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A rapid review of evidence of infection of pets and livestock with human-associated coronavirus diseases, SARS, MERS, and COVID-19, and evidence of the fomite potential of pets and livestock

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Impacts

- To date, all reported cases of SARS-CoV-2 infected animals have been living in close quarters with SARS-CoV-2 infected owners. No cases of cat/dog to human transmission have been reported.
- Two asymptomatic dogs living with SARS-CoV-2 infected owners in Hong Kong tested PCR positive to SARS-CoV-2. One of those dogs, a Pomeranian, has been reported as

positive on serology. Virus isolation was performed on previous samples taken from the Pomeranian with a negative result, indicating that no live virus was retrieved.

- A cat, that lived with SARS-CoV-2 infected owners in Belgium, has been reported as positive. No information about testing, samples, virus isolation are currently available.
- No studies were found that evaluated fur, hair, skin, feathers, or hides as a source of transmission from domestic animals for SARS, MERS or SARS-CoV-2.
- SARS was detected in 4/36 domestic cats at an animal market in China. Six cats artificially infected with SARS shed the virus and were able to infect 2 cats that were housed with them, although these 2 cats did not shed the virus.

Summary

A rapid review was undertaken for two questions of interest to veterinarians related to COVID-19: whether domestic animals can be infected with SARS-CoV-2 and could serve as fomites for SARS-CoV-2. As little evidence is available, we also assessed other known human coronaviruses, SARS and MERS. Searches were conducted on 26 March 2020 using all databases in the Michigan State University Web of Science™ Interface, BioRxiv, MedRxiv and ProMed.

In the current outbreak of COVID-19, 17 dogs and 8 cats tested that lived with SARS-CoV-2 infected owners in Hong Kong, two asymptomatic dogs were PCR positive. One of those dogs, a Pomeranian, has been reported as positive on serology. Virus isolation was performed on previous samples taken from the Pomeranian with a negative result, indicating that no live virus was retrieved. A cat, that lived with SARS-CoV-2 infected owners in Belgium, has been

reported as positive. No information about testing, samples, virus isolation are currently available.

SARS was detected in 4/36 domestic cats at an animal market in China in 2004. Six cats artificially infected with SARS shed the virus and were able to infect 2 cats that were housed with them, although these 2 cats did not shed the virus.

No studies were found that evaluated fur, hair, skin, or hides as a source of transmission from cats or dogs for SARS-CoV, MERS-CoV or SARS-CoV-2.

Keywords

COVID-19, SARS-CoV-2, cat, dog, SARS, livestock

Rationale

As COVID-19 is a newly emerging disease, information about the causal virus, Sudden Acute Respiratory syndrome coronavirus (SARS-CoV-2), and its relationship to domestic animals is sparse (OIE, 23 March 2020). Veterinarians need the most up-to-date and accurate information on potential transmission of SARS-CoV-2 from pets, livestock, or poultry to people in order to set standards to protect themselves and staff at their own farms or clinics as well as to advise companion animal owners of potential risks to human health.

There were two research questions:

- **Question 1:** "What is the evidence that domestic animals (cats, dogs, swine, cattle, sheep, goats, poultry, horses) can be infected with, or shed, the human-associated coronaviruses SARS-CoV, MERS-CoV, and SARS-CoV -2 which are associated with the disease SARS, MERS and COVID-19 respectively?"

- **Question 2:** "What is the evidence that domestic animals (cats, dogs, swine, cattle, sheep, goats, poultry, horses) can act as a fomite for the human-associated coronaviruses SARS-CoV, MERS-CoV, and SARS-CoV -2 which are associated with the disease SARS, MERS and COVID-19 respectively?"

Protocol

A protocol was not developed for this review. Instead, in response to the outbreak of SARS-Cov-2, a rapid review on the topic was conducted and made publicly available online on the Systematic Reviews for Animals and Food website (<http://www.syreaf.org/covid-19-and-animals/>) on the 20th March 2020. We disseminated the review using an EpiVet list and Twitter (@oconnorwalker) and encouraged comments. The modifications to the methods and materials described below due to the discussion period were as follows:

- The original search used only terms for cats and dogs. Based on feedback we expanded the search terms to include livestock and poultry due to a request.
- The original search used did not include the following terms "novel coronavirus" OR "2019-novel coronavirus" which we identified in the BioRxiv searches.
- The original search did not include the term "fomites", which was added based on feedback from twitter

Eligibility criteria

The eligibility criteria were:

- Populations: domestic animals designated as cats, dogs, cattle, pigs, sheep, goats, horses, and poultry.
- Exposure of interest: human-associated coronaviruses: SARS-CoV, MERS-CoV, and SARS-CoV -2.

- Q1 Outcome of interest: Evidence of infection with SARS-CoV, MERS-CoV, and SARS-CoV-2 based on antibodies or PCR or virus isolation in saliva or serum.
- Q2 Outcome of interest: Detection of SARS-CoV, MERS-CoV, and SARS-CoV -2 on hair/fur/coat/hide/skin of cats, dogs, swine, cattle, sheep, goats, horses, poultry or camels.

Search

The search was designed based on three concepts: 1) the animals, 2) the virus 3) the outcome. Due to concern about designing the search for an area with few potentially relevant studies, positive control terms were included to provide some validation for the search strategy. For Question 1, because we were aware that literature existed identifying dogs that were antibody positive to Ebola, we included the Ebola term in the search. For Question 2, because there is such a strong link between camels and MERS, we anticipated that studies about fomites, if they existed, would be available of this topic, so we included camels. The concept behind the positive controls is to ensure that studies of similar type were captured. In both situations, we confirmed that the searches were effective for the positive control topics. These terms were subsequently dropped from the search. The final search strings are reported in Table 1.

Information sources

The searches reported here were conducted on 27 March 2020 using all databases in the Michigan State University Web of ScienceTM Interface (Table 2). We hand-searched the titles of pre-prints listed online at BioRxiv and MedRxiv using the search string "(COVID-19 OR SARS-CoV-2 OR SARS OR MERS) AND (cat OR dog OR cow OR pig OR sheep OR goats OR horses OR chicken)". We also hand-searched the report titles for ProMed Mail in the COVID-19 collection (<https://promedmail.org/coronavirus/>) using the find function (⌘f) and searching for dog, cat, cow, pig, sheep, poultry, goat and horse. We did not assess ProMed mail for SARS or

MERS, as we consider that enough time had passed since those outbreaks that such reports should be in the indexed literature.

Screening

Study selection: For Question 1, the screening question asked if the study reported evidence of infection for human coronavirus OR Ebola in cats, dogs, cattle, pigs, sheep, goats, horses or chickens. At level 2, the Ebola level studies were excluded as they were not relevant.

For Question 2, the screening question asked if the study reported human coronavirus (SARS-CoV-2, MERS-CoV, or SARS-CoV) on the fur, hair, hide, skin or feathers in cats, dogs, cattle, pigs, sheep, goats, horses or chickens.

Screening was initially conducted by two reviewers, with only one person required to reject or accept. We used the Distiller SR® AI tool to conduct automated screening. The decision rule for using the AI reviewer, was that when the AI tool indicated that it had "0 incorrect excludes", it was used based on 80% training set and 20% testing. The AI reviewer excluded studies it considered irrelevant and then a human reviewer evaluated the remaining studies.

RESULTS

Question 1: Infection in domestic animals

The database search was conducted on 26th March 2020; 2392 studies were found in the search and 5 ProMED-mail reports. The AI reviewer was used when, at Level 1, 500 studies had been reviewed, and it excluded 1241 citations and left 651 citations for a human reviewer to assess.

Three published studies (Table 3) evaluating infection of cats or dogs with human-associated coronaviruses were found. All three evaluated SARS. One study reported that 2 cats housed with 6 SARS-infected cats had detectable viral titers within 2 days and seroconverted to the virus within 28 days (Martina et al., 2003). There was no report of whether there was viral shedding in

the two cats co-housed with the infected cats. The 6 inoculated cats did shed virus based on pharyngeal swabs. These 6 cats were inoculated intratracheally with 10^6 median tissue-culture infectious dose units (TCID₅₀), which were obtained from a patient who died from SARS and then passaged four times on Vero 118 cells *in vitro*.

SARS was detected in a longitudinal observational study at an animal market in China which included sampling domestic cats (Wang et al., 2005). Four of 36 cats tested were positive; all positives were very early in the study period. The third study on cats was not relevant, as it did not assess natural routes of infection but rather described a SARS challenge model (van den Brand, Haagmans, van Riel, Osterhaus, & Kuiken, 2014).

In contrast, there are several studies of infection with Ebola in dogs which indicated that the search strategy was able to identify such studies for human corona virus if they were in the literature.

In ProMed-mail, the Hong Kong Government officials reported that two dogs living with COVID-19 infected owners tested PCR positive to SARS-CoV-2 (ProMed-mail, 2020a, 2020b, 2020c, 2020d, 2020e, 2020f). Neither dog showed clinical signs. One dog, identified as a 17-year-old Pomeranian, was weakly positive on PCR, virus isolation negative and serology positive. The second dog had nasal and rectal swabs collected, and was PCR positive. No information is available about virus isolation or serology for the second dog. As of 25th Mar 2020, the Agriculture, Fisheries and Conservation Department (AFCD), Hong Kong Special Administrative Region Government, Hong Kong, Hong Kong (SAR-PRC) has conducted tests on 17 dogs and 8 cats from households with confirmed COVID-19 cases or persons in close contact with confirmed patients, and only 2 dogs have tested positive (discussed above) for the SARS-CoV-2 virus. On the 27th March, a cat living with a SARS-CoV-2 infected owners in

Belgium, was been reported as SARS-CoV-2 positive (ProMed-mail, 2020g). No information about testing, samples, virus isolation are currently available from the Belgium's Federal Agency for the Safety of the Food Chain.

Animals as fomites

The search for literature about domestic animals as fomites found 863 citations. AI was utilized after the human reviewers screened 500 citations. The AI reviewer excluded all but 98 citations, which then were evaluated by a human; none were relevant. In total, 0 relevant studies were identified. No studies were found that evaluated fur, hair, skin, or hides as a source of transmission from domestic animals for SARS-CoV-2, MERS-CoV or SARS-CoV. It is interesting that we did not identify any studies describing camels as fomites for MERS as the relationship between camels and MERS is well investigated.

CONFLICT OF INTEREST

AOC, JS and ST have no conflicts of interest to declare.

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Table 1: Search strategy details used for the rapid review in Michigan State University Web of Science™

Question 1	#3 AND #2 AND #1	2,392
	#3: TS=(serology OR serum OR antibodies OR titre OR ELISA OR PCR OR detection OR serological OR sample OR sampling OR "virus isolation" OR assay)	16,183,945
	#2: TS = (dog OR canine OR cat OR feline OR cattle OR bovine OR pig OR swine OR hog OR porcine OR sheep OR ovine OR goat OR caprine OR hen OR poultry OR horse OR equine)	4,795,754
	#1: TS=(COVID OR SARS-CoV-2 OR COVID OR COVID-19 OR 2019-nCoV OR "novel coronavirus" OR "2019-novel coronavirus" OR "Middle east respiratory syndrome" OR MERS OR MERS-CoV OR SARS OR SARS-CoV OR "sudden acute respiratory syndrome" or EBOLA OR EVD)	96,957
Question 2	#4 AND #3 AND #2 AND #1	863
	#4 TS = (dog OR canine OR cat OR feline OR cattle OR bovine OR pig OR swine OR hog OR porcine OR sheep OR ovine OR goat OR caprine OR hen OR poultry OR horse OR equine OR animal OR camel)	28,439,869
	#3 TS=(transmission OR zoonotic OR exposure OR infection OR contamination OR transfer)	16,044,140
	#2 TS=(skin OR fur OR hair OR fomite OR "direct contact" OR petting OR Patting OR brushing OR saliva OR hide OR leather OR grooming OR fomites OR feather OR feathers)	3,977,025
	#1 TS=(COVID OR SARS-CoV-2 OR COVID OR COVID-19 OR 2019-nCoV OR "novel coronavirus" OR "2019-novel coronavirus" OR "Middle east respiratory syndrome" OR MERS OR MERS-CoV OR SARS OR SARS-CoV OR "sudden acute respiratory syndrome" or EBOLA OR EVD)	96,957

Table 2: Citations Databases in the Michigan State University Library Collection in the Web of Science™ interface

Web of Science Core Collection (1900-present)
Science Citation Index Expanded (1900-present)
Social Sciences Citation Index (1900-present)
Arts & Humanities Citation Index (1975-present)
Conference Proceedings Citation Index- Science (1990-present)
Conference Proceedings Citation Index- Social Science & Humanities (1990-present)
Book Citation Index– Science (2005-present)
Book Citation Index– Social Sciences & Humanities (2005-present)
Emerging Sources Citation Index (2005-present)
Current Chemical Reactions (1985-present)
(Includes Institut National de la Propriete Industrielle structure data back to 1840)
Index Chemicus (1993-present)
Biological Abstracts (1926-present)
BIOSIS Citation Index (1926-present)
CABI: CAB Abstracts® (1910-present)
Current Contents Connect (1998-present)
Data Citation Index (1900-present)
Derwent Innovations Index (1963-present)
FSTA® - the food science resource (1969-present)
KCI-Korean Journal Database (1980-present)
MEDLINE® (1950-present)
Russian Science Citation Index (2005-present)

SciELO Citation Index (2002-present)

Zoological Record (1864-present)

Table 3: Studies investigating infection of domestic cats with SARS virus

Manuscript	Summary of finding
Martina et al. (2003)	Experimental infection study: Full text Non-inoculated cats and ferrets housed with cats and ferrets inoculated with SARS became infected with SCV: viral titres gradually increased from 2 days post inoculation onwards, peaking at days 6–8 post inoculation. Neither of the cats showed clinical signs of infection, but both had seroconverted by day 28 (virus-neutralizing antibody titres of 40 and 160, respectively).
Wang et al. (2005)	Observational study: Abstract only This study looked at naturally infected cats at multiple times points. Jan 2004: 4 of 20 sampled cats were infected with SARS-CoV like virus by RT-PCR methods Jan 20 204: 0 of 13 cats were infected April, May, June, July, Aug., Nov, Dec: 0 of 3 cats and 0 of 5 dogs were infected.
Van den Brand et al. (2008)	Not relevant. Cats were evaluated for pathology of SARS, but the route of infection was not aerosol.