Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Clinical Microbiology and Infection 26 (2020) 1709–1710

Contents lists available at ScienceDirect

Clinical Microbiology and Infection

journal homepage: www.clinicalmicrobiologyandinfection.com

Letter to the Editor

Body temperature and host species preferences of SARS-CoV-2

Chika Edward Uzoigwe*

Trauma and Orthopaedics, Harcourt House, Sheffield, UK

ARTICLE INFO

Article history:
Received 27 May 2020
Received in revised form
8 July 2020
Accepted 12 July 2020
Available online 17 July 2020

Editor: S.J. Cutler

To the Editor,

There is currently uncertainty regarding the zoonotic repertoire of SARS-CoV-2. Shi et al. observed that cats were susceptible. Dogs and ferrets show intermediate vulnerability. The pathogen failed to infect or replicate in pigs, chickens and ducks [1]. Their data strongly suggest that the pathogen's species predilection may be related to body temperature. The preferred hosts, human and cats, exhibit mean body temperatures below that of more resistant hosts such as pigs, chicken and ducks (Table 1), whose corporal temperatures can range between 39°C and 42°C (Table 1).

A similar pattern has been observed with the suspected hosts, South East Asian bats, the Chinese pangolin and masked palm civets (*Paguma larvata*); all modest corporal temperature heterotherms and homeotherms (Table 1). Bats do show considerable diurnal and seasonal variation in body temperature, notably with precipitous drops during periods of torpor and hibernation. This may render them an idoneous host to act as a viral reservoir.

In addition, Shi et al. reported that SARS-CoV-2 infectious virions were only isolated in upper airways but not in other viscera following inoculation [1]. Further the virus was only able to replicate in the upper respiratory tract [1]. This is notwithstanding the fact the docking ACE2 enzyme receptor is located throughout the airways and lungs of ferrets. Indeed *ex vivo* SARS-CoV-2 did bind to ferret bronchiolar cells [1]. It is noteworthy that the ferret holds a somewhat intermediate core temperature, higher than that of favoured hosts, humans and cats, but less than that of pigs and ducks (Table 1). Clearly the upper airways are at a lower temperature than core temperature, potentially explaining the predisposition of SARS-CoV-2 for the upper respiratory tract.

The European mink has also been found to be vulnerable to SARS-CoV-2, with significant animal attrition observed in two mink farms in The Netherlands due to the virus [2]. Tellingly, the European mink has recorded corporal temperatures of between 36.2°C and 38.4°C (Table 1).

In further support of this SARS-CoV-2 temperature phenomenon, the virus has been shown to be exquisitely temperature labile, more so than ancestral SARS-CoV-1. Ou et al. demonstrated the S surface protein of SARS-CoV-2, responsible for binding to ACE2, to be particularly temperature sensitive, with activity dropping precipitously as temperatures rise above 37.5°C [3].

Interestingly Wan et al. found pig, ferret and cat ACE2 to be identical or very similar to human ACE2 at “critical virus binding residues” [4]. However Shi et al. showed only the cat to be an

Table 1
Rectal/core temperatures (in degrees Celsius) of animals/species and their proclivity to SARS-CoV-2 Infection

Animal	Mean temperature	Source
Suspected hosts		
Chinese pangolin	33.4–35.5	Heath 1986 [8]
South East Asian bats	37.1	Hu 2011 [9]
Golden hamster	36.1	Eberli 2011 [10], Sia 2020 [11]
Permissive hosts		
Masked palm civets (*Paguma larvata*)	36.9	Wu 2005 [12]
Humans	37	
Cats	37.8	Levy 2015 [13]
European mink	36.2–38.4	Youngman 1990 [14]
Intermediate host		
Ferret	38.2–38.8	Maxwell 2016 [15]
Beagle dogs	39.1	Refinetti 2003 [16]
Resistant host		
Large white pigs	39.3–39.8	Reneaudeau 2007 [17] Reneaudeau 2010 [18] Heldmaier 1974 [19]
Ducks	40.0–41.2	Smith 1976 [20] Artoni 1989 [21] Marais 2011 [22]
White leghorn chickens	41.6–41.9	Hu 2019 [23,24]

* **Corresponding author**. Trauma and Orthopaedics, Harcourt House, Sheffield, UK.
E-mail address: chika@doctors.org.uk.

https://doi.org/10.1016/j.cmi.2020.07.017

unequivocal host [1]. Pig ACE2 shows greater homology to human ACE2 than either that of cats and ferrets but only the last two were shown to be hosts [1,4]. Further, cat and ferret ACE are identical at critical viral-binding residues and yet the cat is a permissive host and the ferret only partially vulnerable. Hence species affinity of SARS-CoV-2 cannot be explained exclusively by ACE2 morphology.

The temperature lability of SARS-CoV-2 may be germane to immune evasion. Ou et al. showed that the S protein of both SARS-CoV 1 and 2 was deactivated even at temperatures of 37°C [3]. The S protein of SARS-CoV-2 was much more susceptible to this deactivation than that of SARS-CoV-1. The fleeting existence of the protein in the blood at these temperatures, prior to denaturation, may prevent the host from mounting a comprehensive immune response. Alternatively, seroconversion may occur to an S protein altered by thermo-degradation and thereby a quasi-decoy antigen. A recent statement from the World Health Organization suggests that infection does not necessarily confer immunity even with the detection of antibodies (https://www.who.int/news-room/commentaries/detail/immunity-passports-in-the-context-of-covid-19) [6]. Questions remain regarding immunity following infection [5]. Further preliminary evidence from the US Centre for Disease Control and Prevention shows that those infected mount a much more consistent IgA than IgG response; indicative of epithelial surface-centred rather than serum-centred immunity (https://wwwnc.cdc.gov/eid/article/26/7/20-0841_article) [7]. Evidence points to a nascent but rather inchoate immune response to SARS-CoV-2, potentially truncated by temperature vulnerability of the spike protein.

In summary, temperature lability of SARS-CoV-2 S-protein may limit its host repertoire but equally may truncate pathogen exposure to host immunity, curtailing the amplificative catenation of cellular and molecular events involved in primary immunity.

References

[1] Shi J, Wen Z, Zhong G, Yang H, Wang C, Huang B, et al. Susceptibility of ferrets, cats, dogs, and other domesticated animals to SARS-coronavirus 2. Science 2020;368:1016.

[2] Oreshkova N, Molenaar RJ, Vreman S, Harders F, Oude Munnink BB, Hakze-van der Honing RW, et al. SARS-CoV-2 infection in farmed minks, The Netherlands, April and May 2020. Euro Surveill 2020;25(23).

[3] Ou X, Liu Y, Lei X, Li P, Mi D, Ren L, et al. Characterization of spike glycoprotein of SARS-CoV-2 on virus entry and its immune cross-reactivity with SARS-CoV. Nat Commun 2020;11:1620.

[4] Wan Y, Shang J, Graham R, Baric RS, Li F. Receptor Recognition by the Novel Coronavirus from Wuhan: an analysis based on decade-long structural studies of SARS coronavirus. J Virol 2020;94:e00127. 20.

[5] Kirkcaldy RD, King BA, Brooks JT. COVID-19 and Postinfection immunity: limited evidence, many remaining questions. JAMA 2020 May 11.

[6] "Immunity passports" in the context of COVID-19. https://www.who.int/news-room/commentaries/detail/immunity-passports-in-the-context-of-covid-19. [Last accessed 23 July 2020]. WHO Scientific Brief 24/04/2020.

[7] Okba NMA, Müller MA, Li W, Wang C, GeurtsvanKessel CH, Corman VM, et al. Severe Acute Respiratory Syndrome Coronavirus 2-Specific Antibody Responses in Coronavirus Disease Patients. Emerg Infect Dis 2020;26(7):1478–88. https://doi.org/10.3201/eid2607.200841.

[8] Heath ME, Hammel HT. Body temperature and rate of O2 consumption in Chinese pangolins. Am J Physiol 1986;250:R377–82.

[9] Hu K, Meng Y, Lei H, Zhang S. Differential changes of regional cerebral blood flow in two bat species during induced hypothermia measured by perfusion-weighted magnetic resonance imaging. J Comp Physiol B 2011;181:117–23.

[10] Eberli P, Gebhardt-Henrich SG, Steiger A. The influence of handling and exposure to a ferret on body temperature and running wheel activity of golden hamsters (Mesocricetus auratus). App Animal Behav Sci App Animal Behav Sci 2011;131:131–7.

[11] Sia SF, Yan LM, Chin AWH, Fung K, Choy KT, Wong AYL, et al. Pathogenesis and transmission of SARS-CoV-2 in golden hamsters. Nature 2020 May 14. https://doi.org/10.1038/s41586-020-2342-5.

[12] Wu D, Tu C, Xin C, Xuan H, Meng Q, Liu Y, et al. Civets are equally susceptible to experimental infection by two different severe acute respiratory syndrome coronavirus isolates. J Virol 2005;79:2620–5.

[13] Levy JK, Nutt KR, Tucker SJ. Reference interval for rectal temperature in healthy confined adult cats. J Feline Med Surg 2015;17:950–2.

[14] Youngman PM. Mustela Lutreola. Mammalian Species 1990;362:1–3. JSTOR, www.jstor.org/stable/3504269.

[15] Maxwell BM, Brunell MK, Olsen CH. Bentzel DE.Comparison of Digital Rectal and Microchip Transponder Thermometry in Ferrets (Mustela putorius furo). J Am Assoc Lab Anim Sci. 2016;55:331–5.

[16] Refinetti R, Piccione G. Daily rhythmicity of body temperature in the dog. J Vet Med Sci. 2003;65:935–7.

[17] Renaudeau D, Huc E, Noblet J. Acclimation to high ambient temperature in Large White and Caribbean Creole growing pigs. J Anim Sci. 2007;85:779–90.

[18] Renaudeau D, Anais C, Tel L, Gourdine JL. Effect of temperature on thermal acclimation in growing pigs estimated using a nonlinear function. J Anim Sci. 2010;88(11):3715–24.

[19] Heldmaier G. Cold adaptation by short daily cold exposures in the young pig. J Appl Physiol 1974;36:163–8.

[20] Smith EN, Peterson C, Thigpen K. Body temperature, heart rate and respiration rate of an unrestrained domestic mallard duck, Anas platyrhynchos domesticus. Comp Biochem Physiol A Comp Physiol 1976;54:19–20.

[21] Artoni SM, Zuim SM, Macari M. Effects of antithyroid drug on the rectal temperature and metabolic parameters of ducks (Cairina moschata). Poult Sci. 1989;68:1381–4.

[22] Marais M, Gugushe N, Maloney SK, Gray DA. Body temperature responses of Pekin ducks (Anas platyrhynchos domesticus) exposed to different pathogens. Poult Sci. 2011;90:1234–8.

[23] Hu JY, Hester PY, Makagon MM, Xiong Y, Gates RS, Cheng HW. Effect of cooled perches on physiological parameters of caged White Leghorn hens exposed to cyclic heat. Poult Sci. 2019;98:2317–25.

[24] Hu JY, Hester PY, Xiong Y, Gates RS, Makagon MM, Cheng HW. Effect of cooled perches on the efficacy of an induced molt in White Leghorn laying hens previously exposed to heat stress. Poult Sci. 2019;98:4290–300.