Transfusion Medicine Reviews xxx (xxxx) xxx

Contents lists available at ScienceDirect

Transfusion Medicine Reviews

journal homepage: https://www.journals.elsevier.com/transfusion-medicine-reviews/

Coronavirus Disease 2019: Coronaviruses and Blood Safety

Le Chang [a,b], Ying Yan [a,b], Lunan Wang [a,b,c,*]

[a] National Center for Clinical Laboratories, Beijing Hospital, National Center of Gerontology; Institute of Geriatric Medicine, Chinese Academy of Medical Sciences, Beijing, PR China
[b] Beijing Engineering Research Center of Laboratory Medicine, Beijing Hospital, PR China
[c] Graduate School, Peking Union Medical College, Chinese Academy of Medical Sciences, Beijing, PR China

ARTICLE INFO

Available online xxxx

Keywords:
Coronavirus
Blood safety
SARS
MERS
2019-nCoV
COVID-19
SARS-CoV-2
Pathogen inactivation technology

ABSTRACT

With the outbreak of unknown pneumonia in Wuhan, China, in December 2019, a new coronavirus, *Severe Acute Respiratory Syndrome Coronavirus 2* (SARS-CoV-2), aroused the attention of the entire world. The current outbreak of infections with SARS-CoV-2 is termed *Coronavirus Disease 2019* (COVID-19). The World Health Organization declared COVID-19 in China as a Public Health Emergency of International Concern. Two other coronavirus infections—SARS in 2002-2003 and Middle East Respiratory Syndrome (MERS) in 2012—both caused severe respiratory syndrome in humans. All 3 of these emerging infectious diseases leading to a global spread are caused by β-coronaviruses. Although coronaviruses usually infect the upper or lower respiratory tract, viral shedding in plasma or serum is common. Therefore, there is still a theoretical risk of transmission of coronaviruses through the transfusion of labile blood products. Because more and more asymptomatic infections are being found among COVID-19 cases, considerations of blood safety and coronaviruses have arisen especially in endemic areas. In this review, we detail current evidence and understanding of the transmission of SARS-CoV, MERS–CoV, and SARS-CoV-2 through blood products as of February 10, 2020, and also discuss pathogen inactivation methods on coronaviruses.

Contents

Since a cluster of unknown pneumonia patients was found in December 2019 in Wuhan, China, a new coronavirus (CoV), which was temporarily named *2019 novel coronavirus* (2019-nCoV) by the World Health Organization (WHO) on January 7, 2020, suddenly came into our sight [1]. The virus was subsequently renamed *Severe Acute Respiratory Syndrome Coronavirus 2* (SARS-CoV-2), and the disease it causes was named *Coronavirus Disease 2019* (COVID-19). As of February 10, 2020, there have been more than 43,000 patients confirmed positive by nucleic acid testing in China and 23 other countries, and it has caused 1017 deaths due to acute respiratory failure or other related complications. In addition, more than 21,000 suspected infected people were isolated and are waiting to be tested. On January 31, WHO announced the outbreak of COVID-19 in China as a Public Health Emergency of International Concern.

In 2002-2003, more than 8000 patients suffered from Severe Acute Respiratory Syndrome (SARS) due to a coronavirus, with 774 virus-related deaths reported to WHO. Since September 2012, there were 2494 laboratory-confirmed cases of infection with Middle East Respiratory Syndrome Coronavirus (MERS-CoV), with 858 virus-related deaths reported to WHO [2,3]. All 3 of these emerging infectious diseases leading to a global spread are caused by β-coronaviruses.

* Corresponding author at: Lunan Wang, No. 1 Dahua Rd, Beijing 100730, PR China.
E-mail address: lunan99@163.com (L. Wang).

https://doi.org/10.1016/j.tmrv.2020.02.003
0887-7963/

Please cite this article as: L. Chang, Y. Yan and L. Wang, Coronavirus Disease 2019: Coronaviruses and Blood Safety, Transfusion Medicine Reviews, https://doi.org/10.1016/j.tmrv.2020.02.003

In China, prior outbreaks of emerging infections have had an unfavorable impact on the blood supply. [4]. However, consideration must also be given to the safety of the transfusion recipient even if the emerging infection is a respiratory disease. Previous studies indicated that viral RNA could be detected from plasma or serum of patients infected with SARS-CoV [5-8], MERS-CoV [9], or SARS-CoV-2 [1] during different periods after the onset of symptoms. However, the detection of viral RNA by polymerase chain reaction (PCR) is not equivalent to the detection of intact infectious virus. Although WHO noted in 2003 that no cases of SARS-CoV have been reported due to transfusion of blood products, there was still a theoretical risk of transmission of SARS-CoV through transfusion [10]. With more and more asymptomatic infections being found among COVID-19 cases, blood safety is worthy of consideration. In this review, we detail current evidence and understanding of the transmission of SARS-CoV, MERS-CoV, and SARS-CoV-2 via transfusion as of February 10, 2020, and discuss pathogen inactivation methods on coronaviruses.

1. Diversity of Coronaviruses

As the largest known RNA viruses, CoVs are further divided into four genera: α-CoVs, β-CoVs, γ-CoVs, and δ-CoVs [11], among which α- and β-CoVs are able to infect mammals, whereas the other two genera can infect birds and could also infect mammals [12]. So far, seven coronaviruses have been found to infect humans and cause respiratory diseases. Four of seven are common human CoVs (HCoVs) usually leading to common self-limited upper respiratory disease: HCoV-229E, HCoV-OC43, HCoV-NL63, and HCoV-HKU1. These viruses can occasionally cause more serious disease in young, elderly, or immunocompromised individuals.

The first two HCoVs, HCoV-229E and HCoV-OC43, have been known since the 1960s. With the emergence of SARS in 2002, a novel β-coronavirus came to attention; and subsequently, HCoV-NL63 and HCoV-HKU1 were identified in 2004 and 2005, respectively [13]. MERS-CoV, which was isolated in 2012, is similar to SARS-CoV—both can infect the lower respiratory tract and usually cause a severe respiratory syndrome in humans [14] with a case fatality rate of 35.5% and 10%, respectively [15]. SARS-CoV-2 was recently isolated from human airway epithelial cells, characterized by next-generation sequencing in January 2020, and identified to be a new member of β-CoVs [16]. SARS-CoV-2 can also infect the lower respiratory tract, but the clinical symptoms are milder than SARS and MERS according to current limited evidence and reports [1].

2. SARS-CoV

Atypical pneumonia putatively caused by SARS-CoV was first identified following an outbreak in Guangdong Province, China, in November 2002. The infection quickly spread to Beijing, Hong Kong, Vietnam, Singapore, and Canada in March 2003. This disease proved to be highly infectious with respiratory droplets as the main route of transmission. Infected feces also played an important role in some cluster outbreak cases [17,18]. Fortunately, it has been proved that SARS patients are not infectious during the period of incubation (within 16 days of infection, usually 3-5 days).

Many studies found that SARS-CoV RNA could be detected in the plasma of SARS patients even though it is a respiratory disease. The first report published on April 10, 2003 [5], indicated that extremely low concentrations of viral RNA existed in plasma of a SARS patient during the acute phase of illness, at 9 days after the onset of symptoms. The viral content of plasma was low. Researchers could only detect SARS-CoV RNA using a nested PCR assay established in-house, and the viral load was 190 copies/mL performed after ultracentrifugation of 2 mL of plasma. They could not detect viral RNA in the plasma collected from two close contacts, although the sputum of one was positive by 3 of 4 different PCR assays and the viral load in sputum was as high as 6.3×10^4 copies/mL. Based on this study and other information, WHO [10] and the US Food and Drug Administration (FDA) [19] drafted recommendations on blood safety and pointed out a theoretical risk of transmission of the SARS virus through transfusion of blood products. They also recommended some precautionary principles regarding the deferral of blood donation by individuals from areas with recent local transmission. In addition, blood donors should report to collection agencies if they were diagnosed as suspected or confirmed SARS patients within 1 month following their donation; and in such instances, efforts would be made to trace recipients or recall any blood products not transfused. Later, two studies focused on new PCR methods for detection of SARS-CoV RNA. One study was based on serial analysis of plasma viral RNA concentrations in adult SARS patients by quantitative reverse-transcription PCR with a limit of detection of 74 copies/mL. The study found that, on the first day of fever onset, 50% (6/12) of confirmed patients had detectable viral RNA in plasma and that, by day 14, the proportion fell to 25% (3/12). Overall, 78% of patients had detectable viral RNA in the first week of their illness [7]. Similar to the first study, the average viral concentration was low at 140 copies/mL in patients who had relatively mild symptoms and did not require intensive care unit admission in hospital. In pediatric patients, 87.5% (7/8) of children had viremia, and the median concentration of plasma was 357 copies/mL based on the same PCR method used with adult SARS patients above [8]. Finally, Grant et al [6] reported that within 3 days after fever onset, 79% (19/24) of patients had detectable SARS-CoV RNA in plasma. The viral load level rose fast, and the maximal viral load was at around day 4 or day 5 after the onset of fever, after which the viral load quickly decreased. Their findings showed viral shedding in plasma was common when people were clinically ill with SARS virus and that plasma may be a better sample compared with nasal and throat swabs. The detection sensitivity of plasma was equivalent to that of nasopharyngeal aspirates within the first 3 days after the onset of fever.

In addition, researchers found that lymphocytes have a much higher concentration of SARS-CoV RNA than plasma whether tested in the acute phase or convalescent phase [20], although plasma viral RNA from only 5 patients in acute phase and 5 in convalescent phase was detected. It was subsequently shown that SARS-CoV could not only infect lymphocytes but also replicate in them in a self-limited manner [21-23]. These findings provided evidence that lymphocytes might be one of targets for SARS-CoV and indicated the potential for a transmission risk by blood products with high concentrations of donor lymphocytes (peripheral blood stem cells, bone marrow, granulocyte concentrates, etc).

Although these findings provided some evidence that SARS-CoV indeed existed in plasma or lymphocytes of SARS patients, no nation including those with local transmission of SARS and no organizations including WHO [10] and the American Association of Blood Banks (AABB) recommended screening donors for SARS-CoV RNA or related antibodies based on the following facts: (1) SARS patients are not infectious in the period of incubation time and the incubation time is relatively short; (2) almost all SARS-CoV–infected people have severe symptoms, and few asymptomatic carriers were found; (3) data showed that the viral load from plasma of SARS patients was low [17,24,25]; (4) no transfusion transmission cases have been reported so far [10], and studies that screened blood donations for SARS-CoV RNA in 2003 failed to identify any positives [26].

However, an alternative view was expressed in 2004. Researchers in Hong Kong [27] found that tests of the plasma from 3 of 400 healthy blood donors and 1 of 131 nonpneumonic pediatric inpatients collected during the outbreak of SARS tested positive for IgG antibody to SARS-CoV. The results were confirmed by two Western blot assays. The presence of antibody does not imply infectious material. Nevertheless, because Hong Kong was among the worst-hit regions in the world during the 2002-2003 outbreak of SARS, they concluded that, in Hong Kong, subclinical or nonpneumonic SARS-CoV infections existed, indicating a potential transmission risk of SARS virus via blood products. Soon afterward, four different groups raised questions and objections

Please cite this article as: L. Chang, Y. Yan and L. Wang, Coronavirus Disease 2019: Coronaviruses and Blood Safety, Transfusion Medicine Reviews, https://doi.org/10.1016/j.tmrv.2020.02.003

to the Hong Kong study focusing on the specificity of the assays and the representativeness of the population [28-31]. To provide additional information, the theoretical the risk of SARS-CoV transmission through blood transfusion was estimated in Shenzhen, Guangdong Province, in China. The estimate used data from Shenzhen, Hong Kong, and Taiwan in 2003 and calculated that the mean risk was 14.11 (95% confidence interval [CI]: 11.00-17.22) per million and the maximum risk was 23.57 (95% CI: 6.83-47.69) per million on April 2, 2003 [32].

3. MERS-CoV

In 2012, the MERS virus was first identified from a 60-year-old man who had acute pneumonia and renal failure with a fatal outcome in Saudi Arabia [33]. At that time, MERS-CoV was the sixth human coronavirus identified. MERS is a highly lethal respiratory disease and had a higher case fatality rate than SARS [3]. It caused large nosocomial outbreaks in Jeddah, Kingdom of Saudi Arabia, in 2014 and the Republic of Korea in 2015 [34].

In a study on the viral load in different samples among 37 MERS patients, investigators found that nearly half of serum samples tested yielded a viral RNA signal during the first week after diagnosis and that the viral load ranged from about 2.1×10^2 to 2.51×10^5 copies/mL. However, they failed to isolate virus from these sera. Therefore, it is not known whether or not there was live MERS virus in the serum, and the patients' blood may not have been infectious [9]. Although almost all MERS patients have severe clinical symptoms, atypical patients were found during the 2015 outbreak of South Korea. One individual had infection of MERS-CoV confirmed by real-time reverse-transcription PCR, but he had no symptoms in the following 4 days. However, it is worthy of note that each of the individuals tested were immunocompromised inpatients. Therefore, the findings are not directly related to risks among blood donors.

In the document from AABB [35], it was noted that populations such as persons in close contact with a confirmed case, camel workers who were visiting or residing in the Middle East, and health care personnel during a nosocomial outbreak were at increased risk of MERS-CoV infection. Because detection of virus from blood was rare and MERS viral load was low, the FDA recommended some deferral criteria similar to the SARS epidemic: 14 days from last exposure or 14 days after arrival in the United States following travel/residence exposure, or 28 days after complete symptom resolution and cessation of a treatment.

4. SARS-CoV-2

In December 2019, an unknown pneumonia rapidly spread in Wuhan, China, and most initial cases were related to source infection from a seafood wholesale market [36]. Quickly, researchers sequenced and identified a new β-coronavirus, the genome of which has 86.9% identity to a previously published bat SARS-like CoV genome (bat-SL-CoVZC45, MG772933.1) and is distinct from human SARS-CoV and MERS-CoV [16]. Individuals with COVID-19 usually have a fever and lower respiratory tract symptoms, and the estimated incubation time is within 14 days.

Limited data have shown that viral RNA could be detected in plasma or serum from COVID-19 patients. In the first 41 patients in the city of Wuhan, viremia was found in 6/41 (15%) patients. The median PCR cycle threshold value was 35.1 (95% CI: 34.7-35.1), suggesting a very low RNA concentration with no difference found between intensive care unit patients and patients with mild symptoms. Of note, 1 of 41 patients was positive for SARS-CoV-2 RNA but did not have a fever [1]. A family cluster of COVID-19 was reported from Shenzhen, China, and it was found that serum from 1 of 6 patients in one family showed a weak positive result for SARS-CoV-2 RNA and a 10-year-old child was confirmed to be an asymptomatic carrier [37]. With the virus spreading all over the world, reports from Vietnam [38], Germany [39], and the United States [40] have described the clinical symptoms, diagnosis, and treatment of COVID-19. One controversial report suggested transmission by contact with an asymptomatic carrier in Germany [39]: an individual from China attended business meetings in Germany and infected at least 2 business partners during the incubation period. This report suggested that, in contrast to SARS, COVID-19 patients might be infectious during an asymptomatic incubation period. However, in this report, the authors did not directly interview the Chinese traveler who later was found to have been symptomatic at the time of the contact. Moreover, the researchers did not detect viral RNA of samples taken from the index patient during the period of incubation.

In January 2020, the European Center for Disease Prevention and Control (ECDC) [41] and AABB [42] published rapid risk assessments of the outbreak of SARS-CoV-2 and blood safety. ECDC implied a precautionary deferral of donation of blood and cells for 21 days after possible exposure to a confirmed patient or anyone who returned from Wuhan, China—applying the approach used for SARS-CoV and MERS-CoV. In addition, recovering confirmed COVID-19 patients should be deferred for at least 28 days after symptom resolution and completion of therapy [41]. AABB updated their Web site to state that, considering the concern regarding SARS-CoV-2 and blood safety, they would continue to closely monitor the outbreak of respiratory illness. The AABB, FDA, and Centers for Disease Control and Prevention do not currently require any action on blood collection and testing because there are no data suggesting a risk of transfusion transmission of SARS-CoV-2 [42].

As the infection continues to demand urgent attention in China and is being very closely monitored worldwide, the following points may be relevant to considerations regarding transfusion and organ transplantation: (1) viral RNA in plasma or serum could be detected in COVID-19 patients on the first 2 or 3 days after onset of symptoms; (2) most patients, especially younger adults who can donate blood, had milder symptoms than the older adults; (3) patients with no fever and asymptomatic carriers have been identified in China, which increase the possibility that a COVID-19 patient or virus carrier could donate blood; (4) the rate of infectivity of patients who are in the incubation period remains uncertain, and there are no data on the viral load in plasma, serum, or lymphocytes among individuals in the incubation period. Therefore, whether the risk of transfusion transmission of SARS-CoV-2 is higher than other coronaviruses, especially in endemic areas such as Wuhan, China, should be further explored as soon as possible. There still needs to be careful assessment on any measures regarding deferral of donors, screening for SARS-CoV-2 RNA, testing for virus-related antibodies, or use of pathogen-inactivated blood products.

5. Inactivation of Coronavirus in Blood Products

Coronaviruses are enveloped, positive-sense, single-stranded RNA viruses. Usually, coronaviruses are vulnerable to acid-pH, basic-pH, and heat [43] but seem to be more stable at 4°C [44]. The infectious titer of virus did not show any significant reduction after 25 cycles of thawing and freezing [44]. After the outbreak of SARS and MERS, a few studies investigated pathogen inactivation/reduction technologies (PRTs) based on in-house or commercial methods with the aim to decrease or completely eradicate the potential risk of transmission of coronaviruses via blood products or blood derivatives [45-54]. These studies are summarized in Table 1.

Generally, no single PRT is suitable for all blood products because some blood components are damaged by the PRT treatment [55,56]. In-house studies of methods to inactivate coronaviruses in plasma and platelet concentrates focused mainly on heat and solvent/detergent (S/D) treatment. Usually, 60°C for 15-30 minutes is enough for reduction of SARS-CoV from plasma without cells [49], and inactivation could be achieved by 60°C for 10 hours for plasma products [52]. In the other study, heating at 56°C for 25 minutes could reduce more than 4 $\log_{10}$ $TCID_{50}$/mL of MERS virus [53]. Because heating could denature protein in blood products, it could only be used in manufactured plasma-derived products. In addition, SARS-CoV was found to be sensitive to solvent and detergent, such as TNBP/Triton X-100, TNBP/Tween 80, and sodium cholate [49]. After 30-minute treatment using S/D

Please cite this article as: L. Chang, Y. Yan and L. Wang, Coronavirus Disease 2019: Coronaviruses and Blood Safety, Transfusion Medicine Reviews, https://doi.org/10.1016/j.tmrv.2020.02.003

Table 1
Different methods on inactivation of coronavirus in blood products and laboratory tissue culture

Methods	Commercial systems	Mechanism of action [56]	SARS-CoV	MERS-CoV
Heat	N/A	Denaturing the secondary structures of proteins	Products without cells 56°C 20 min in serum 65°C 10 min in serum 60°C 25 min in 25% BSA solution [49] Plasma products 60°C 10 h [52]	DMEM + 5% FBS 56°C 25 min (reduction of 4 $\log_{10}$ $TCID_{50}$/mL) [53]
S/D treatments	Octaplas (Octapharma)	Disruption of lipid membranes	Products without cells 2 h for TNBP/Triton X-100 in PBS or 10% BSA 2 h for TNBP/Tween 80 in PBS or 10% BSA 24 h for sodium cholate in 10% BSA [49] Products without cells 30 min (reduction of >5.75±0.3 $\log_{10}$ $TCID_{50}$/mL) [50]	N/A
Amotosalen + UV-A light	INTERCEPT Blood system for plasma and platelets (Cerus)	Amotosalen (S-59) intercalates into nucleic acid and induces covalent cross-linking upon UV-A exposure	MEM + 10% FBS (reduction of >5.8 $\log_{10}$ PFU/mL) [51]	Platelet concentrate (reduction of 4·48 ± 0.3 $\log_{10}$ PFU/mL) [46] Fresh-frozen plasma (reduction of 4.67 ± 0.25 $\log_{10}$ PFU/mL) [47]
Riboflavin + UV-B light	MIRASOL PRT system for plasma and platelets (Terumo)	Riboflavin associates with nucleic acids and mediates an oxygen-independent electron transfer upon UV exposure	N/A	reduction of >4.07 $\log_{10}$ PFU/mL for pooled plasma reduction of >4.42 $\log_{10}$ PFU/mL for individual donor plasma[54]
UV-C light	THERAFLEX UV-Platelets (Macopharma)	UV-C directly interacts with nucleic acids, causing the formation of nucleotide dimers	Platelet concentrates (reduction of ≥3.4 $\log_{10}$ $TCID_{50}$/mL) [45]	Platelet concentrates (reduction of ≥3.7 $\log_{10}$ $TCID_{50}$/mL) [48]
Methylene blue + Visible light	THERAFEX MB (Macopharma)	MB intercalates into nucleic acid and mediates the formation of singlet oxygen upon illumination	Plasma (reduction of >3.1 $\log_{10}$ $TCID_{50}$/mL [45]	Plasma (reduction of >3.3 $\log_{10}$ $TCID_{50}$/mL) [48]

BSA, bovine serum albumin; DMEM, Dulbecco modified Eagle medium; FBS, fetal bovine serum; MB, methylene blue; N/A, not available; PBS, phosphate-buffered saline; PFU, plaque-forming units; TNBP, tri-*n*-butyl phosphate.

produced by Octaplas (Octapharma), the virus was reduced more than 5.75 ± 0.3 $\log_{10}$ $TCID_{50}$/mL [50].

Illumination with different wavelengths also influenced activities of SARS and MERS virus in blood. Ultraviolet (UV)-A [46,47,51]and UV-B light [54] in the presence of amotosalen or riboflavin could inactivate the pathogens' nucleic acids, whereas a third PRT method uses UV-C light only [45,48]. These commercial systems could reduce the activities of SARS and MERS virus in plasma or platelet concentrates to different degrees. Methylene blue plus visible light also has the ability to inactivate coronaviruses in plasma [45,48]. Cost remains a major administrative obstacle to PRT use [55]. Therefore, whether or not these PRTs should be implemented in response to SARS-CoV-2depends on the severity and prevalence of COVID-19 in different regions and on the actual risk of transfusion transmission of SARS-CoV-2.

6. Conclusions

Although coronaviruses cause primarily mild to severe respiratory infections, the potential for transmission by transfusion is worthy of consideration. In China, most of blood centers or blood banks have taken the following measures during the current outbreak: (1) taking body temperature before blood donation; (2) additional questions in the donor screening questionnaire regarding whether the donor or relatives have related symptoms, have traveled to areas with local transmission of SARS-CoV-2 (Wuhan or Hubei province) within 28 days, or are donors with high risk; (3) calling back all blood donors and asking the donors and their family about their current physical condition after donation; and (4) recalling untransfused blood products from infected donors [57]. However, given the differences between SARS-CoV, MERS-CoV, and SARS-CoV-2, it is not known if the prior recommendations used for SARS and MERS are sufficient. We are facing many unknowns, and careful monitoring and further studies should continue. Stricter measures could be implemented if necessary, such as viral RNA and virus-related antibody screening of blood donations or use of PRT in some regions. As we know, the Wuhan Blood Center and all blood banks in Hubei province have started to test SARS-CoV-2 RNA from blood donations since February 10. Meanwhile, because coronaviruses RNA could be detected in plasma or lymphocytes, staff in blood centers and laboratories should improve biosafety protection during the epidemic. The coming months will provide an enormous amount of new information on SARS-CoV-2 and COVID-19—information which will allow us to make decisions regarding this new virus and public safety.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for profit sectors.

Declarations of interest

None.

References

[1] Huang C, Wang Y, Li X, Ren L, Zhao J, Hu Y, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan. China Lancet 2020. https://doi.org/10.1016/s0140-6736(20)30183-5.

Please cite this article as: L. Chang, Y. Yan and L. Wang, Coronavirus Disease 2019: Coronaviruses and Blood Safety, Transfusion Medicine Reviews, https://doi.org/10.1016/j.tmrv.2020.02.003

[2] World Health Organization. Summary of probable SARS cases with onset of illness from 1 November 2002 to 31 July 2003, https://www.who.int/csr/sars/country/table2004_04_21/en/; 2004 [accessed 2020-2-5].
[3] World Health Organization. Middle East respiratory syndrome coronavirus (MERS-CoV) https://www.who.int/emergencies/mers-cov/en/; 2013 [accessed 2020-2-5].
[4] Shan H, Zhang P. Viral attacks on the blood supply: the impact of severe acute respiratory syndrome in Beijing. Transfusion 2004;44:467–9 http://doi.org/10.1111/j.0041-1132.2004.04401.x.
[5] Drosten C, Gunther S, Preiser W, van der Werf S, Brodt HR, Becker S, et al. Identification of a novel coronavirus in patients with severe acute respiratory syndrome. N Engl J Med 2003;348:1967–76 http://doi.org/10.1056/NEJMoa030747.
[6] Grant PR, Garson JA, Tedder RS, Chan PK, Tam JS, Sung JJ. Detection of SARS coronavirus in plasma by real-time RT-PCR. N Engl J Med 2003;349:2468–9 http://doi.org/10.1056/nejm200312183492522.
[7] Ng EK, Hui DS, Chan KC, Hung EC, Chiu RW, Lee N, et al. Quantitative analysis and prognostic implication of SARS coronavirus RNA in the plasma and serum of patients with severe acute respiratory syndrome. Clin Chem 2003;49:1976–80 http://doi.org/10.1373/clinchem.2003.024125.
[8] Ng EK, Ng PC, Hon KL, Cheng WT, Hung EC, Chan KC, et al. Serial analysis of the plasma concentration of SARS coronavirus RNA in pediatric patients with severe acute respiratory syndrome. Clin Chem 2003;49:2085–8 http://doi.org/10.1373/clinchem.2003.024588.
[9] Corman VM, Albarrak AM, Omrani AS, Albarrak MM, Farah ME, Almasri M, et al. Viral shedding and antibody response in 37 patients with Middle East respiratory syndrome coronavirus infection. Clin Infect Dis 2016;62:477–83 http://doi.org/10.1093/cid/civ951.
[10] World Health Organization. WHO recommendations on SARS and blood safety, https://www.who.int/csr/sars/guidelines/bloodsafety/en/; 2003 [accessed 2020-2-5].
[11] Yin Y, Wunderink RG. MERS, SARS and other coronaviruses as causes of pneumonia. Respirology 2018;23:130–7 http://doi.org/10.1111/resp.13196.
[12] Chen Y, Liu Q, Guo D. Emerging coronaviruses: genome structure, replication, and pathogenesis. J Med Virol 2020. https://doi.org/10.1002/jmv.25681.
[13] Enjuanes L, Zuniga S, Castano-Rodriguez C, Gutierrez-Alvarez J, Canton J, Sola I. Molecular basis of coronavirus virulence and vaccine development. Adv Virus Res 2016;96:245–86 http://doi.org/10.1016/bs.aivir.2016.08.003.
[14] Ding Y, Wang H, Shen H, Li Z, Geng J, Han H, et al. The clinical pathology of severe acute respiratory syndrome (SARS): a report from China. J Pathol 2003;200:282–9 http://doi.org/10.1002/path.1440.
[15] de Wit E, van Doremalen N, Falzarano D, Munster VJ. SARS and MERS: recent insights into emerging coronaviruses. Nat Rev Microbiol 2016;14:523–34 http://doi.org/10.1038/nrmicro.2016.81.
[16] Zhu N, Zhang D, Wang W, Li X, Yang B, Song J, et al. A novel coronavirus from patients with pneumonia in China, 2019. N Engl J Med 2020. https://doi.org/10.1056/NEJMoa2001017.
[17] Cheng PK, Wong DA, Tong LK, Ip SM, Lo AC, Lau CS, et al. Viral shedding patterns of coronavirus in patients with probable severe acute respiratory syndrome. Lancet 2004;363:1699–700 http://doi.org/10.1016/S0140-6736(04)16255-7.
[18] Hui DSC, Zumla A. Severe acute respiratory syndrome: historical, epidemiologic, and clinical features. Infect Dis Clin North Am 2019;33:869–89 http://doi.org/10.1016/j.idc.2019.07.001.
[19] US Food and Drug Administration. Revised recommendations for the assessment of donor suitability and blood product safety in cases of suspected severe acute respiratory syndrome (SARS) or exposure to SARS: guidance for industry, https://www.fda.gov/media/124354/download; 2003.
[20] Wang H, Mao Y, Ju L, Zhang J, Liu Z, Zhou X, et al. Detection and monitoring of SARS coronavirus in the plasma and peripheral blood lymphocytes of patients with severe acute respiratory syndrome. Clin Chem 2004;50:1237–40 http://doi.org/10.1373/clinchem.2004.031237.
[21] Li L, Wo J, Shao J, Zhu H, Wu N, Li M, et al. SARS-coronavirus replicates in mononuclear cells of peripheral blood (PBMCs) from SARS patients. J Clin Virol 2003;28:239–44 http://doi.org/10.1016/s1386-6532(03)00195-1.
[22] Yilla M, Harcourt BH, Hickman CJ, McGrew M, Tamin A, Goldsmith CS, et al. SARS-coronavirus replication in human peripheral monocytes/macrophages. Virus Res 2005;107:93–101 http://doi.org/10.1016/j.virusres.2004.09.004.
[23] Law HK, Cheung CY, Ng HY, Sia SF, Chan YO, Luk W, et al. Chemokine up-regulation in SARS-coronavirus-infected, monocyte-derived human dendritic cells. Blood 2005;106:2366–74 http://doi.org/10.1182/blood-2004-10-4166.
[24] Hung IF, Cheng VC, Wu AK, Tang BS, Chan KH, Chu CM, et al. Viral loads in clinical specimens and SARS manifestations. Emerg Infect Dis 2004;10:1550–7 http://doi.org/10.3201/eid1009.040058.
[25] Poon TC, Chan KC, Ng PC, Chiu RW, Ang IL, Tong YK, et al. Serial analysis of plasma proteomic signatures in pediatric patients with severe acute respiratory syndrome and correlation with viral load. Clin Chem 2004;50:1452–5 http://doi.org/10.1373/clinchem.2004.035352.
[26] Schmidt M, Brixner V, Ruster B, Hourfar MK, Drosten C, Preiser W, et al. NAT screening of blood donors for severe acute respiratory syndrome coronavirus can potentially prevent transfusion associated transmissions. Transfusion 2004;44:470–5 http://doi.org/10.1111/j.1537-2995.2004.03269.x.
[27] Woo PC, Lau SK, Tsoi HW, Chan KH, Wong BH, Che XY, et al. Relative rates of non-pneumonic SARS coronavirus infection and SARS coronavirus pneumonia. Lancet 2004;363:841–5 http://doi.org/10.1016/s0140-6736(04)15729-2.
[28] Zhou YH. Prevalence of non-pneumonic infections with SARS-correlated virus. Lancet 2004;363:1825–6 author reply 6-7. http://doi.org/10.1016/s0140-6736(04)16313-7.
[29] Young M. Prevalence of non-pneumonic infections with SARS-correlated virus. Lancet 2004;363: 1826; author reply -7. http://doi.org/10.1016/s0140-6736(04)16314-9.
[30] Yip CW, Hon CC, Zeng F, Chow KY, Leung FC. Prevalence of non-pneumonic infections with SARS-correlated virus. Lancet 2004;363:1825 author reply 6-7. http://doi.org/10.1016/s0140-6736(04)16311-3.
[31] Theron M. Prevalence of non-pneumonic infections with SARS-correlated virus. Lancet 2004;363:1825 author reply 6-7. http://doi.org/10.1016/s0140-6736(04)16312-5.
[32] Shang G, Biggerstaff BJ, Yang B, Shao C, Farrugia A. Theoretically estimated risk of severe acute respiratory syndrome transmission through blood transfusion during an epidemic in Shenzhen, Guangdong, China in 2003. Transfus Apher Sci 2007;37:233–40 http://doi.org/10.1016/j.transci.2007.09.004.
[33] Zaki AM, van Boheemen S, Bestebroer TM, Osterhaus AD, Fouchier RA. Isolation of a novel coronavirus from a man with pneumonia in Saudi Arabia. N Engl J Med 2012;367:1814–20 http://doi.org/10.1056/NEJMoa1211721.
[34] Chafekar A, Fielding BC. MERS-CoV: understanding the latest human coronavirus threat. Viruses 2018;10 http://doi.org/10.3390/v10020093.
[35] American Association of Blood Banks. Middle East respiratory syndrome coronavirus, http://www.aabb.org/tm/eid/Documents/middle-east-respiratory-syndrome-coronavirus.pdf; 2013 [accessed 2020-2-5].
[36] Li Q, Guan X, Wu P, Wang X, Zhou L, Tong Y, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. N Engl J Med 2020. https://doi.org/10.1056/NEJMoa2001316.
[37] Chan JF, Yuan S, Kok KH, To KK, Chu H, Yang J, et al. A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: a study of a family cluster. Lancet 2020. https://doi.org/10.1016/S0140-6736(20)30154-9.
[38] Phan LT, Nguyen TV, Luong QC, Nguyen TV, Nguyen HT, Le HQ, et al. Importation and human-to-human transmission of a novel coronavirus in Vietnam. N Engl J Med 2020. https://doi.org/10.1056/NEJMc2001272.
[39] Rothe C, Schunk M, Sothmann P, Bretzel G, Froeschl G, Wallrauch C, et al. Transmission of 2019-nCoV infection from an asymptomatic contact in Germany. N Engl J Med 2020. https://doi.org/10.1056/NEJMc2001468.
[40] Holshue ML, DeBolt C, Lindquist S, Lofy KH, Wiesman J, Bruce H, et al. First case of 2019 novel coronavirus in the United States. N Engl J Med 2020. https://doi.org/10.1056/NEJMoa2001191.
[41] Control Ecfdpa. Outbreak of acute respiratory syndrome associated with a novel coronavirus, Wuhan, China; first update, https://www.ecdc.europa.eu/sites/default/files/documents/Risk-assessment-pneumonia-Wuhan-China-22-Jan-2020.pdf; 2020 [accessed 2020-2-5].
[42] American Association of Blood Banks. Update: impact of 2019 novel coronavirus and blood safety, http://www.aabb.org/advocacy/regulatorygovernment/Documents/Impact-of-2019-Novel-Coronavirus-on-Blood-Donation.pdf; 2020 [accessed 2020-2-5].
[43] 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 http://doi.org/10.1007/s00430-004-0219-0.
[44] Lamarre A, Talbot PJ. Effect of pH and temperature on the infectivity of human coronavirus 229E. Can J Microbiol 1989;35:972–4 http://doi.org/10.1139/m89-160.
[45] Eickmann M, Gravemann U, Handke W, Tolksdorf F, Reichenberg S, Muller TH, et al. Inactivation of three emerging viruses—severe acute respiratory syndrome coronavirus, Crimean-Congo haemorrhagic fever virus and Nipah virus—in platelet concentrates by ultraviolet C light and in plasma by methylene blue plus visible light. Vox Sang 2020. https://doi.org/10.1111/vox.12888.
[46] Hashem AM, Hassan AM, Tolah AM, Alsaadi MA, Abunada Q, Damanhouri GA, et al. Amotosalen and ultraviolet A light efficiently inactivate MERS-coronavirus in human platelet concentrates. Transfus Med 2019;29:434–41 http://doi.org/10.1111/tme.12638.
[47] Hindawi SI, Hashem AM, Damanhouri GA, El-Kafrawy SA, Tolah AM, Hassan AM, et al. Inactivation of Middle East respiratory syndrome-coronavirus in human plasma using amotosalen and ultraviolet A light. Transfusion 2018;58:52–9 http://doi.org/10.1111/trf.14422.
[48] Eickmann M, Gravemann U, Handke W, Tolksdorf F, Reichenberg S, Muller TH, et al. Inactivation of Ebola virus and Middle East respiratory syndrome coronavirus in platelet concentrates and plasma by ultraviolet C light and methylene blue plus visible light, respectively. Transfusion 2018;58:2202–7 http://doi.org/10.1111/trf.14652.
[49] Darnell ME, Taylor DR. Evaluation of inactivation methods for severe acute respiratory syndrome coronavirus in noncellular blood products. Transfusion 2006;46:1770–7 http://doi.org/10.1111/j.1537-2995.2006.00976.x.
[50] Rabenau HF, Biesert L, Schmidt T, Bauer G, Cinatl J, Doerr HW. SARS-coronavirus (SARS-CoV) and the safety of a solvent/detergent (S/D) treated immunoglobulin preparation. Biologicals 2005;33: 95-9. http://doi.org/10.1016/j.biologicals.2005.01.003.
[51] Lin L, Hanson CV, Alter HJ, Jauvin V, Bernard KA, Murthy KK, et al. Inactivation of viruses in platelet concentrates by photochemical treatment with amotosalen and long-wavelength ultraviolet light. Transfusion 2005;45:580–90 http://doi.org/10.1111/j.0041-1132.2005.04316.x.
[52] Yunoki M, Urayama T, Yamamoto I, Abe S, Ikuta K. Heat sensitivity of a SARS-associated coronavirus introduced into plasma products. Vox Sang 2004;87:302–3 http://doi.org/10.1111/j.1423-0410.2004.00577.x.
[53] Leclercq I, Batejat C, Burguiere AM, Manuguerra JC. Heat inactivation of the Middle East respiratory syndrome coronavirus. Influenza Other Respir Viruses 2014;8:585–6 http://doi.org/10.1111/irv.12261.
[54] Keil SD, Bowen R, Marschner S. Inactivation of Middle East respiratory syndrome coronavirus (MERS-CoV) in plasma products using a riboflavin-based and ultraviolet light-based photochemical treatment. Transfusion 2016;56:2948–52 http://doi.org/10.1111/trf.13860.

Please cite this article as: L. Chang, Y. Yan and L. Wang, Coronavirus Disease 2019: Coronaviruses and Blood Safety, Transfusion Medicine Reviews, https://doi.org/10.1016/j.tmrv.2020.02.003

[55] Rebulla P. The long and winding road to pathogen reduction of platelets, red blood cells and whole blood. Br J Haematol 2019;186:655–67 http://doi.org/10.1111/bjh.16093.
[56] Seltsam A, Muller TH. Update on the use of pathogen-reduced human plasma and platelet concentrates. Br J Haematol 2013;162:442–54 http://doi.org/10.1111/bjh.12403.
[57] Chinese Society of Blood Transfusion. Recommendations on blood collection and supply during the epidemic of novel coronavirus pneumonia in China (1st edition) [Chinese], https://www.csbt.org.cn/plus/view.php?aid=16530; 2020 [accessed 2020-2-5].

Please cite this article as: L. Chang, Y. Yan and L. Wang, Coronavirus Disease 2019: Coronaviruses and Blood Safety, Transfusion Medicine Reviews, https://doi.org/10.1016/j.tmrv.2020.02.003