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.

Journal of Hospital Infection 105 (2020) 348–349

Available online at www.sciencedirect.com

Journal of Hospital Infection

journal homepage: www.elsevier.com/locate/jhin

Letter to the Editor

Inactivation of coronaviruses by heat

Sir

The global spread of COVID-19 has resulted in a huge demand for personal protective equipment including face masks [1]. Even some hospitals face a substantial shortage of suitable face masks (e.g. FFP masks or N95 masks) resulting in an evaluation of various procedures to reprocess them for a limited re-use. Although they are classified as single use products the question was raised if a thermal disinfection may be effective to reduce coronaviruses. That is why published data were reviewed to find out which temperature and exposure time is necessary for inactivation of coronaviruses.

A Medline search has been done on 20th March 2020. The following terms were used, always in combination with "coronavirus": heat inactivation (17 hits), heat disinfection (5 hits), heat inactivate (5 hits), heat kill (1 hit), thermal inactivation (6 hits), thermal disinfection (2 hits), thermal inactivate (3 hits) and thermal kill (0 hits). Publications were included and results were extracted given they provided original data on human (Severe Acute Respiratory Syndrome [SARS] coronavirus and Middle East Respiratory Syndrome [MERS] coronavirus) or zoonotic coronaviruses (Transmissible Gastroenteritis Virus [TGEV], Mouse Hepatitis Virus [MHV] and Porcine Epidemic Diarrhoea Virus [PEDV]) and their inactivation by various temperatures used for thermal disinfection. Reviews were not included but screened for any information within the scope of this review.

A total of 10 studies with original data were found. Overall a thermal disinfection at 60°C for 30 min, 65°C for 15 min and 80°C for 1 min was effective to strongly reduce coronavirus infectivity by at least 4 $\log_{10}$ (Table 1).

The effect of heat is explained by thermal aggregation of the SARS-CoV membrane protein [2]. It was shown that the nucleocapsid protein of SARS-CoV is completely denatured in 10 min at 55°C [3]. Health care providers may now have an idea what parameter for thermal disinfection may be effective in case of a lack of supply of appropriate face masks. One limitation is that all data described here were obtained with coronaviruses in suspension. That is why it may be possible that the results on dry surfaces may be different but this appears to be unlikely. Our data do not allow to evaluate if the function of a face mask remains unchanged after heat treatment. If thermal disinfection is used for the re-use of masks all institutions should evaluate the effect on their own masks in use, as different brands of masks and different specifications (e.g. with or without cellulose) will react individually towards a combination of time and heat. Easy tests to do are "fitting" and "water-resistance". In addition, the numbers of re-uses should be traced (mark at the side of mask per cycle) and its effects examined.

Conflict of interest statement
None declared.

References

[1] Mahase E. Novel coronavirus: Australian GPs raise concerns about shortage of face masks. BMJ (Clinical Research Ed) 2020;368:m477.
[2] Lee YN, Chen LK, Ma HC, Yang HH, Li HP, Lo SY. Thermal aggregation of SARS-CoV membrane protein. Journal of Virological Methods 2005;129:152–61.
[3] Wang Y, Wu X, Wang Y, Li B, Zhou H, Yuan G, et al. Low stability of nucleocapsid protein in SARS virus. Biochemistry 2004;43:11103–8.
[4] Rabenau HF, Cinatl J, Morgenstern B, Bauer G, Preiser W, Doerr HW. Stability and inactivation of SARS coronavirus. Med Microbiol Immunol 2005;194:1–6.
[5] Quist-Rybachuk GV, Nauwynck HJ, Kalmar ID. Sensitivity of porcine epidemic diarrhea virus (PEDV) to pH and heat treatment in the presence or absence of porcine plasma. Vet Microbiol 2015;181:283–8.
[6] Leclercq I, Batejat C, Burguiere AM, Manuguerra JC. Heat inactivation of the Middle East respiratory syndrome coronavirus. Influenza and Other Respiratory Viruses 2014;8:585–6.
[7] Laude H. Thermal inactivation studies of a coronavirus, transmissible gastroenteritis virus. The Journal of General Virology 1981;56:235–40.
[8] Saknimit M, Inatsuki I, Sugiyama Y, Yagami K. Virucidal efficacy of physico-chemical treatments against coronaviruses and parvoviruses of laboratory animals. Jikken Dobutsu Experimental Animals 1988;37:341–5.
[9] Hulst MM, Heres L, Hakze-van der Honing RW, Pelser M, Fox M, van der Poel WHM. Study on inactivation of porcine epidemic diarrhoea virus, porcine sapelovirus 1 and adenovirus in the production and storage of laboratory spray-dried porcine plasma. J Appl Microbiol 2019;126:1931–43.
[10] Kariwa H, Fujii N, Takashima I. Inactivation of SARS coronavirus by means of povidone-iodine, physical conditions, and chemical reagents. The Japanese Journal of Veterinary Research 2004;52:105–12.
[11] Darnell ME, Taylor DR. Evaluation of inactivation methods for severe acute respiratory syndrome coronavirus in noncellular blood products. Transfusion 2006;46:1770–7.
[12] Yunoki M, Urayama T, Yamamoto I, Abe S, Ikuta K. Heat sensitivity of a SARS-associated coronavirus introduced into plasma products. Vox Sanguinis 2004;87:302–3.
[13] Lelie PN, Reesink HW, Lucas CJ. Inactivation of 12 viruses by heating steps applied during manufacture of a hepatitis B vaccine. Journal of Medical Virology 1987;23:297–301.

https://doi.org/10.1016/j.jhin.2020.03.025

Table I
Heat inactivation of coronaviruses in test tube suspensions

Temperature	Virus	Strain/isolate	Exposure time	Reduction of viral infectivity (log_{10})	Reference
4°C	SARS-CoV	Strain FFM-1	30 min	0.0	[4]
4°C	PEDV	Strain CV777	2 h	0.0	[5]
25°C	MERS-CoV	Strain Hu/France–FRA2_130569/2013 (FRA2)	2 h	0.0	[6]
31°C	TGEV	Strain D_{52}	80 min	0.7	[7]
35°C	TGEV	Strain D_{52}	80 min	1.2	[7]
39°C	TGEV	Strain D_{52}	80 min	3.0	[7]
40°C	MHV	Strains MHV-2 and MHV-N	30 min	0.3	[8]
40°C	PEDV	Strain CV777	2 h	1.0	[5]
			75 min#	4.7	
43°C	TGEV	Strain D_{52}	50 min	3.8	[7]
44°C	PEDV	Strain CV777	2 h	1.5	[5]
			45 min#	4.7	
44°C	PEDV	Strain CV777	10 min	0.3	[9]
47°C	TGEV	Strain D_{52}	20 min	4.2	[7]
48°C	PEDV	Strain CV777	2 h	4.7	[5]
			15 min#	4.7	
48°C	PEDV	Strain CV777	10 min	1.0–1.7	[9]
51°C	TGEV	Strain D_{52}	5 min	4.4	[7]
55°C	TGEV	Strain D_{52}	2 min	4.6	[7]
56°C	MERS-CoV	Strain Hu/France–FRA2_130569/2013 (FRA2)	30 s	0.1–0.9	[6]
			15 min	$\geq$ 4.6	
			30 min	$\geq$ 4.3	
56°C	SARS-CoV	Strain Hanoi	5 min	5.8	[10]
			10 min	6.4	
			30 min	> 6.4	
56°C	SARS-CoV	Strain FFM-1	30 min	1.9–5.0	[4]
56°C	SARS-CoV	Strain Urbani	20 min	$\geq$ 4.3	[11]
60°C	MHV	Strains MHV-2 and MHV-N	1 min	2.6–2.9	[8]
			5 min	3.6–3.9	
			15 min	> 3.9	
			30 min	> 3.9	
60°C	SARS-CoV	Strain FFM-1	30 min	$\geq$ 5.0	[4]
60°C	SARS-CoV	Strain FFM-1	30 min	$\geq$ 4.0*	[12]
			60 min	$\geq$ 4.0	
65°C	SARS-CoV	Strain Urbani	15 min	$\geq$ 4.3**	[11]
65°C	MERS-CoV	Strain Hu/France–FRA2_130569/2013 (FRA2)	30 s	0.9–3.6	[6]
			15 min	$\geq$ 4.9	
			30 min	$\geq$ 4.9	
65°C	SARS-CoV	Strain Urbani	10 min	$\geq$ 4.3	[11]
65°C	MHV	Not described	15 min	$\geq$ 6.0	[13]
80°C	MHV	Strains MHV-2 and MHV-N	1 min	> 3.9	[8]

* Not with anti-thrombin III as organic load;
** One outlier at 25 min with 3.6 log_{10} explained by the authors with an experimental error;
\# In porcine plasma.

G. Kampf[a,*]
A. Voss[b]
S. Scheithauer[c]
[a]*University Medicine Greifswald, Institute for Hygiene and Environmental Medicine, Ferdinand-Sauerbruch-Strasse, 17475, Greifswald, Germany*
[b]*Radboudumc and Canisius-Wilhelmina Hospital, Department of Medical Microbiology and Infectious Diseases, Nijmegen, The Netherlands*
[c]*Institute of Infection Control and Infectious Diseases, University Medical Center, Georg August University, Göttingen, Germany*

* Corresponding author. University Medicine Greifswald, Institute for Hygiene and Environmental Medicine, Ferdinand-Sauerbruch-Strasse, 17475 Greifswald, Germany:
E-mail address: guenter.kampf@uni-greifswald.de (G. Kampf)

Available online 31 March 2020