A Critical Needs Assessment for Research in Companion Animals and Livestock Following the Pandemic of COVID-19 in Humans

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Abstract

Problem: The emergence of novel coronavirus (SARS-CoV-2) in Wuhan, China, in November 2019 and a growing body of information compel inquiry regarding the transmissibility of infection between humans and certain animal species. Although there are a number of issues to be considered, the following points are most urgent:

- The potential for domesticated (companion) animals to serve as a reservoir of infection contributing to continued human-to-human disease, infectivity, and community spread.
- The ramifications to food security, economy, and trade issues should coronavirus establish itself within livestock and poultry.
- The disruption to national security if SARS-CoV-2 and its fairly well-established effects on smell (hyposmia/anosmia) to critical military service animals including explosive detector dog, narcotics detector dog, specialized search dog, combat tracker dog, mine detection dog, tactical explosive detector dog, improvised explosive device detector dog, patrol explosive detector dog, and patrol narcotics detector dog, as well as multipurpose canines used by special operations such as used by the U.S. customs and border protection agency (*e.g.*, Beagle Brigade).

This article presents in chronological order data that both individually (as received independently from multiple countries) and collectively urge studies that elucidate the following questions.

1. What animal species can be infected with SARS-CoV-2, the likely sources of infection, the period of infectivity, and transmissibility between these animals and to other animal species and humans?
2. What are the best diagnostic tests currently available for companion animals and livestock?
3. What expressions of illness in companion and other animal species can serve as disease markers?

Although it is recognized that robust funding and methodology need to be identified to apply the best scientific investigation into these issues, there may be easily identifiable opportunities to capture information that can guide decision and study.

First, it may be possible to quickly initiate a data collection strategy using in-place animal gatekeepers, such as zookeepers, veterinarians, kennel owners, feed lots, and military animal handlers. If provided a simple surveillance form, their detection of symptoms (lethargy, hyposmia, anosmia, and others) might be quickly reported to a central data collection site if one were created.

Second, although current human COVID-19 disease is aligning around areas of population density and cluster events, it might be possible to overlay animal species density or veterinary reports that could signal some disease association in animals with COVID-19 patients. Unfortunately, although companion animals and zoo species have repeatedly served as sentinels for emerging infectious diseases, they do not currently fall under the jurisdiction of any federal agency and are not under surveillance.

Keywords: COVID-19, coronavirus, companion animals, livestock

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Background: Companion Animals

THE ISSUE OF the need to evaluate companion animals and their status with regards to SARS-CoV-2 was first raised on January 29 when a member of the senior expert team from China's National Health Commission stated on Chinese state television that pet owners should take extra care of their animals because (1) the virus "moves between mammals"; (2) if your animals "come into contact with the outbreak or people infected with the virus, then your pets should be put in quarantine"; and (3) "because the epidemic spreads between mammals, therefore we should take precaution against other mammals" (Safoora 2020). No scientific data were presented to support this statement but, nonetheless, it prompted a severe public response that resulted in many pet dogs and cats being killed and thousands being abandoned (Wan et al. 2020, Daniels 2020, Thomson 2020b).

This prompted the World Health Organization to state that "there is no evidence dogs and cats can be infected with the virus" (Thomson 2020a, Williams 2020). No scientific data were provided to support this statement about a novel zoonotic threat either. Despite this appeal, the culling of pets continued in China through February 21 (Albawaba 2020). On February 26, Hong Kong's Agriculture, Fisheries, and Conservation Department announced that a pet dog of a COVID-19 patient had tested "weak positive" through RT-PCR. The fact that the dog was asymptomatic along with the inability to recover live virus led to this finding being attributed to environmental contamination from the owner (Simin et al. 2020). However, on March 9, ProMED-mail posted the remarks of the associate director for the Joint Institute for Virology at Hong Kong University who stated "the dog's lack of symptoms showed the virus could live inside it, allowing the animal to secrete and spread the virus at the same time" (Simin et al. 2020).

On March 2, the French Agency for Food, Environmental and Occupational Health & Safety received a formal request from the Directorate General for Food to assess risks—specifically to give an opinion regarding the potential role of domestic animals (livestock animals and pets) in the spread of SARS-CoV-2. With the exception of work on infections undertaken in transgenic mice (Bao et al. 2020) expressing the human form of ACE2 receptor for the SARS-CoV-2, very few studies have described animals experimentally infected with SARS-CoV-2. They concluded that "additional studies on the interactions between SARS-CoV-2 and ACE2 homologues from various animal species, as well as studies on the distribution of ACE2 in tissue, are necessary to further knowledge on the possible transmission of infection to other species. However, cross-species transmission does not rely solely on the presence of the receptor but also on the presence of other cellular factors required for viral replication. Further studies should also be undertaken to identify these factors" (ANSES 2020).

At the same time, the Ministry of Health in Singapore released a statement discussing the theoretical possibility that COVID-19 could spread from animals to humans or *vice versa* but that they did not see pets as a "serious vector of transmission" and that there were "no plans to isolate, do contact tracing for pets, or exercise any form of quarantine for animals" (Mahmud 2020). On March 13, the IDEXX veterinary diagnostic laboratory announced that it had tested >3500 dog, cat, and equine specimens from across the United States and

South Korea with their COVID-19 RT-qPCR and that they had no positives (IDEXX 2020). What the press release did not make clear, however, is the fact that although animals tested were from affected areas, it is "unknown if any of the animals lived in homes with people that had COVID-19" (ScienceNews 2020). WHO, CDC, and the AVMA accepted IDEXX's assertion that pets posed little risk to public health at face value. On March 13, WHO stated that "pets are generally safe from being infected with coronavirus" (Zhou 2020). But they recently admitted "that pets can get infected, but there is no evidence pets can spread the disease or that the disease can cause an animal to fall ill" (Zhou 2020). On March 16, the AVMA admitted it did not "have a clear answer as to whether SARS-CoV-2 can infect pets at this time...and there is no evidence that pets can become sick. Infectious disease experts, as well as CDC, OIE and WHO indicate there is no evidence to suggest that pet dogs and cats can be a source of infection with SARS-CoV-2, including spread to people" (AVMA 2020). On March 19, a second dog tested positive by RT-PCR in Hong Kong (ScienceNews 2020). The first dog was later found to be positive for SARS-CoV-2-specific antibodies confirming the initial test was not a false positive and that the dog had actually been infected (Systematic Reviews for Animals & Food 2020).

On March 27, the first positive cat was diagnosed with COVID-19 in Belgium (Brown 2020, Bryner 2020). Contrary to earlier assertions by health agencies that the virus could not cause illness in pets, the cat developed both respiratory and enteric symptoms and took 9 days to recover. Large amounts of antigen were repeatedly demonstrated in vomit and feces over multiple days, which led scientists to conclude that the cat had indeed been infected by SARS-CoV-2. The Scientific Committee in Belgium said it was "unable to assess the risk" of animal-to-human transmission but did not recommend testing pets until validated diagnostics were available (AFSCA 2020). Between March 27 and 30, scientists still said they considered pets to be "dead end hosts" (Stone 2020) that "the risk of animal to human transmission is very small" and that "animals are not vectors of the epidemic, so there is no reason to abandon your animal" while advising owners "not to rub their nose against their pets" (Brown 2020). On April 3, research was published on the BioRxiv website by Chinese researchers who studied 100 stray and house cats from Wuhan, China, for the presence of SARS-CoV-2-specific antibodies. They found ~15% of them had antibodies in their blood that were specific to the novel coronavirus. On April 18, two cats reportedly tested positive for SARS-CoV-2 in New York. Both cats had owners who were COVID-19 positive, and both animals were exhibiting respiratory signs (Promed mail posted on April 18, 2020) (Zhang 2020).

On April 1, Chinese authors posted several preprint nonpeer-reviewed publications on transmission studies in animals (Shi et al. 2020a), a serological study in cats (Zhang et al. 2020), and ACE2 gene expression in animals (Sun et al. 2020). These studies are the first experimental studies in animals and provide valuable insights into SARS-CoV-2 infection in a variety of species. The transmission study showed that the virus replicates efficiently in cats, that it causes severe disease in juvenile cats, and that there is droplet transmission of the virus from infected to naïve cats. Both, RT-qPCR and immunohistochemistry assays revealed abundant RNA or antigen in respiratory and gut epithelium. The virus did not replicate efficiently in dogs, ducks,

chickens, and pigs but did replicate efficiently in cats and ferrets (Shi et al. 2020). The authors said “surveillance for SARS-CoV-2 should be considered as an adjunct to elimination of COVID-19 in humans.” The gene expression study found that ACE2 was “highly expressed in skin, ear tips, lungs and retina of cats and in skin and retina of dogs.” “In addition, we also observed ACE2 expression in the lungs of cats and ferrets, which suggested that these animals may be more suitable for SARS-CoV-2 studies than rodent models” (Sun et al. 2020). As interesting as these studies are, it must be noted that they are small studies and are not peer reviewed at this time. One scientist stated that she doubts the results of the transmission study because they infected cats with very high doses of virus and they do not replicate nature (Zhen 2020).

Background: Working Dogs

Several articles announced an unusual presentation of COVID-19 in asymptomatic people (Young 2020, Yeager 2020, Kwong et al. 2020, Lanse 2020). Patients who subsequently tested positive for COVID-19 reported an early loss of smell and taste. The American College of Otolaryngology proposed adding anosmia, hyposmia, dysgeusia, and ageusia to the list of screening items for COVID-19 patients (Young 2020). This raises the question of whether hyposmia/anosmia and ageusia/dysgeusia occur in animals, specifically in military working dogs, in beagle brigades at CBP and K9 first responder teams?

The U.S. government spends millions of dollars to train bomb-sniffing dogs essential to federal and local law enforcement capabilities (Homeland Security Today 2019, Nelson 2020). Dogs serve many roles in the military and as multipurpose canines as already mentioned. A fully trained bomb detection canine is likely worth over \$150,000. Despite decades of trying, researchers have yet to develop a machine as exquisitely sensitive and discerning as a dog's nose (Murphy 2020). Dogs have 220 million scent receptors that is 44 times more than humans. What happens if working dogs lose their sense of smell? Unfortunately, the only susceptibility study published on dogs (Shi et al. 2020a) did not include histopathologic evaluation or immunohistochemical staining of the nasal passages in the experimentally SARS-CoV-2-infected dogs that were necropsied, so this remains an important but unanswered question. If hyposmia/anosmia does occur in dogs, it will have a devastating impact on U.S. national security. In contrast, if an effect of SARS-CoV-2 on smell is conclusively ruled out, perhaps dogs can be trained to detect people with COVID-19 and enhance surveillance for the disease (BBC 2020). Either way, there is a critical need for studies to investigate this issue.

Background: Livestock and Poultry

The COVID-19 pandemic is significantly impacting the U.S. food supply and agricultural systems. There is a need to develop and deploy rapid strategies that allow mitigation of threats from SARS-CoV-2 across the food and agriculture enterprise. It is critical to ensure the availability of a safe, nutritious, and abundant food supply for U.S. citizens, and respective tools and technologies have to be developed to protect the food and agricultural supply chain, safety of our foods, health, and security of livestock, as well as the well-being of farmers, food service providers, and rural Americans. Therefore, reliable data are needed on the susceptibility of livestock (cattle, sheep, goats, horses, alternative livestock, and others)

and poultry (chickens, turkey, ducks, and others) to SARS-CoV-2 and the potential transmissibility within a species and across species to guide politicians and other decision makers. The susceptibility of livestock and poultry that could act as virus reservoirs, might serve as animal models for COVID-19 or are possibly in close contact with infected humans, is still understudied. Recent work at the Harbin Veterinary Research Institute (Shi et al. 2020b) in China and the Friedrich-Loeffler-Institut (Swine Health Information Center 2020, Friedrich-Loeffler-Institut 2020) in Germany examined SARS-CoV-2 susceptibility of pigs, chickens, and ducks (only studied by Shi et al. 2020b). They reported that pigs, chickens, and ducks could not be productively infected by SARS-CoV-2 under the experimental conditions used in their work.

This raises many questions: What is the susceptibility of livestock and poultry to SARS-CoV-2? Do we know the potential transmission of SARS-CoV-2 from humans to livestock/poultry and among different livestock/poultry species? Do we have methods for detection and surveillance of SARS-CoV-2 in livestock/poultry?

Background: Zoo Species

As of today (April 19, 2020), a Malayan tiger, her sister, three African lions, and two Amur tigers at the Bronx Zoo developed clinical disease and tested positive for SARS-CoV-2. It is hypothesized that they contracted the virus from an asymptomatic COVID-19 positive keeper. This raises a host of questions. Did the large cats develop a dry cough? Given their large size, how much virus will they shed through the respiratory route? Will they shed virus in feces and urine? What will be the duration of shedding? The reports attribute their infection to the keeper but, once infected, will the cats be able to transmit the virus to other people? Will SARS-CoV-2 have an impact on reproduction of captive endangered species? What other species in a zoological collection can be infected by SARS-CoV-2? Are there potential reservoirs of SARS-CoV-2 in animals maintained in zoological collection? How can surveillance of zoo species be performed on a national basis? What diagnostic tests should be used to diagnose zoo species? These are many questions and many of them also apply to other animal species including companion animals and livestock.

Summary

Concerns about the need to investigate SARS-CoV-2 in companion animals was first shared with the “Red Dawn Breaking” COVID-19 group of federal officials and academics on February 13, 2020, by one of the authors (T.M.). It was then discussed with members of the Department of Homeland Security (DHS) between mid-March and early April by all authors. This information was pulled together in response to an informal e-mail from DHS and was submitted to DHS on April 6, 2020.

A thorough review of the literature concerning SARS-CoV-2 as it relates to companion animals was conducted. Although there was early indication that cats might be susceptible to SARS-CoV-2 infection based on their ACE2 receptor structure (Wan et al. 2020), no investigations were performed. Instead, there have been repeated assertions by WHO, CDC, and several veterinary entities that companion animals were “unlikely” to get infected with SARS-CoV-2. But then dogs and cats tested positive in Hong Kong and Belgium and recently cats in the United States (NY Times 2020). Although these same

organizations also had stated that pets would not become ill, the cat in Belgium presented with clinical signs. More cats and dogs have since tested positive in Hong Kong and ~15% of stray and house cats in Wuhan, China, have been found seropositive (Zhang, 2020). In addition to domestic cats and exotic felids, natural infections have now also been confirmed in mink at two farms in the Netherlands (ProMED 2020c). Along the way, the public messaging about companion animals has shifted from “there is no threat” to “in an abundance of caution, be sure to wash your hands after petting your animals and be careful not to let your dog lick your face.” Less than a week ago, Chinese researchers published a nonpeer-reviewed study that, if accurate, indicates that juvenile cats can not only become infected and develop serious disease but that they also efficiently transmit the infection to adjacent uninfected cats. If these findings can be replicated and verified, they raise serious implications for pet cats, cats in shelters, exotic felids in zoos, and possibly people. Tigers and lions in a U.S. zoo have tested positive for SARS-CoV-2, raising more questions about species susceptibility, duration of infection, viral shedding, and asymptomatic reservoirs.

In its February 3 Strategic Preparedness and Response Plan on COVID-19, WHO lists the need to “*identify and reduce transmission from the animal source*; address crucial unknowns regarding clinical severity, extent of transmission and infection, treatment options, and accelerate the development of diagnostics, therapeutics and vaccines; and communicate critical risk and event information to all communities and counter misinformation” as strategic objectives (World Health Organization 2020b). In the situation reports of February 5 and 22 (World Health Organization 2020a), WHO again states there is a need to “*identify and reduce transmission from the animal source*.” On April 3, OIE reported another positive cat in Hong Kong that has been quarantined and put under veterinary surveillance for 14 days. Under “Zoonotic impact” the report says “Zoonotic potential unknown at this time.” The recent Chinese studies conclude that “surveillance (in cats) for SARS-CoV-2 should be considered an adjunct to the elimination of COVID-19 in humans” (Shi et al. 2020a) and that “more studies are needed” (Zhang et al. 2020). We agree.

With regard to diagnostics, molecular diagnostic kits used for human COVID-19 testing can be easily adapted to animal testing—as long as the SARS-CoV-2 does not dramatically mutate after cross-species transmission from humans to animals. To determine whether such mutations are occurring, it is critical that next-generation sequencing technology be applied on SARS-CoV-2 samples recovered from animals. In terms of serological tests, the high-throughput indirect ELISA systems available already for humans cannot be used for animals. Novel validated indirect ELISA tests for individual animal species, and importantly competitive ELISA tests that can be used independent of the animal species are badly needed. Neutralization antibody tests, which are unfortunately labor and time consuming, can be adapted for animal sera. In addition, antigen detection assays for the presence of SARS-CoV-2 antigens in animal samples should be developed, since they can be used independent of animal species. The potential to use serological and antigen-based SARS-CoV-2 assays in a point of care environment, that is, in veterinary practices, zoos, kennels, at ports, airports, and border crossings, is enormous.

In the immediacy of the COVID-19 crisis, the focus has understandably been on human health. But we have ignored the

opposite side of the coin of emerging zoonotic disease threats—the animals themselves. This lack of a One Health approach has resulted in an unnecessary delay in the investigation of important veterinary issues as they pertain to public health. Had we taken a proactive approach, we could have gotten ahead of this.

We are now faced with many urgent questions that can only be answered through investigative studies and surveillance. In the September 2000 GAO report “West Nile Virus Outbreak—Lessons for Public Health Preparedness” (GAO/HEHS-00-180 West Nile Virus Outbreak), the authors emphasized the need to “expect the unexpected.” With regard to SARS-CoV-2 in animals, this admonition seems to have been forgotten. Anecdotal information and assumptions are no substitute for stringent studies. Absence of evidence is not the same thing as evidence of absence.

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(Appendix follows →)

Appendix

Appendix A1. Critical Need for Pathogenesis, Pathology, and Diagnostics Research in Companion Animals

1. Questions That Must Be Answered Through Experimental Studies

Transmission studies

- Can dogs/cats be infected with SARS-CoV-2?
- Can dogs/cats shed live virus?
- What is the incubation period in dogs/cats?
- What is the duration of shedding in companion animals?
- What are the routes of shedding? (Saliva? Fecal? Respiratory?)
- Can dogs/cats be asymptomatic shedders of SARS-CoV-2?
- If yes, how long can they shed live virus?
- If COVID-19 spreads into other species, will it mutate?
- Are cats a good experimental model for SARS-CoV-2?

Comparative pathology

- What is the pathogenesis of COVID-19 in companion animals?
- What is the histopathology of COVID-19 in companion animals?
- Has immunohistochemical staining of SARS-CoV-19 tissues been developed and validated against known positives in companion animals?

Diagnostics

- What validated diagnostic tests are available for testing of companion animals?
- Has the molecular RT-qPCR assay specific for the SARS-CoV-2 (CDC or WHO assay) been validated for use in companion animals?
- What serological tests are available for testing for SARS-CoV-2 in companion animals?
- Has an indirect antibody-based ELISA been developed?
- Has a competitive ELISA (cELISA) been developed?
- Have antigen detection systems for the detection of SARS-CoV-2 in companion animals been developed? (Antigen-based indirect ELISA; antigen-based point of care Lateral Flow Assay)
- Can point-of-care assays be developed for testing of companion animals in veterinary practices? Animal shelters? (High-risk population/high-volume turnover to public)

Vaccines

Owing to the proximity of companion animals to humans and the potential for zoonotic spread, are vaccines or antivirals being developed for companion animals?

Epidemiological surveillance

- How will surveillance of companion animals that have been exposed to COVID-19 positive owners be tracked?
- How will epidemiological data be collected so that links between positive owners/pets can be evaluated?
- Who would pay for testing of companion animals that potentially pose a public health risk? (Owners? Public health entities?)
- What risk will companion animals pose to veterinarians and staff?
- What risk will companion animals pose to shelter workers?
- What risks will possible positive dogs/cats pose to dog/cat day care settings?
- Will this virus pose a threat to military working dogs? (loss of smell?)
- What risk does this pose to service animals?

Critical Need for Pathogenesis, Pathology, and Diagnostics in Working Dogs

1. Questions that must be answered through experimental studies:

- Do SARS-CoV-2 infected dogs lose their sense of smell and does this affect the performance of working dogs: military, first responder, border control, etc.?
- Does SARS-CoV-2 attach to ACE2 receptors in the canine nasal passages or the ocular system?
- If loss of smell occurs in dogs, is it transient or permanent?
- Does SARS-CoV-2 enter the brain and damage neurons as has been suggested in humans and has been shown experimentally in mice infected with SARS-CoV?
- What is the pathogenesis of COVID-19 in dogs? Sequential necropsies will be required.
- What is the incubation period in dogs and the duration of shedding?
- What are the routes of shedding? (Saliva? Fecal? Urine? Nasal/Respiratory? Aerosol? Tears/Lacrimal gland?)
- What clinical signs, if any, are associated with infection of SARS-CoV-2 in dogs?

2. Which validated diagnostic tests are available for testing of working dogs?

- If SARS-CoV-2 replicates in dogs, can it mutate and will it still be detectable by the CDC and/or WHO-SARS-CoV-2 diagnostic test?
- Has a molecular RT-qPCR assay specific for the SARS-CoV-2 been validated for use in dogs?
- What serological tests are available for testing for SARS-CoV-2 in dogs?
- Does a validated indirect antibody-based or competitive ELISA exist?

3. Controlled Epidemiological Studies and Surveillance

- Incidence and prevalence of clinical and subclinical COVID-19 in working dogs.

(Appendix continues →)

- Risk factors for infection and COVID-19 disease among working dogs including host and environmental determinants.
 - Knowledge of risk factors by veterinarians and dog handlers to identify high-risk dogs and decrease exposure by owners and veterinary personnel.
4. Development of vaccines and or therapeutics to prevent and treat COVID-19 disease in working dogs if warranted by the risk of infections in various dog populations.

Appendix A2. Timeline of COVID-19 Events Pertaining to Animals*

January 29, 2020

Prof. Li Lanjuan, a member of the senior expert team from China's National Health Commission and also an academician from the Chinese Academy of Engineering, told the state broadcaster CCTV that pet owners should take extra care of their animals because the virus "moves between animals." Prof. Li stated, "In this epidemic season, pet owners should strengthen their management of their pets." She added, "If your dogs run around outside and come into contact with the outbreak or people infected with the virus, then your pets should be put in quarantine." "Because the epidemic spreads between mammals, therefore we should take precaution against other mammals."

"Online accounts suggested Prof. Li's comments prompted pet owners to abandon their animal companions, with some suggesting that dogs and cats had been smashed to death. However, according to the World Health Organization, no evidence has suggested that cats and dogs are susceptible to the coronavirus" (Safoora 2020).

January 29, 2020

Receptor recognition by novel coronavirus from Wuhan: An analysis based on decade-long structural studies of SARS causing symptoms in humans similar to those caused by SARS coronavirus (SARS-CoV) (Wan et al. 2020).

"Since SARS-CoV outbreak in 2002, extensive structural analyses have revealed 28 key atomic-level interactions between SARS-CoV spike protein receptor-binding domain (RBD) and its host receptor angiotensin-converting enzyme 2 (ACE2), which regulate both the cross-species and human-to-human transmissions of SARS-CoV. Here we analyzed the potential receptor usage by 2019-nCoV, based on the rich knowledge about SARS-CoV and the newly released sequence of 2019-nCoV. First, the sequence of 2019-nCoV RBD, including its receptor-binding motif (RBM) that directly contacts ACE2, is 34 similar to that of SARS-CoV, strongly suggesting that 2019-nCoV uses ACE2 as its receptor. Second, several critical residues in 2019-nCoV RBM (particularly Gln493) provide favorable interactions with human ACE2, consistent with 2019-nCoV's capacity for human cell infection. Third, several other critical residues in 2019-nCoV RBM (particularly Asn501) are compatible with, but not ideal for, binding

human ACE2, suggesting that 2019-nCoV has acquired some capacity for human-to-human transmission. Last, while phylogenetic analysis indicates a bat origin of 2019-nCoV, 2019-nCoV also potentially recognizes ACE2 from a diversity of animal species (except mice and rats), implicating these animal species as possible intermediate hosts or animal models for 2019-nCoV infections. These analyses provide insights into the receptor usage, cell entry, host cell infectivity and animal origin of 2019-nCoV, and may help epidemic surveillance and preventive measures against 2019-nCoV.

Our decade long structural studies on the receptor recognition by SARS-CoV have identified key interactions between SARS-CoV spike protein and its host receptor angiotensin converting enzyme, which regulate both the cross-species and human-to human transmissions of SARS-CoV. One of the goals of SARS-CoV research was to build an atomic-level iterative framework of virus-receptor interactions to facilitate epidemic surveillance, predict species-specific receptor usage, and identify potential animal hosts and animal models of viruses. Based on the sequence of 2019-nCoV spike protein, we apply this predictive framework to provide novel insights into the receptor usage and likely host range of 2019-nCoV. Like SARS-CoV, 2019-nCoV will likely replicate inefficiently in mice and rats, ruling them out as intermediate hosts for 2019-nCoV. Moreover, we predict that either 2019-nCoV or laboratory mice and rats would need to be genetically engineered before a robust mouse or rat model for 2019-nCoV would become available. Pigs, ferrets, cats and non-human primates contain largely favorable 2019-nCoV-contacting residues in their ACE2, and hence may serve as animal models or intermediate hosts for 2019-nCoV" (Wan et. al 2020).

February 13

Animal humane experts estimate tens of thousands of pets have been abandoned or killed in China during the coronavirus crisis. "Things can get worse if the epidemic remains uncontrolled," Vshine's chief of staff Deng Fang told the outlet. The organization, which partners with Humane Society International, has estimated that the number of dogs and cats left behind in apartments in Hubei province are in the tens of thousands (Daniels 2020).

February 13

Officials of Peng'an, China, started to cull pets activists claimed. They paid door-to-door visits to villagers to kill their cats and dogs, it is alleged. "The advice by the World Health Organization that there is no evidence dogs and cats can be infected with the virus, needs to be heard throughout China" (Thomson 2020a, Williams 2020).

February 13

The widespread fears were sparked by comments made by one of China's top experts for infectious diseases; Prof. Li Lanjuan, a member of the senior expert team from China's National Health Commission, last month warned that pets would also need to be quarantined should they be exposed to coronavirus patients. Authorities in China are now desperately trying to stop people from throwing away their pets.

Animal welfare organization Humane Society International (HSI) condemned the Chinese Sichuan worker's

*Additional references can be found in the cited text.

behavior. HIS's spokesperson Wendy Higgins said "Any evidence of animals being beaten to death is extremely distressing, no matter what the circumstances. If these videos do indeed show dogs being brutally killed in China out of an unwarranted fear of spreading coronavirus, then it is doubly upsetting." Community officers should be charged with disseminating accurate information and scientifically supported information to the public at this time, not in carrying out cruel and pointless culls of dogs."

The advice by the World Health Organization that there is no evidence dogs and cats can be infected with the virus needs to be heard throughout China (Thomson 2020b).

February 21

Chinese officials continue to kill pets to stop coronavirus spread—community officers in Sichuan province ordered villagers to hand over their pets. An activist group claims the animals were killed moments later in the streets (Albawaba 2020).

February 26

AVMA—Hong Kong's Agriculture, Fisheries, and Conservation Department has indicated that a pet dog whose owner had contracted COVID-19 had been tested for SARS-CoV-2 and that multiple tests over several day's time had come back "weak positive" (AVMA 2020b). The ACFD first collected samples from the 17-year-old Pomeranian on February 26 and detected low levels of SARS-CoV-2 material in samples from its nasal and oral cavities on February 27, using RT-PCR that is sensitive, specific, and does not cross-react with other coronaviruses of dogs and cats. The ACFD repeated the test February 28, March 2, and March 5 with continued "weak positive."

March 2

ANSES opinion—French Agency for Food, Environmental and Occupational Health & Safety received a formal request from the Directorate General for Food to assess risks, specifically to give an opinion regarding the potential role of domestic animals (livestock animals and pets) in the spread of SARS-CoV-2.

With the exception of work on infections undertaken in transgenic mice (Bao et al. 2020) expressing the human form of ACE2 receptor for the SARS-CoV-2, *very few studies have described animals experimentally infected with SARS-CoV-2.*

The experts consider that *additional studies on the interactions between SARS-CoV-2 and ACE2 homologues from various animal species, as well as studies on the distribution of ACE2 in tissue, are necessary* to further knowledge on the possible transmission of infection to other species. However, cross-species transmission does not rely solely on the presence of other cellular factors required for viral replication (ANSES 2020). *Further studies should also be undertaken to identify these factors.*

March 6

ProMED-mail—Hong Kong dog suspected.

"The multiple weak positives showed the dog had been infected, and perhaps could serve as a potential intermediate host for cross-species transmission of the new coronavirus,

Zhu Huachen, associate director of the Joint Institute of Virology at Hong Kong University told Caixin. She said the dog's lack of symptoms showed the virus could live inside it, allowing the animal to secrete and spread the virus at the same time"

Jonathan Ball, a professor of molecular virology at the University of Nottingham, also stressed the importance of differentiating between a real infection (Simin et al. 2020).

March 6

Singapore—Article discusses the "Theoretical possibility" that COVID-19 can spread from animals to humans, but pets not a serious vector of transmission. At a news conference, MOH discussed findings of positive dog in Hong Kong; Assoc. Prof. Mak said while scientific evidence did not point to the infection spreading either from pets to pets or from animals to human or vice versa, he acknowledged that this could happen." "We don't assess at this point that pets are a serious vector of transmission. This is also the view of health authorities around the world." At this point in time, there are no plans to isolate, do contact tracing for pets, or exercise any form of quarantine measures for those animals as well" (Mahmud 2020).

March 13

IDEXX—IDEXX tested >3500 canine, feline, and equine specimens as part of the validation of a COVID-19 PCR assay. Patient samples were submitted for a 4-week period beginning February 14, 2020, from across the United States and South Korea, included from regions where human COVID-19 cases were occurring. None was positive (IDEXX 2020).

March 13

WHO says pets are generally safe from being infected with coronavirus

The WHO now says that pets can get infected, but there is no evidence that pets can spread the disease or that the disease can cause an animal to fall ill. Further studies may bring new findings, it says. A relief to pet owners: there is no evidence that companion animals such as dogs or cats can be infected with the new coronavirus as of now, according to the World Health Organization. Like previous SARS viruses, COVID-19 transmits primarily through droplets of coughing, sneezing, saliva, or discharge from the nose. While pets generate droplets quite easily, there are significant barriers for the virus to jump from humans to animals, and vice versa. In rare situations, when a pet carries the virus, it is unlikely that it would spread to a person. Knowing the science about how the virus transmits could help combat the abundance of misinformation amid the epidemic. Just a month ago when the daily death toll reached its peak in China, local officials of a village in Zhejiang province asked all residents to quarantine animals and slaughtered all stray dogs on the street (link in Chinese). Another village in China made a similar rule (link in Chinese) at the end of January to kill animals to contain the spread of the virus. As more people start exercising social distancing and working from home, more frequent contact with your dog, cat, or another pet is inevitable. WHO advises washing your hands with soap and water after

(Appendix continues →)

contact with pets. It is the pet owners, rather than pets, who have a higher risk of spreading the virus (Zhou 2020).

March 16

AVMA—Q—Can SARS-CoV-2 infect pets at this time?

“We do not have a clear answer as to whether SARS-CoV-2 can infect pets at this time. That said, currently, there is no evidence that pets become sick. Infectious disease experts, as well as CDC, OIE and WHO indicate there is no evidence to suggest that pet dogs and cats can be a source of infection with SARS-CoV-2, including spread to people....However good idea to wash your hands.” “Out of an abundance of caution, the AVMA recommends common sense approach...” (AVMA 2020a).

March 19

Second dog tests positive in Hong Kong (ScienceNews 2020).

March 23

New England Journal of Medicine Journal Watch announces that the American Academy of Otolaryngology—Head and Neck Surgery has proposed adding anosmia and dysgeusia to a list of screening items for potential novel coronavirus disease COVID-19 (Young 2020).

March 24

Lost Smell and Taste Hint COVID-19 Can Target the Nervous System—article documents peculiar symptoms showing up in people that could serve as early warning of COVID-19 infection. Like other coronaviruses such as SARS-CoV and MERS-CoV, SARS-CoV-2 may target the nervous system, possibly infecting neurons in the nasal passage and disrupting the senses of taste and smell. A 2008 study on SARS-CoV showed the virus entered the brain of transgenic mice expressing ACE2 through the neurons of the nose. The virus then spread rapidly to connecting nerve cells. SARS-CoV-2 also enters human cells using the ACE2 receptor (Yeager 2020).

March 26

“Is Loss of Smell and Taste A Symptom of COVID-19? Doctors want to Find Out.” Article describes anecdotal reports of patients reporting a loss of smell and taste and subsequently testing positive for COVID-19 (Kwong et al. 2020).

March 27

“COVID-19 might cause loss of smell. Here’s what that could mean.” Article describes three potential explanations for how COVID-19 might affect smell (Lanese 2020).

March 27

“A cat appears to have caught the coronavirus, but it’s complicated.”

A cat in Belgium seems to have become infected with the coronavirus and may have COVID-19, the disease that the virus causes. Although the case—the first reported in cats—suggests that the animals can catch the virus, there is no evidence that felines play a role in spreading the coronavirus, and it is still unclear how susceptible they are to the disease.

“This is an isolated case, so it is not the rule.” (March 27 news conference held by Belgium’s public health institute). The cat probably picked up the virus, called SARS-CoV-2 from its owner, who fell ill, a week later, the cat started to show signs of illness: respiratory issues, nausea, and diarrhea. In laboratory tests, feces and vomit samples showed high levels of SARS-CoV-2’s genetic material.

But the positive results come with caveats. The samples were collected and sent to the laboratory by the owner, and a veterinarian has yet to examine the cat. The cat recovered after 9 days, and once it is released from quarantine, researchers will run a blood test...

“What makes us actually believe that this cat was infected is that there was quite a lot of virus detected in the feces and vomit in multiple tests over several days” says Jane Sykes, a vet at UC Davis.

“Earlier in March, the first dog tested positive for SARS-CoV-19, followed by another pup on March 19.”

ACE2 looks a bit different in dogs, which might make it harder for the virus to recognize and could make dogs less susceptible to infection.... “As in people, more testing could provide a crisper snapshot of how the coronavirus affects pets.”

As of March 25, Hong Kong has continued to screen some animals in the homes with people with COVID-19. Out of 17 dogs and 8 cats, only those 2 dogs have been positive.

IDEXX developed an RT-PCR, tested several thousand animals from affected areas and reported that none were positive. However, “while the tests did include animals from hotspots like Seattle, *it’s unknown if any of the animals lived in homes with people that had COVID-19.*”

March 27

COVID-19 in a cat in Belgium

“As for the risk of contamination of humans by animals, with regard to current data, the Scientific Committee is UNABLE TO ASSESS THE RISK. However, it considers that the risk is negligible compared to the risk to humans of contamination from human-human transmission.” The Scientific Committee does not recommend testing suspect pets *until the diagnostic options are drastically increase*. “The absence of symptoms in the two infected dogs and the improved health of the cat advocate either for an ASYMPTOMATIC CARRIER or, for a non-lethal infection of the pet animal.” “This virus secretion by the animal adds to the pre-existing risk of direct and indirect contamination of the environment by the infected patient.”

March 27

New York Post—“We want to stress that this is an isolated case”—“The risk of animal-to-human transmission is very small” “Animals are not vectors of the epidemic, so there is no reason to abandon your animal,” the agency said—while advising owners “not to rub their nose against their pets.”

“Belgium’s National Council for Animal Protection (CNPA) also told the paper that there is no known threat from pets.”

March

Live Science—“We think the cat is a side victim of the ongoing epidemic in humans and does not play a significant role in the propagation of the virus,” he said. (Van Guht)

(Appendix continues →)

“To prove definitively that the cat was infected with SARS-CoV-2, scientists will need a blood test to look for antibodies” (Bryner 2020).

March 30

Forbes—“The cat was quite ill and there were large amounts of genetic material present in its excretions.” “The Belgian Scientific Committee responsible for COVID-19 oversight concluded that the risk of people being infected by their pets is negligible compared to the risk from people or a contaminated environment. At this point, they consider domestic animals as dead end” hosts for SARS-CoV-2, and not of significance epidemiologically (Stone 2020).

April 1

Preprint—Susceptibility of ferrets, cats, dogs, and different domestic animals to SARS-coronavirus-2.

“WE found that SARS-CoV-2 replicates poorly in dogs, pigs, chickens, and ducks, but efficiently in ferrets and cats. WE found that the virus transmits in cats via respiratory droplets. Our study provides important insights into the animal reservoirs of SARS-CoV-2 and animal management for COVID-19 control”

“We found that SARS-CoV-2 replicates poorly in dogs, pigs, chickens and ducks, but efficiently in ferrets and cats.”

“We replicated the replication and transmission studies in juvenile cats (aged 70–100 days). Histopathologic studies performed on samples from the virus-inoculated juvenile cats that died or euthanized on day 3 p.i. revealed massive lesions in the nasal and tracheal mucosa epitheliums, and lungs of both cats. These results indicate that SARS-CoV-2 can replicate efficiently in cats, with younger cats being more permissive and, perhaps more importantly, the virus can transmit between cats via respiratory droplets”

“Uninfected cat was placed in a cage adjacent to each of the infected cats”

“Viral RNA was detected in the soft palate and tonsils of the virus-inoculated animal and in the nasal turbinate, soft palate, tonsils, and trachea of the exposed animal indicating that respiratory transmission had occurred in this pair of cats”

“Large amounts of viral antigen were detected in the epithelium of the nasal respiratory mucosa; epithelial cells of the small intestine also showed strong positive staining for viral antigen”

“Antibodies against SARS-CoV-2 were detected in all three virus-inoculated subadult cats and one exposed cat by use of an ELISA and neutralization assay”

“The cats we used in this study were outbred, and were highly susceptible to SARS-CoV-2, which replicated efficiently and transmitted to naïve cats. Surveillance for SARS-CoV-2 should be considered as an adjunct to elimination of COVID-19 in humans” (Shi et al. 2020a).

April

SARS-CoV-2 neutralizing serum antibodies in cats: a serological investigation (Zhang et al. 2020).

“Coronavirus disease 2019 (COVID-19) caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was first reported in Wuhan, China, and rapidly spread worldwide. Previous studies suggested cat could be a po-

tential susceptible animal of SARS-CoV-2. Here, we investigated the infection of SARS-CoV-2 in cats by detecting specific serum antibodies. A cohort of serum samples were collected from cats in Wuhan, including 102 sampled after COVID-19 outbreak, and 39 prior to the outbreak. 15 of 102 (14.7%) cat sera collected after the outbreak were positive for the receptor binding domain (RBD) of SARS-CoV-2 by indirect enzyme linked immunosorbent assay (ELISA). Among the positive samples, 11 had SARS-CoV-2 neutralizing antibodies with a titer ranging from 1/20 to 1/1080. No serological cross-reactivity was detected between the SARS-CoV-2 and type I or II feline infectious peritonitis virus (FIPV). Our data demonstrates that SARS-CoV-2 has infected cat population in Wuhan during the outbreak.

As one of the most popular pets, cats have very close contact with humans. Therefore, it is very important to investigate the prevalence of SARS-CoV-2 in cat, especially in the outbreak areas. However, there is no survey about the prevalence of SARS-CoV-2 in cats so far. Serological studies are suitable for the screening of antibody against the SARS-CoV-2 in animals (Reusken et al. 2013). At present, several methods have been applied for the antibody test of SARS-CoV-2 in human (Li et al. 2020b). However, there is no available method for the detection of cat antibody against the SARS-CoV-2. Here, we investigate the serological prevalence of SARS-CoV-2 in cats by an indirect ELISA and virus neutralization test, providing the first evidence of SARS-CoV-2 infection in cats.

Discussion In this study, we detected the presence of SARS-CoV-2 antibodies in cats in Wuhan during the COVID-19 outbreak with ELISA, VNT and western blot. A total of 102 cats were tested, 15 (14.7%) were positive for RBD based ELISA and 11 (10.8%) were further positive with VNT. These results demonstrated that SARS-CoV-2 has infected cat populations in Wuhan, implying that this risk could also occur at other outbreak regions. Retrospective investigation confirmed that all of ELISA positive sera were sampled after the outbreak, suggesting that the infection of cats could be due to the virus transmission from humans to cats. Certainly, it is still needed to be verified via investigating the SARS-CoV-2 infections before this outbreak in a wide range of sampling. At present, there is no evidence of SARS-CoV-2 transmission from cats to humans. However, a latest report shows that SARS-CoV-2 can transmit between cats via respiratory droplets (Hualan Chen, 2020), so, a strong warning and regulations still should be issued to block this potential transmission route. The three cats owned by COVID-19 patients had the highest neutralization titer (1/360, 1/360, and 1/1080, respectively). On the contrary, the sera collected from pet hospital cats and stray cats had neutralizing activity of 1/20 to 1/80, indicating that the high neutralization titers could be due to the close contact between cats and COVID-19 patients. Although the infection in stray cats was not fully understood, it is reasonable to speculate that these infections are probably due to the contact with SARS-CoV-2 polluted environment, or COVID-19 patients who fed the cats. In addition, we also collected nasopharyngeal and anal swabs of each cat, and conducted SARS-CoV-2 specific qRT-PCR using a commercial kit which targeted ORF1ab and N genes. However, no double gene positive sample was detected. The reason might be (1) that the viral RNA load is too low to be detected; (2) as SARS-CoV (Martina et al. 2003), the period

(Appendix continues →)

that cat shed SARS-CoV-2 may be very short, along with asymptomatic infection, we didn't catch the moment of acute infection; (3) there may be variants in the genomic sequences in cats, leading to the failure in amplification in cat samples. To the best of our knowledge, this is the first report that animals produce specific neutralizing antibodies against SARS-CoV-2 under natural conditions. Our study pointed out the risk of cats involved in the transmission of SARS-CoV-2. More studies are needed to investigate the transmission route of SARS-CoV-2 from humans to cats. Importantly, an immediate action should be implemented to keep in a suitable distance between humans and companion animals such as cats and dogs, and strict hygiene and quarantine measures should also be carried out for these animals" (Zhang et al. 2020).

April

Atlas of ACE2 gene expression in mammals reveals novel insights into transmission of SARS-CoV-2 (Sun et al. 2020).

Results: We first found high conservation of ACE2 genes among common mammals at both DNA and peptide levels, suggesting that a broad range of mammalian species can potentially be the hosts of SARS-CoV-2. Next, we showed that high level of ACE2 expression in certain human tissues is consistent with clinical symptoms of COVID-19 patients. Furthermore, we observed that ACE2 expressed in a species-specific manner in the mammals examined. Notably, high expression in skin and eyes in cat and dog suggested that these animals may play roles in transmitting SARS-CoV-2 to humans.

Conclusions: Through building the first atlas of ACE2 expression in pets and livestock, we identified species and tissues susceptible to SARS-CoV-2 infection, yielding novel insights into the viral transmission.

Among myriad biological questions to be answered regarding SARS-CoV-2, one that is crucial and has intrigued much interest is the host origin and its mode of transmission to humans. SARS-CoV-2 and SARS-CoV are closely related, and both invade human cells through attaching their S proteins to a host transmembrane protein called angiotensin converting enzyme 2 (ACE2) as the entry point. Using transcriptome data, some studies analyzed spatial expression patterns of ACE2 in various tissues and cell types of the human body, and reported that the receptor gene is indeed expressed in the lungs. The connections between ACE2 expression and viral infection are further supported by cases from the United States, which confirmed for the first time the presence of SARS-CoV-2 in both the upper respiratory tract and stool sample of COVID-19 patients.

Some studies have suggested that the original host of SARS-CoV-2 may be bats. However, in the case of COVID-19, the outbreak occurred in winter when bats were under hibernation, making them unlikely to be the direct source of human infection. Hence, SARS-CoV-2 was likely transmitted to humans through some small carnivores like civet, the intermediate host of SARS-CoV. Recent studies have pointed to pangolins as the natural host of the virus, while minks being the possible intermediate host. Virus tracing has thus been continuously carried out and attracted much attention. The mystery remains as which wild animals are definitive and intermediate hosts of the new coronavirus, and virus tracing has been continuously carried out and attracted much atten-

tion. Furthermore, is it possible that some of the animals living in proximity to humans may also be susceptible to the virus and could potentially become additional hosts to SARS-CoV-2 hence further facilitating its transmission? Since SARS-CoV-2 invades both bat and human cells through ACE2, we reasoned that if animals have ACE2 proteins similar to human, they could also become the targets of SARS-CoV-2, we thus evaluated the conservation of ACE2 gene across mammals. We further investigated ACE2 expression in various tissues among human and common mammals. In particular, we included species that live in proximity with humans, that is, pets and livestock. Our analyses identified potential species susceptible to SARS CoV-2 and yielded novel insights into virus tracing and transmission, which may further contribute to the prevention and control of the COVID-19 pandemic.

Pets are the most intimate animals to humans and may thus very likely to be contracted by human COVID-19 patients or to transmit the virus to humans if they are infected. We examined ACE2 expression patterns in cats and dogs, the most popular pets worldwide, as well as ferrets and hamsters, which are also very common in China. ACE2 gene was highly expressed in various tissues in these animals, such as kidney, heart, and liver (figs. 5A–5C and S2A in supplementary data). For cats, ACE2 was also highly expressed in skin, ear tip, lungs, and retina; for dogs, ACE2 was expressed in skin and retina. These data suggested that cats and dogs may be highly susceptible to SARS-CoV-2 infection. In addition, we also observed ACE2 expression in the lungs of cats and ferrets, which suggested that these animals may be more suitable for SARS CoV-2 studies than rodent models (Sun et al. 2020).

April 2

Cats more susceptible to COVID-19 than dogs but pet lovers have “no cause for alarm”: researchers

“Cats appear to be more susceptible to COVID-19 infection than dogs, and kittens may be more susceptible than older cats, say researchers investigating infection and transmission in domesticated animals. Other scientists say there is still no conclusive evidence to suggest the virus can be passed from pets to humans, but people should keep their animals indoors as much as possible to reduce the possibility of exposing them to infection. In a new study, Chinese researchers have found that though cats may be “highly susceptible” to the virus and can transmit it to other cats, they are not a -major factor in spreading the disease. It has previously been reported that cats could be infected after pets in both Belgium and Hong Kong tested positive. In a series of laboratory experiments by the research team from the Chinese Academy of Agricultural Sciences’ Harbin Veterinary Research Institute in northeast China, cats inoculated with the virus developed obvious infections. The team’s non peer-reviewed article was published on Biorxiv.org on Tuesday. They found that cats that did not receive the inoculation but were kept near the infected cats also became infected. “The researchers in Harbin used two strains of viruses, one from the environment sample collected from Huanan Seafood Market in Wuhan, which was linked to the initial outbreak, and one from a human patient from Wuhan. These were then used to infect six cats, while

12 others were used for a transmission test. Of the six, lesions were found in two juveniles.” The experiments were conducted in the institute’s biosafety level 4 animal laboratory, China’s only veterinary laboratory at this high level. The human virus was inoculated through the nose into the subadult feline subjects. In 3 to 5 days, the viral RNA was detected in their feces, and after the cats died or were euthanized, the infectious virus was also widely detected in their organs, including nasal turbinates, soft palates, tonsils, and trachea. RNA—or ribonucleic acid—is a molecule that carries genetic codes in some viruses. After experiments were conducted on two younger cats, aged 70–100 days and designated as “juvenile cats,” massive lesions were found in the nasal and tracheal mucosa epitheliums, as well as the lungs. “These results indicate that SARS-CoV-2 can replicate efficiently in cats, with younger cats being more permissive,” the researchers said. In the transmissibility experiments, cats that were placed in separate cages next to the virus-inoculated cats were also found infected later, which suggested the cat-to-cat transmission took place not through direct contact, but possibly through respiratory droplets—in the same way the disease transmits between humans, according to the researchers. In similar experiments, dogs showed low susceptibility. Although inoculated beagles tested positive to the viral RNA in their rectal swabs, no infectious virus was found. No trace of the virus was detected in their organs after euthanasia. Researchers also carried out virus inoculation and transmissibility experiments on ferrets and other common animals. Livestock that have close contact with humans, including pigs, chickens, and ducks, were found not susceptible to the virus, while ferrets, an animal frequently used for the study of human respiratory viruses, were found “highly susceptible,” much like the cats. A separate evaluation by U.S.-based Idexx Laboratories showed no positive results in either cats or dogs from 3,500 cat and dog specimens in South Korea and all 50 U.S. states, suggesting that COVID-19 is primarily transmitted person-to-person. The research follows reports that a cat in Belgium developed breathing difficulties and tested positive to coronavirus and that a cat living with an infected woman in Hong Kong tested positive but showed no signs of the disease.

The two cases triggered concerns over whether pets were a key factor in spreading the disease, but there is no evidence that cats can spread the deadly virus to humans. Hong Kong has reported two dogs testing positive but neither had apparent symptoms, suggesting limited reproduction of the virus in these pets. Other scientists said the research findings were valid, but that the results did not suggest cat owners should be alarmed. Edgar Wayne Johnson, a veterinarian and senior technical consultant at Enable Ag-Tech Consulting in Beijing, said it was important not to overreact to the findings as the cats had been exposed to a large dose of the virus. “It is an interesting study, but I suggest calmness in the face of this report,” he said. “Since I don’t hear of any reports of feline illness in households with SARS2, I am not ready to suggest to people that they take their cats to the vet for examination or anything.” He said cat owners were advised to keep their pets inside so as to reduce the chances of exposure to an infected animal. “At this point I would advise benign neglect. Take care of

your pets much the same as you would any other day. If your pet is ill, seek professional assistance,” he said. The most important message of the research was that dogs are quite unlikely to spread the disease, he said. “There had indeed been a great deal of concern about dogs and this virus.” Muhammad Munir, a virologist at Lancaster University in northern England, said it was too early to say whether COVID-19 was spreading among animals, but it was advisable for animals to be tested to see whether they were capable of causing infection or carried the virus on their bodies.

The question was whether the virus could be transmitted between animals and humans, and if animals showed any clinical signs if infected, he said. “This is a new disease and it’s only three and a half months old, so we need to be keeping an eye open to all of the possibilities,” he said.

“On the safe side, it would be best to be testing animals, the same way as we do for humans ... that would be advisable in the situation, when we are not 100 per cent clear cut about the circulation of Covid-19 in animals, and until we know, it is advisable to screen those animals, especially cats, based on this study.” Munir advised pet owners to have their cats and dogs tested for COVID-19, and to quarantine them if they tested positive.

Linda Saif, a virologist at the Ohio State University in Wooster, was quoted by *Nature* as saying that there was no direct evidence that infected cats would spread the coronavirus to humans. The research findings were based on laboratory experiments and deliberate use of high doses of the virus, which did not suggest genuine interactions between human and pets (Zhen 2020).

April

Coronavirus disease 2019 (COVID-19) caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was first reported in Wuhan, China, and rapidly spread worldwide. Previous studies suggested cat could be a potential susceptible animal of SARS-CoV-2. Here, we investigated the infection of SARS-CoV-2 in cats by detecting specific serum antibodies. A cohort of serum samples were collected from cats in Wuhan, including 102 sampled after COVID-19 outbreak and 39 before the outbreak. A total of 15 of 102 (14.7%) cat sera collected after the outbreak were positive for the receptor binding domain (RBD) of SARS-CoV-2 by indirect enzyme-linked immunosorbent assay (ELISA). Among the positive samples, 11 had SARS-CoV-2 neutralizing antibodies with a titer ranging from 1/20 to 1/1080. No serological cross-reactivity was detected between the SARS-CoV-2 and type I or feline infectious peritonitis virus (FIPV). Our data demonstrate that SARS-CoV-2 has infected the cat population in Wuhan during the outbreak (Zhang et al. 2020).

April

ProMED-mail:

Of the 15 ELISA-positive cats, 3 were home-kept (owned by COVID-19 patients); they presented the highest neutralization titers. The other 12 cats came from pet hospitals or were stray cats—6 each. No information on clin-

ical signs in any of the tested cats is included. These results are in agreement with earlier reports on two PCR-positive cats that had been exposed to their COVID-19-infected owners: one from Belgium (with mild clinical signs [ProMED 2020a]) and the other one from Hong Kong (without clinical signs [ProMED 2020b]). The current report is also in agreement with the results of an experimental infection trial, undertaken by HVRI (Harbin, China), which revealed that SARS-CoV-2 will infect cats both by inoculation and by contact with infected cats (item 2 in the said posting).

The possible role of cats in the epidemiology of COVID-19 is yet to be further studied; their infection could rather

present a case of anthroponozoonosis. This, obviously, does not preclude the need to prevent exposure of humans to infected cats or other pets. Excrements from infected stray cats may, at least theoretically, contribute to environmental contamination (*e.g.*, Wuhan's seafood market?).

April 18

On April 18, two cats reportedly tested positive for SARS-CoV-2 in New York. Both cats had owners who were COVID-19 positive, and both animals were exhibiting respiratory signs (Promed mail posted on April 18, 2020).