Female| Domestic Shorthair | Intact | Comas             | 12                                                            | 14.47                  |
| C         | 10/9/2020               | 10           | Female| Domestic Shorthair | Intact | Comas             | 12                                                            | 16.18                  |
| C         | 10/9/2020               | 60           | Female| Domestic Shorthair | Intact | Comas             | 12                                                            | 3.99                   |
| C         | 10/9/2020               | 5            | Female| Domestic Shorthair | Intact | Comas             | 12                                                            | 1.8                    |
| C         | 10/24/2020              | 9            | Male| Domestic Shorthair | Intact | Comas             | 12                                                            | 61.22                  |
| C         | 10/24/2020              | 6            | Male| Domestic Shorthair | Intact | Comas             | 12                                                            | 49.87                  |
| C         | 10/24/2020              | 11           | Male| Domestic Shorthair | Intact | Comas             | 12                                                            | 38.03                  |
| C         | 10/24/2020              | 8            | Female| Domestic Shorthair | Intact | Comas             | 12                                                            | –8.38                  |
| C         | 10/24/2020              | 8            | Female| Domestic Shorthair | Intact | Comas             | 12                                                            | –8.75                  |
| C         | 10/24/2020              | 24           | Female| Domestic Shorthair | Intact | Comas             | 12                                                            | 12.58                  |
| C         | 10/24/2020              | 7            | Female| Domestic Shorthair | Intact | Comas             | 12                                                            | 8.18                   |
| C         | 10/24/2020              | 6            | Female| Domestic Shorthair | Intact | Comas             | 12                                                            | –5.59                  |
| D         | 1/27/2021               | 24           | Female| Domestic Shorthair | Intact | Independencia     | 3                                                             | 38.73                  |
| D         | 1/27/2021               | 60           | Male| Domestic Shorthair | Intact | Independencia     | 3                                                             | 30.96                  |
| F         | 8/17/2020               | 84           | Male| Russian Blue | Neutered | Miraflores | 8                                                             | 21.88                  |
| F         | 8/31/2020               | 72           | Female| Russian Blue | Spayed | Miraflores | 10                                                            | 9.41                   |
| F         | 8/31/2020               | 12           | Male| Bengal | Neutered | Miraflores | 10                                                            | 11.26                  |
| F         | 8/31/2020               | 12           | Male| Bengal | Neutered | Miraflores | 10                                                            | 15.04                  |
| G         | 2/14/2021               | 46           | Female| Maine Coon | Spayed | Miraflores | 10                                                            | 10.48                  |
| H         | 12/29/2020              | 96           | Female| Domestic Shorthair | Intact | Surco         | 24                                                            | 5.06                   |
| I         | 1/13/2021               | 6            | Male| Domestic Shorthair | Neutered | Surco         | Not available                                                 | –7.98                  |
| J         | 4/03/2021               | 58           | Male| Domestic Shorthair | Neutered | Surco         | 8                                                             | 1.31                   |
| K         | 1/02/2021               | 64           | Male| Domestic Shorthair | Neutered | Surco         | Not available                                                 | –4.48                  |
| L         | 2/06/2021               | 42           | Female| Domestic Shorthair | Intact | Surquillo     | 8                                                             | –6.33                  |
| M         | 2/06/2021               | 77           | Male| Domestic Shorthair | Neutered | San Luis      | 28                                                            | 1.39                   |
| N         | 1/03/2021               | 124          | Male| Domestic Shorthair | Neutered | San Juan de Lurigancho | Not available   | 12.19                  |

(continued on next page)
controls, (−): negative, (+): positive. The 17.1% (7/41) and 31.7% (13/41) shows the frequency of cats with neutralizing antibodies with 30% and 20% of cut-off values of inhibition, respectively.

Different capital letters represent different households. Percent inhibition (%) in bold denotes positivity (>20%).

Fig. 1. Percent inhibition against SARS-COV-2 receptor binding-domain (RBD) in serum of domestic cats whose owners had a history of COVID-19 (n = 41). C controls, (−): negative, (+): positive. The 17.1% (7/41) and 31.7% (13/41) shows the frequency of cats with neutralizing antibodies with 30% and 20% of cut-off values of inhibition, respectively.

Investigation, Writing – review & editing, Methodology. Angela Montalvan: Investigation, Writing – review & editing, Methodology. Luis Guevara Sarmiento: Conceptualization, Formal analysis, Writing – review & editing, Methodology. Manolo Fernández: Conceptualization, Data curation, Formal analysis, Writing – review & editing, Methodology. Mirko Zimic: Conceptualization, Formal analysis, Funding acquisition, Writing – review & editing, Methodology.

Acknowledgements

Partial funding was received by D43TW007393 from the Emerging Diseases and Climate Change Research Unit (Emerge), Universidad Peruana Cayetano Heredia, Lima, Peru. We would like to acknowledge Macarena Llalla, DVM, and Camila Talavera, DVM, for helping with the collection of cat serum samples, as well as all other Veterinary supportive staff.

References

[1] L.D. Bertbach, D. Vladimirova, K. Dietert, A. Abdelgawad, A.D. Gruber, N. Ostierredder, J. Trimpert, SARS-COV-2 infection of Chinese hamsters (Cricetulus griseus) reproduces COVID-19 pneumonia in a well-established small animal model, Transbound. Emerg. Dis. 68 (2021) 1075–1079. https://doi.org/10.1111/tbed.13877.
[2] M.A.A. Mahdy, W. Younis, Z. Ewaida, An overview of SARS-COV-2 and animal infections, Front. Vet. Sci. 7 (2020) 596391, https://doi.org/10.3389/fvets.2020.596391.
[3] B.B. Oude Munnink, R.S. Sikkema, D.F. Nieuwenhuijze, R.J. Molenaar, E. Pauvolid-Corréa, Evidence of exposure to SARS-COV-2 in domestic cats and companion animals to SARS-covirus 2, Science 368 (2020) 1016–1020. https://doi.org/10.1126/science.abb7015.
[4] T.H.C. Sit, C.J. Brackman, M.S. Ip, K.W.S. Tam, P.Y.T. Law, F.M.W. To, Y.V.Y. Yu, L.D. Sims, D.N.C. Tsang, D.K.W. Chu, R.A.P.M. Perera, L.L.M. Poon, M. Peiris, Infection of dogs with SARS-COV-2, Nature 586 (2020) 776–778. https://doi.org/10.1038/s41586-020-2354-5.
[5] L. Wang, P.K. Mitchell, P.P. Calle, S.L. Bartlett, D.M. McAlloose, M.L. Kiliann, F. Yuan, Y. Fang, L.B. Goodman, F. Reddixton, E. Elvinger, K. Terio, S. Franzen, T. Stuber, D.G. Diek, M.R. Torchetti, Complete genome sequence of SARS-COV-2 in a tiger from an U.S. zooological collection, Microbiol. Resour. Announ. 9 (2020), https://doi.org/10.1016/j.mranna.2020.100668.
[6] C.C. Sreenivasan, M. Thomas, D. Wang, F. Li, Susceptibility of livestock and companion animals to COVID-19, J. Med. Virol. 93 (2021) 1351–1360. https://doi.org/10.1002/jmv.26621.
[7] P.J. Halfmann, M. Hatta, S. Chiba, T. Maemura, S. Fan, M. Takeda, N. Kinoshiba, S.-I. Hattori, Y. Sakai-Tagawa, K. Iwatsuki-Horimoto, M. Imai, Y. Kawaoka, Transmission of SARS-COV-2 in domestic cats, N. Engl. J. Med. 383 (2020) 592–594. https://doi.org/10.1056/NEJMc2103400.
[8] X. Chen, Z. Pan, S. Yue, F. Yu, J. Zhang, Y. Yang, R. Li, B. Liu, X. Yang, L. Gao, Z. Li, Y. Lin, Q. Huang, L. Xu, J. Tang, L. Hu, J. Zhao, P. Liu, G. Zhang, Y. Chen, K. Deng, L. Ye, Disease severity dictates SARS-COV-2-specific neutralizing antibody responses in COVID-19, Signal Transduct. Target Ther. 5 (2020) 186. https://doi.org/10.1038/s41392-020-00301-z.
[9] H.G. Dias, M.E.B. Resch, G.C.aldas, A.F. Resch, N.V. da Silva, A.M.V. dos Santos, T.C. das Sousa, M.H. Ogrzewalska, M.M. Siqueira, A. Pauvolid-Corréa, F.B. dos Santos, Neutralizing antibodies for SARS-COV-2 in stray animals from Rio de Janeiro, Brazil, PlosOne 16 (2021) e0248578. https://doi.org/10.1371/journal.pone.0248578.
[10] A. Michelitch, D. Hoffmann, K. Wernike, M. Beer, Occurrence of antibodies against SARS-COV-2 in the domestic cat population of Germany, Vaccines 8 (2020) E772. https://doi.org/10.3390/vaccines8040772.
[11] E.I. Patterson, G. Elia, A. Grassi, A. Giordano, C. Desario, M. Medardo, S.L. Smith, E.R. Anderson, T. Prince, G.T. Patterson, E. Loruno, M.S. Lucente, G. Lanave, S. Lanzu, U. Bonfanti, A. Stranieri, V. Martella, F. Solari Basano, V.R. Barrs, A. D. Radford, U. Agrimi, G.L. Hughes, S. Paltrinieri, N. Decaro, Evidence of exposure to SARS-COV-2 in cats and dogs from households in Italy. Nat. Commun. 11 (2020) 6231, https://doi.org/10.1038/s41467-020-02097-6.
[12] Q. Zhang, H. Zhang, J. Guo, K. Huang, Y. Yang, X. Hui, X. He, C. Li, W. Gong, Y. Zhang, Y. Zhao, C. Peng, X. Gao, H. Chen, Z. Zou, Z.-L. Shi, K. Jin, A serological survey of SARS-COV-2 in cat in Wuhan, Emerg. Microbes Infect. 9 (2020) 2013–2019. https://doi.org/10.1002/emm2.121779.
[13] K. Sharan, K. Dhamo, A.M. Powde, C. Gortazar, R. Tiwar, D.K. Bonilla-Aldana, A.J. Rodriguez-Morales, J. de la Fuente, I. Michalach, Y.A. Attia, SARS-COV-2 in animals: potential for unknown reservoir hosts and public health implications, Vet. Q. 41 (4) 181–201. doi:https://doi.org/10.1080/01652176.2021.1921311.
[14] S.A. Hamer, A. Pauvolid-Corréa, L.B. Ek, Z. Zou, E. Davila, L.D. Auckland, C.M. Roundsy, W. Tang, M.K. Torchetti, M.L. Kiliann, M. Jenkins-Moore, K. Mozingo, Y. Alpakul, R. R. Gha, J.R. Spangler, C. Barthrebeharn, R.S.B. Fischer, G.L. Hamer, SARS-COV-2 infections and virus isolations among serially tested cats and dogs in households with infected owners in Texas, USA, Viruses 13 (2021) 938, https://doi.org/10.3390/v13050938.
[15] A.M. Bosco-Lauth, A.E. Hartwig, S.M. Porter, P.W. Gordy, M. Nehring, A.D. Byas, S. VandreHoude, K.J. Ragan, R.M. Maison, R.A. Bowen, B. Rockx, M.P.G. Koopmans, Transmission of SARS-COV-2 in mink farms between humans and mink and back to humans, Science 371 (2021) 172–177. https://doi.org/10.1126/science.abc5901.
[16] J. Shi, Z. Wen, G. Zhang, H. Yang, C. Wang, B. Huang, R. Liu, X. He, L. Shuai, Z. Sun, Y. Zhao, P. Liu, L. Liang, P. Gui, J. Wang, X. Zhang, Y. Guan, W. Tan, G. Wu, H. Chen, Z. Bu, Susceptibility of ferrets, cats, dog, and other domesticated animals to SARS-covirus 2, Science 368 (2020) 1073–1078. https://doi.org/10.1126/science.abc5870.
Evaluation of a multi-species SARS-CoV-2 surrogate virus neutralization test, One Health 100313 (2021), https://doi.org/10.1016/j.onehlt.2021.100313.

[21] M. Fritz, B. Rosolen, E. Krafft, P. Becquart, E. Elguero, O. Vratskikh, S. Denolly, B. Boson, J. Vanhomwegen, M.A. Gouilh, A. Kodjo, C. Chirouze, S.G. Rosolen, V. Legros, E.M. Leroy, High prevalence of SARS-CoV-2 antibodies in pets from COVID-19+ households, One Health 11 (2021) 100192, https://doi.org/10.1016/j.onehlt.2020.100192.

[22] Md.G. Hossain, A. Javed, S. Akter, S. Saha, SARS-CoV-2 host diversity: An update of natural infections and experimental evidence, J. Microbiol. Immunol. Infect. 54 (2021) 175–181, https://doi.org/10.1016/j.jmii.2020.06.006.