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Review article

Relationship between blood type and outcomes following COVID-19 infection

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ABSTRACT

Since the onset of the COVID-19 pandemic, a concentrated research effort has been undertaken to elucidate risk factors underlying viral infection, severe illness, and death. Recent studies have investigated the association between blood type and COVID-19 infection. This article aims to comprehensively review current literature and better understand the impact of blood type on viral susceptibility and outcomes.

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1. Introduction

The COVID-19 pandemic began in December 2019. An outbreak of severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) began as a cluster of patients developing pneumonia of unknown origin linked to a seafood market in the city of Wuhan [1]. From there, COVID-19 quickly spread throughout the Wuhan region. Despite stringent measures to contain the viral outbreak, the illness continued to proliferate throughout China, overwhelming its hospitals resources and health care workers [2]. In January 2020, the first case of COVID-19 was reported in the United States [3]. SARS-CoV-2 continued to spread through person-to-person transmission and swiftly escalated into a global emergency [4,5].

Robust research efforts have been undertaken to determine risk factors for viral susceptibility and severe illness [6]. The importance of deciphering COVID-19–related risk factors has significant implications for triage and prognosis. To date, multiple, population-based studies have discovered patient-level factors associated with worse outcomes after contracting COVID-19, including sex, race, ethnicity, age, obesity, and preexisting medical conditions [7–16]. Recent studies have investigated blood type as a risk factor for COVID-19 [17–23].

Blood type has been identified as a risk factor in many disease processes, ranging from malignancy [24,25] to venous and arterial thromboembolism [26–28]. The most widely studied associations, however, have been in the realm of infectious diseases. Blood group antigens play a direct role in infection through various mechanisms. On a molecular level, they can serve as receptors and coreceptors for pathogens; and can also facilitate intracellular uptake of viral particles [29]. Clinically, blood types have been linked to bacterial, parasitic, and viral infections [30–37]. One study,

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in particular, found that ABO polymorphism was associated with susceptibility to infection with SARS-CoV-1 [30]. Further investigations discovered a protective effect of anti-A antibodies against intracellular uptake of SARS-CoV-1 [38,39]. Using a cellular model of adhesion, Guillen et al [39] discovered that human anti-A antibodies inhibited interaction between angiotensin converting enzyme-2-dependent cellular adhesion to angiotensin converting enzyme-2–expressing cells. These results propose a molecular mechanism by which ABO polymorphism impacts susceptibility to SARS-CoV-1 infection and transmission [38]. These and other articles have led investigators to investigate whether an association exists between SARS-CoV-2 and blood antigen grouping [40].

Currently, 9 large studies have analyzed the effect of blood type and COVID-19–related illness (Tables 1 and 2) [17–23]. These studies span multiple countries with widely different patient populations. The majority of these studies report an association between blood type and viral infection, although they differ with regard to which blood type portends susceptibility to infection. Among these studies, 8 of 9 articles associated blood type with COVID-19 susceptibility. Four studies found a correlation between blood type and severity of COVID-related illness, and 5 studies did not. The key findings of these studies are detailed below.

### 2. Methods

There was a significant amount of literature published about the relationship between blood type and SARS-CoV-2 and this field continues to evolve as the pandemic continues. For this comprehensive review, we included only peer-reviewed journal articles, articles in English, and those published from March 2020 to January 2021. All articles were identified via searches on PubMed for terms including COVID-19 or SARS-CoV-2 and blood type, severity COVID and blood type. The articles for reviewed by 2 reviewers for sample size, diversity of population, and methodology to ensure a thorough, diverse representation of the literature. To minimize bias, single case reports and small case series were excluded.

#### 2.1. Data supporting blood type correlation with severity of illness

Ray et al [21] published the largest study to date in Canada, investigating the association of blood type with COVID-19. This population-based cohort study from Ontario included a total of 225,556 patients who underwent polymerase chain reaction testing for SARS-CoV-2. Among these, 7,071 (3.1%) tested positive for the virus. Adjusted relative risks (ARRs) were calculated after adjusting for patient demographic data and medical comorbidities. The authors found that individuals with type O blood were less likely to contract SARS-CoV-2 compared with non–type O blood groups (ARR = 0.88; 95% confidence interval [CI], 0.84–0.92). Rhesus (Rh)–negative individuals were also less likely to be diagnosed with SARS-CoV-2 (ARR = 0.79; 95% CI, 0.73–0.85). Interestingly, individuals with O–negative blood type were further protected against viral infection (ARR = 0.74; 95% CI, 0.66–0.83). Type O individuals were at decreased risk compared to non–type O individuals with regard to secondary outcomes, such as severe illness and death (ARR = 0.87; 95% CI, 0.78–0.97). Rh–negative individuals were also at lower risk of severe illness and mortality compared to Rh–positive patients (ARR = 0.82; 95% CI, 0.68–0.96).
together, the authors concluded that type O and Rh-negative blood groups may be protective against SARS-CoV-2 infection and illness.

In China, Zhao et al [22] conducted a retrospective analysis on 2,173 patients who tested positive for SARS-CoV-2. Subjects were pooled from 3 hospitals in 2 cities. The majority of patient data were collected from Jinyintan Hospital in Wuhan, with the remainder from Renmin Hospital of Wuhan University and Shenzhen Third People’s Hospital. The authors compared COVID-19–infected patients with healthy population controls within the same region. Using a random effects model, the pooled data were used to determine the risk of blood type on COVID-19 infection and death. Zhao et al found that blood type A patients were at significantly increased risk of infection compared with non–type A patients (odds ratio [OR] = 1.21; 95% CI, 1.02–1.43; P = .03). Conversely, type O individuals were at lower risk of infection compared to non–type O individuals (OR = 0.67; 95% CI, 0.60–0.75; P < .001). Types B and AB were not at increased risk of COVID-19 infection. In terms of mortality, blood type A patients were at increased risk of death (OR = 1.48; 95% CI, 1.11–1.97) and type O patients had a decreased risk of death (OR = 0.66; 95% CI, 0.48–0.91) (P = .01 each). Similar to Ray et al [21], the authors concluded that type O blood group may be protective against SARS-CoV-2 infection and mortality.

Zietz et al [23] also found that blood type groupings were associated with both risk of intubation and death. Zietz et al performed a retrospective cohort analysis using electronic health record data from the New York Presbyterian/Columbia University database. A total of 13,051 patients were tested between March to August 2020; among whom 2,394 were diagnosed with SARS-CoV-2. Altogether, 399 patients (16.7%) required mechanical ventilation and 331 patients (13.8%) died of COVID-19–related illness. On multivariate analysis, after adjusting for race and ethnicity, individuals with type A blood were at increased risk of infection compared with type O individuals (absolute risk difference [ARD] = 1.3; 95% CI, –0.3 to 3.0). Blood type AB (ARD = 0.1; 95% CI, –2.8 to 3.2) and type B (ARD = 1.3; 95% CI, –0.7 to 3.3) patients were also at increased risk of infection, using type O as a reference. Rh-negative patients were at lower risk of infection compared with Rh-positive patients (ARD = –2.7; 95% CI, –4.7 to –0.8). With regard to intubation and death, type A blood was associated with decreased risk of both intubation (ARD = –2.9; 95% CI, –7.2 to 0.6) and death (ARD = –1.6; 95% CI, –4.9 to 1.6). Type AB individuals were at increased risk of both intubation (ARD = 1.8; 95% CI, –8.3 to 12.2) and death (ARD = 1.4; 95% CI, –6.9 to 8.9). Type B individuals were at increased risk of intubation (ARD = 2.5, CI = 2.7 to 7.5), but lower risk of death (ARD = –2.6; 95% CI, –6.6 to 1.3). Compared with Rh-positive patients, Rh-negative patients were at decreased risk of both intubation (ARD = –5.2; 95% CI, –10.7 to 1.0) and death (ARD = –8.2; 95% CI, –11.7 to –3.7), corresponding with a lower risk of initial infection. Taken together, the authors surmised that blood type plays a substantial role in COVID-19 infection and outcomes.

In Canada, Hooland et al [17] focused their investigation on patients with COVID-19 in the intensive care unit (ICU) setting. This multicenter retrospective analysis included 95 patients critically ill with COVID-19 in ICUs across 6 metropolitan Vancouver hospitals. Given previous reports of the protective effect of anti–A antibodies in SARS-CoV-1 infection [38,39], Hooland et al hypothesized that anti–A antibodies might also be protective against severe viral infection with SARS-CoV-2. Subjects were therefore grouped into blood types A/AB and types O/B. Multivariate analysis was performed adjusting for patient age, sex, and comorbidities. In this patient population, blood types A and AB were more likely to require mechanical ventilation, chronic renal replacement therapy, and prolonged ICU stay compared with types O (P < .05) and B (P < .05). However, no differences were noted in hospital length of stay or in-hospital mortality between groups.

Other studies have also supported correlation between blood type with infection and illness in smaller populations. In Turkey, Gökker et al [41] found that blood type A was associated with higher rates of infection without any impact on severity of illness (n = 186). In a separate study, Kübler et al [42] found that patients with aortic stenosis status post transcatheter aortic valve replacement (n = 22) with blood type A were more likely to become severely ill with COVID-19. Given the small size of these and other similar series, these studies did not weigh into our overall conclusions.

### 2.2. Data against blood type correlation with severity of illness

Five studies found that ABO blood type was not associated with severity of illness or mortality after infection. Barnkob et al [43] published the largest study to date overall, including a total of 841,327 subjects from Denmark. Among tested subjects, 473,654 had ABO blood type data available and 7,422 were positive for COVID-19. In this cohort, the majority (74%) of COVID–19–positive subjects had mild disease and did not require inpatient hospitalization. Data from tested subjects were compared with 2,204,742 nontested individuals, which accounted for nearly 40% of the total Danish population. The authors found that individuals with type O blood were relatively protected from viral infection (relative risk [RR] = 0.87; 95% CI, 0.82–0.91). Unlike previous studies, however, there was no difference between ABO blood type and progression of illness to hospitalization or mortality (each, P > .40). Rh typing was not collected in this analysis.

In our investigation, we performed a multi-institutional analysis across 5 hospitals in the New England region [18]. A total of 7,648 patients were tested for SARS-CoV-2 during the study period, of which 1,289 (16.9%) were positive. Among positive subjects, 484 (37.5%) required inpatient admission, 123 (9.5%) were admitted to the ICU setting, and 108 (8.4%) required mechanical ventilation. On univariate analysis, ABO and Rh types were not associated with infection, hospital admission, or ICU admission rates. Blood antigen groupings did not correlate with peak inflammatory markers, including white blood cell count, lactate dehydrogenase, erythrocyte sedimentation rate, and C-reactive protein levels. Individuals with type AB (OR = 1.37; 95% CI, 1.02–1.83), type B (OR = 1.28; 95% CI, 1.08–1.52), or Rh-positive blood groups (OR = 1.23; 95% CI, 1.00–1.50) were more likely to test positive for SARS-CoV-2. Type O individuals, on the other hand, were protected against infection (OR = 0.84; 95% CI, 0.75–0.95). Neither ABO or Rh types were associated with risk of intubation or mortality. As a result, we concluded that blood types may be associated with
infection rates, but in contrast to other studies, no association was noted with progression to severe illness or death.

A second retrospective cohort study from China was published by Li et al [20] in July 2020. This study included 2,153 patients across 3 hospitals in Wuhan, including Jinyintan Hospital, Renmin Hospital of Wuhan University, and the Central Hospital of Wuhan. It is unclear whether these subjects overlap with those in Zhao et al's [22] article, given that 2 of the hospitals reviewed are the same. On univariate analysis, a greater proportion of patients infected with SARS-CoV-2 were of type A blood compared with healthy controls (38.0% vs 32.2%, \( P < .001 \)). The proportion of infected type O individuals were significantly lower than healthy controls (25.7% vs 33.8%, \( P < .001 \)). With these findings, Li et al [20] suggested that type A individuals might be at greater risk of infection, and type O individuals may be less susceptible. The authors did not report any association between blood type grouping and severity of illness, and covariate adjustment was not performed in this analysis.

In a confirmatory analysis, Dzik et al [44] analyzed ABO distribution among patients in both Wuhan and Boston. Using Wuhan data already published by Zhao et al [22] and Li et al [2], the authors did not find any associations between blood type and COVID-19–related severity of illness. This reaffirms the conclusions made by the original authors. In terms of their Boston data, Dzik et al’s investigation is more comprehensively collected and analyzed in our study, as it uses the same database with fewer patients. Therefore, the study by Dzik et al did not weigh into our discussion or conclusions.

Leaf et al [19] investigated critically ill patients with COVID-19 in the ICU setting. In a multicenter cohort study, the authors examined SARS-CoV-2–positive patients admitted to ICUs from 67 hospitals across the United States. Among the 3,239 critically ill patients during the study period, a total of 2,033 patients had ABO blood group data available. Rh-type data was not reported in this analysis. Leaf et al found that the distribution of ABO phenotypes in critically ill patients differed substantially from the expected distribution in healthy subjects. Among White patients, type A individuals were overrepresented (45.1% observed vs 39.8% expected) and type O individuals were underrepresented (37.8% observed vs 45.2% expected) compared to healthy subjects. No differences were noted between observed and expected distributions of ABO blood groups in Black or Hispanic patients. Leaf et al concluded that type A blood might be a risk factor among White patients with COVID-19–related critical illness, and type O blood might be protective. Within this critically ill cohort, the mortality rate was 39.3% within 28 days, and ABO blood type did not affect mortality rates.

In France, Boudin et al [45] studied a unique patient population impacted by SARS-CoV-2 infection. The authors investigated all crew members from the French Navy nuclear aircraft carrier, Charles de Gaulle, who were exposed to a viral outbreak while on board. Of the 1,769 crew members, 1,279 (76%) tested positive for COVID-19. After the ship returned to base, all members were quarantined and underwent medical monitoring for 2 weeks post landing. In contrast with other studies, the median crewmember age was 28 years, 87% were men, and no significant medical comorbidities were reported. No significant association was found between ABO or Rh blood groups with viral infection, progression to severe illness, or death after infection.

3. Summary of key findings and limitations

Eight of 9 studies demonstrated an association between blood type and susceptibility to infection with SARS-CoV-2. Four of these 9 studies also revealed an association with severity of illness. Ray et al [21] found that subjects with type O and Rh-negative blood were protected from viral infection, severe illness, and mortality. Although the data are convincing, this study was limited by the inability to test critically ill patients who died quickly after hospital admission. Zietz et al [23] also found that ABO and Rh types were associated with infection, mechanical ventilation, and death. This study was significantly limited by the circumstances of limited testing capability, however, with the majority of subjects being tested in an inpatient setting due to illness. Hoiland et al [17] focused primarily on critically ill subjects, reporting an association with blood types A and AB with risk of intubation, chronic renal replacement therapy, and prolonged ICU stay. This study was limited by a very small sample size, with missing blood group data in 25% of subjects.

In China, Zhao et al [22] reported type A subjects were at increased risk of infection and mortality, and type O subjects were protected from both outcomes. Li et al [20] also found type A–associated susceptibility to viral infection, but did not find an association with mortality. Both Zhao et al’s and Li et al’s articles were limited by a small sample size of a single ethnic group. In addition, given that both authors used data from the same hospitals during the same study period, there is potential for subject overlap between the 2 studies. A third study from China by Wu et al [46] supported these findings, noting an increased risk of infection with type A blood. Of note, this third study from China (n = 187) was much smaller in scale compared to the investigations by Zhao et al and Li et al (n = 2,153 and n = 2,173, respectively).

In the largest study to date, Barnkob et al [43] found a protective effect of type O blood with viral susceptibility. We also found that subjects with type O and Rh-negative blood appeared to be at decreased risk for infection on multivariate analysis [18]. Unlike previous reports, neither Barnkob nor our study found any association between blood type and progression to severe illness or death. Our investigation was limited by small sample size and lead-time bias, however, with subjects analyzed early in their hospital course. Similarly, Leaf et al [19] also found that blood type O and Rh-negative subjects were at decreased risk of infection, with no association with mortality rates. These results were also limited by small sample size, along with missing blood group data in approximately one-third of subjects.

Unlike other analyses, Boudin et al [45] did not find any association between ABO or Rh types with infection, severe illness, or death. These results were impacted by the healthy patient population and high rate of infection (76%); however, and might not be reflective of normal societal conditions. Finally, all 9 studies were retrospective analyses of observational data and, therefore, subject to selection bias. A summary of key study limitations are detailed in Table 3.
As a group, one collective limitation among this set of articles is the significant variability in testing of ABO and Rh blood types. Only 3 of the 9 studies tested and analyzed Rh types, which are summarized in the next section. The proportion of ABO types represented appears to vary widely between studies (Table 1); however, this appears to reflect the natural ABO blood group distribution within each individual study population. For example, Zhao et al [22] and Li et al [20] both report an AB blood group prevalence of > 10%, but this is representative of the Chinese population. Each of these studies should therefore be taken in context of their individual study populations and limitations (Table 3).

### 3.1 Rhesus type and COVID-19

The impact of Rh-type on COVID-19 infection deserves a special focus (Table 2). Rh-type is the second most important blood group system after ABO typing. Like ABO types, Rh-type refers to proteins on surface of red blood cells [47]. Clinically, this system plays an important role in blood transfusion and erythroblastosis fetalis [47,48]. Recent studies also demonstrate a significant impact in COVID-19 infection and illness as well. As mentioned previously, of the 9 studies included in this review, 5 investigated Rh blood type. Four of 5 studies found significant associations with Rh-negative blood groups [18,19,21,23]. Both Ray et al [21] and Zietz et al [23] found that subjects with Rh-negative blood type were at lower risk of viral infection, severe illness, and mortality after infection. Our study, along with Leaf et al’s [19], also found that Rh-negative subjects were at lower risk of infection, but did not find any impact on COVID-19-related illness or mortality. Although overall results might be mixed, there is a consistent theme on Rh-type and susceptibility to COVID-19 infection.

### 3.2 Anti-A antibodies and COVID-19

As mentioned previously, Hoiland et al [17] reported an association with blood types A and AB with worse clinical outcomes. Although this study was limited by a very small sample size, the authors hypothesized that the presence of anti-A antibodies might play a key role in viral susceptibility. In their discussion, Hoiland et al refer to a growing body of scientific work comparing SARS-CoV-1 and SARS-CoV-2 viruses. Both viral strains appear to share similar receptor-binding domains [49]. The anti-A antibody inhibits interaction between SARS-CoV-1 and the angiotensin converting enzyme-2 receptor [38], suggesting that the ABO antibodies might influence SARS-CoV-2 infection as well. Other scientific reports have implicated viral infection with other factors, such as anti-A immunoglobulin isotype [50], ABO-type differences in von Willebrand factor [51], and anti-A isohemagglutinin titers [52]. Interestingly, recent genomic analyses have identified specific gene clusters (3p21.31) as susceptibility markers in patients with COVID-19 and respiratory failure. Given the association of this specific locus with the ABO blood group locus, the authors suggest that this may be one mechanism for the involvement of ABO typing with COVID-19-related illness [40]. Although the complete mechanism has yet to be fully elucidated, future studies in this field may help the development of prophylactic and therapeutic interventions for COVID-19 infection.

### 4 Conclusions

Since the onset of the COVID-19 pandemic, a concentrated research effort has been undertaken to elucidate risk factors underlying viral susceptibility and illness. Among these efforts, several recent studies have investigated the association between blood type and COVID-19 infection. Each of these reports provides important information with regard to understanding the underlying disease process. Although these reports might be inconsistent in their findings, certain trends are evident. Many studies report that blood type A might predispose one to increased susceptibility of infection with SARS-CoV-2, and type O and Rh-negative blood groups might be protective. Although this appears to be an emerging trend, the impact of blood type on clinical outcomes remains unclear. At this point in time, there does not appear to be any relationship between blood type and COVID-19-related severity of illness or mortality. Current literature does not support blood type as part of a predictive model of viral illness or mortality, and ABO/Rh screening should not be used as a triage mechanism. Future investigations can focus on the creation of a global COVID-19 database to account for population-based differences in blood types and testing protocols. In addition, further studies are necessary to understand the
molecular mechanisms by which blood types might gender susceptibility to SARS-CoV-2 infection, and ultimately, develop countermeasures to viral infection and illness.

REFERENCES

[1] Zhu N, Zhang D, Wang W, et al. A novel coronavirus from patients with pneumonia in China, 2019. N Engl J Med 2020;382:727–33.
[2] Li Q, Guan X, Wu P, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. N Engl J Med 2020;382:1199–207.
[3] Holshue ML, DeBolt C, Lindquist S, et al. First case of 2019 novel coronavirus in the United States. N Engl J Med 2020;382:929–36.
[4] Chan JF, Yuan S, Kok KH, 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;395(10223):514–23.
[5] Phan LT, Nguyen TV, Luong QC, et al. Importation and human-to-human transmission of a novel coronavirus in Vietnam. N Engl J Med 2020;382:872–4.
[6] Fauci AS, Lane HC, Redfield RR. Covid-19–navigating the uncharted. N Engl J Med 2020;382:1268–9.
[7] Omrani AS, Almaslamani MA, Daghfal J, et al. The first consecutive 5000 patients with Coronavirus Disease 2019 from Qatar, a nation-wide cohort study. BMC Infect Dis 2020;20:777.
[8] Deng G, Yin M, Chen X, et al. Clinical determinants for fatality of 44,672 patients with COVID-19. Crit Care 2020;24:179.
[9] Docherty AB, Harrison EM, Green CA, et al. Features of 20 133 UK patients in hospital with covid-19 using the ISARIC WHO Clinical Characterisation Protocol: prospective observational cohort study. BMJ 2020;369:m1985.
[10] Guan WJ, Ni ZY, Hu Y, et al. Clinical characteristics of coronavirus disease 2019 in China. N Engl J Med 2020;382:1708–20.
[11] Khunti K, Singh AK, Pareek M, et al. Is ethnicity linked to incidence or outcomes of covid-19? BMJ 2020;369:m1548.
[12] Parohan M, Yaghoubi S, Seraji A, et al. Risk factors for mortality in patients with Coronavirus disease 2019 (COVID-19) infection: a systematic review and meta-analysis of observational studies. Aging Male 2020;23:1416–24.
[13] Richardson S, Hirsch JS, Narasimhan M, et al. Presenting characteristics, comorbidities, and outcomes among 5700 patients hospitalized with COVID-19 in the New York City area. JAMA 2020;323:2052–9.
[14] Wenham C, Smith J, Morgan R, et al. COVID-19: the gendered impacts of the outbreak. Lancet 2020;395(10227):846–8.
[15] Yancy CW. COVID-19 and African Americans. JAMA 2020;323:1891–2.
[16] Williamson EJ, Walker AJ, Bhaskaran K, et al. Factors associated with COVID-19-related death using OpenSAFELY. Nature 2020;584(7821):430–6.
[17] Hoolan RL, Fergusson NA, Mitra AR, et al. The association of ABO blood group with indices of disease severity and multiorgan dysfunction in COVID-19. Blood Adv 2020;4:4981–9.
[18] Latz CA, DeCarlo C, Boitano L, et al. Blood type and outcomes in patients with COVID-19. Ann Hematol 2020;99:2113–18.
[19] Leaf RK, Al-Samkari H, Brenner SK, et al. ABO phenotype and death in critically ill patients with COVID-19. Br J Haematol 2020;190:e204–8.
[20] Li J, Wang X, Chen J, et al. Association between ABO blood groups and risk of SARS-CoV-2 pneumonia. Br J Haematol 2020;190:24–7.
[21] Ray JC, Schull MJ, Vermeulen MJ, et al. Association between ABO and Rh blood groups and SARS-CoV-2 infection or severe COVID-19 illness: a population-based cohort study. Ann Intern Med 2021;174:308–15.
[22] Zhao J, Yang Y, Huang H, et al. Relationship between the ABO blood group and the COVID-19 susceptibility. Clin Infect Dis 2021;73:328–31.
[23] Zietz M, Zucker J, Tattonetti NP. Associations between blood type and COVID-19 infection, intubation, and death. Nat Commun 2020;11:5761.
[24] Mao Y, Yang W, Qi Q, et al. Blood groups A and AB are associated with increased gastric cancer risk: evidence from a large genetic study and systematic review. BMC Cancer 2019;19:164.
[25] Wang W, Liu L, Wang Z, et al. ABO blood group and esophageal carcinoma risk: from a case-control study in Chinese population to meta-analysis. Cancer Causes Control 2014;25:1369–77.
[26] Jenkins PV, O’Donnell JS. ABO blood group determines plasma von Willebrand factor levels: a biologic function after all? Transfusion 2006;46:1836–44.
[27] Tregouet DA, Heath S, Saut N, et al. Common susceptibility alleles are unlikely to contribute as strongly as the FV and ABO loci to VTE risk: results from a GWAS approach. Blood 2009;113:5298–303.
[28] Kamphuisen PW, Elkenboom JC, Bertina RM. Elevated factor VIII levels and the risk of thrombosis. Arterioscler Thromb Vasc Biol 2001;21:731–8.
[29] Cooling L. Blood groups in infection and host susceptibility. Clin Microbiol Rev 2015;28:801–70.
[30] Cheng Y, Cheng G, Chui CH, et al. ABO blood group and susceptibility to severe acute respiratory syndrome. JAMA 2005;293:1450–1.
[31] Lindesmith L, Moe C, Marionneau S, et al. Human susceptibility and resistance to Norwalk virus infection. Nat Med 2003;9:548–53.
[32] Wang DS, Chen DL, Ren C, et al. ABO blood group, hepatitis B viral infection and risk of pancreatic cancer. Int J Cancer 2012;131:461–8.
[33] Rowe JA, Handel IG, Thera MA, et al. Blood group O protects against severe Plasmodium falciparum malaria through the mechanism of reduced rosetting. Proc Natl Acad Sci U S A 2007;104:17471–6.
[34] Tiongco RE, Paragas NA, Dominguez MJ, et al. ABO blood group antigens may be associated with increased susceptibility to schistosomiasis: a systematic review and meta-analysis. J Helminthol 2018;94:e21.
[35] Foster MT Jr, Labrum AH. Relation of infection with Neisseria gonorrhoeae to ABO blood groups. J Infect Dis 1976;133:329–30.
[36] Boren T, Falk F, Roth KA, et al. Attachment of Helicobacter pylori to human gastric epithelium mediated by blood group antigens. Science 1993;262(5141):1892–5.
[37] Barua D, Paggioo AS. ABO blood groups and cholera. Ann Hum Biol 1977;4:489–92.
[38] Guillen P, Clement M, Sehille V, et al. Inhibition of the interaction between the SARS-CoV spike protein and its cellular receptor by anti-histo-blood group antibodies. Glycobiology 2008;18:1085–93.
[39] Ritchie G, Harvey DJ, Feldmann F, et al. Identification of N-linked carbohydrates from severe acute respiratory syndrome (SARS) spike glycoprotein. Virology 2010;399:257–69.
[40] Covid Severe, Group GWAS, Ellinghaus D, Degenhardt F, et al. Genomewide association study of severe covid-19 with respiratory failure. N Engl J Med 2020;383:1522–34.
[41] Goker H, Aladag Karakulak E, Demiroglu H, et al. The effects of blood group types on the risk of COVID-19 infection and its clinical outcome. Turk J Med Sci 2020;50:679–83.
[42] Kibler M, Dietrich L, Kanso M, et al. Risk and severity of COVID-19 and ABO blood group in transcatheter aortic valve patients. J Clin Med 2020;9:3769.
Barnkob MB, Pottegard A, Stovring H, et al. Reduced prevalence of SARS-CoV-2 infection in ABO blood group O. Blood Adv 2020;4:4990–3.

Dzik S, Eliason K, Morris EB, et al. COVID-19 and ABO blood groups. Transfusion 2020;60:1883–4.

Boudin L, Janvier F, Bylicki O, et al. ABO blood groups are not associated with risk of acquiring the SARS-CoV-2 infection in young adults. Haematologica 2020;105:2841–3.

Wu Y, Feng Z, Li P, et al. Relationship between ABO blood group distribution and clinical characteristics in patients with COVID-19. Clin Chim Acta 2020;509:220–3.

Quraishy N, Sapatnekar S. Advances in blood typing. Adv Clin Chem 2016;77:221–69.

Geifman-Holtzman O, Wojtowycz M, Kosmas E, et al. Female alloimmunization with antibodies known to cause hemolytic disease. Obstet Gynecol 1997;89:272–5.

Lu R, Zhao X, Li J, et al. Genomic characterisation and epidemiology of 2019 novel coronavirus: implications for virus origins and receptor binding. Lancet 2020;395(10224):565–74.

Gerard C, Maggipinto G, Minon JM. COVID-19 and ABO blood group: another viewpoint. Br J Haematol 2020;190(2):e93–4.

Franchini M, Capra F, Targher G, et al. Relationship between ABO blood group and von Willebrand factor levels: from biology to clinical implications. Thromb J 2007;5:14.

Focosi D. Anti-A isohaemagglutinin titres and SARS-CoV-2 neutralization: implications for children and convalescent plasma selection. Br J Haematol 2020;190:e148–50.

Frances TF. Blood groups (ABO groups). Common Laboratory and Diagnostic Tests. 3rd ed. Lippincott; 2002.