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Development of a nomogram for high antibody titre of COVID-19 convalescent plasma

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Abstract

This study aimed to develop a predictive tool for identifying individuals with high antibody titers crucial for recruiting COVID-19 convalescent plasma (CCP) donors and to assess the quality and storage changes of CCP. A convenience sample of 110 plasma donors was recruited, of which 75 met the study criteria. Using univariate logistic regression and random forest, 6 significant factors were identified, leading to the development of a nomogram. Receiver operating characteristic curves, calibration plots, and decision curve analysis (DCA) evaluated the nomogram's discrimination, calibration, and clinical utility. The nomogram indicated that females aged 18 to 26, blood type O, receiving 1 to 2 COVID-19 vaccine doses, experiencing 2 symptoms during infection, and donating plasma 41 to 150 days after symptom onset had higher likelihoods of high antibody titres. Nomogram's AUC was 0.853 with good calibration. DCA showed clinical benefit within 9% ~ 90% thresholds. CCP quality was qualified, with stable antibody titres over 6 months ($P > 0.05$). These findings highlight developing predictive tools to identify suitable CCP donors and emphasize the stability of CCP quality over time, suggesting its potential for long-term storage.

Introduction

Convalescent plasma (CP) is derived from individuals who have recovered from a specific disease, containing disease-specific antibodies and immune factors [1]. It serves as passive antibody therapy, aiding in combating pathogens linked to the disease. Existing for over a century [2], convalescent plasma therapy (CPT) has been used for various illnesses [1, 3]. Compared to immunotherapies specifically tailored for new virus strains, CPT adapts quickly to evolving viruses, serving as a crucial tool in managing infectious diseases [4].

During the early COVID-19 pandemic, emergency approval for COVID-19 convalescent plasma (CCP) usage was granted based on prior CPT experiences [5]. Regarding efficacy, research emphasizes 3 main aspects concerning CPT [4, 6]: First, specificity—CP must contain effective specific antibodies. Notably, due to the variability of SARS-CoV-2, studies suggest that CP reflects the antigenic composition of local strains. Therefore, CP exhibits higher efficacy when the donor plasma closely matches the geographical location of the patients [7]. Timeliness—CP is more effective when transfused in the early stages of the disease. Third, quantity—CP must contain sufficient levels of antibodies. A meta-analysis indicated that early administration of high antibody titres CCP reduces mortality rates in COVID-19 patients compared to standard treatment [8].

Emergency collection of CCP faces difficulties due to some individuals not meeting the criteria for plasma donation and others being unwilling to donate [9]. For instance, a study noted that among 496 discharged COVID-19 convalescents, only 113 met the plasma donation criteria and merely 13 agreed to donate plasma [10]. Additionally, the demand for high antibody titre CCP donors poses challenges regarding the quantity of CCP. The specificity, timeliness, and emergent nature of SARS-CoV-2 require hospitals to identify a significant number of local CCP donors. Given the mutability of the novel coronavirus, other immune therapies might fail [11], suggesting that SARS-CoV-2 might not be the last pandemic. Hence, proactive collection of high antibody titre CCP is crucial for next outbreaks.

However, it is crucial to note that CCP antibody levels are influenced by various factors, including individual related factors such as gender [12], age [12], BMI [13], and ABO blood type [14]; infection-related factors such as the severity of the infection [12, 15], symptoms during the infection period [13], and vaccination status [13]; and blood collection related factors such as the interval between symptom onset and blood collection [16].

Existing articles on recruiting eligible CCP donors focus on predictive factors [12, 14, 16, 17], with limited predictive models offering simple analyses of model performance [13]. Nomograms, graphical tools transforming statistical prediction models into visual representations, aid

decision making and have been widely used in clinical settings [18]. However, there is no report on using nomograms to predict high antibody titres among CCP donors. Therefore, this study analyses CCP antibody titre characteristics, explores the predictive value of different variables, constructs a nomogram-based predictive model for high antibody titre CCP, and examines CCP quality and storage variations. The aim is to provide reference guidelines for identifying qualified CCP donors and preserving CCP, holding significance for plasma therapy in various diseases.

Methods

Design of the study and data collection

This cross-sectional study was conducted in Chongqing, China, from May 2023 to June 2023, employing convenient sampling methods. Plasma donors were recruited from the People's Liberation Army Blood Center in Chongqing. The inclusion criteria were as follows: (1) compliance with the requirements of GB 18467–2011 "Health examination requirements for blood donors" in China [19] and (2) completion of plasma donation. Exclusion criteria were (1) not infected with COVID-19, (2) not recovered from COVID-19, and (3) blood donation more than 8 months after last COVID-19 symptom onset [20, 21] (considering generally lower antibody titres after 8 months, and China's change in COVID-19 management policy around November 2022). A total of 110 questionnaires were collected, with 2 being excluded due to not meeting Chinese blood quality requirements (testing positive for hepatitis B virus or HIV), 22 answering that they had not been infected with COVID-19, 1 indicating that he had not recovered from COVID-19, and 10 indicating that it had been more than 8 months since infection, resulting in 75 valid responses. To further observe the quality characteristics of CCP and the change of low-temperature storage on antibodies, 63 CCP samples that met Chinese standards (antibody titre ≥1:160) were utilized. Plasma protein (successfully tested in 61 cases) and factor VIII (successfully tested in 60 cases) were examined. Plasma was virus inactivated using the THERAFLEX methylene blue plasma system (4 °C, 35,000 Lux, 35 min), then filtered to remove methylene blue, and subsequently stored at −30 °C. Their SARS-CoV-2 IgG titres were measured before inactivation, after inactivation, and at the 1st, 3rd, and 6th month. This study was approved by the Ethics Committee of the First Affiliated Hospital of Army Medical University, PLA (No. (A) KY2023108) and obtained informed consent from the CCP donors participating in this research.

Epidemiological investigation

A self-designed general information questionnaire was used for the survey. Referring to relevant literature [12-16], the questionnaire included factors that might influence CCP antibody titres, including gender, age, ABO blood type, vaccination history, number of symptoms during infection (including fever; cough, sore throat, and difficulty breathing; nausea, vomiting, and diarrhoea; fatigue, malaise, and weakness; muscle and joint pain), number of COVID-19 infections, interval between symptom onset, and blood collection.

Among these questionnaires, 30 out of 75 (40.0%) lacked specific date information for COVID-19 infection, though year and month were provided. Of these 30 participants, 28 (93.3%) indicated that they were infected between November and December 2022, and all of them were subsequently categorized into the " ≥ 150 days" subgroup. Additionally, 5 out of 75 (6.7%) were missing data on symptoms during infection, and 1 out of 75 (1.3%) lacked details on the number of COVID-19 infections.

Quality testing of CCP

In accordance with the 'Quality Requirements for Whole Blood and Blood Components (18469–2012)' in China, the appearance of CP, factor VIII content (Factor VIII activity was determined on a Sysmex CS5100 coagulation analyser), and plasma protein content (total protein was analysed by the biuret method using the Olympus AU5400) were measured.

Detection of SARS-CoV-2 antibody titres in CCP

Plasma, stored at −30 °C, was thawed and tested using a commercially available Magnetic Chemiluminescence Enzyme Immunoassay Kit (Novel Coronavirus IgG Antibody Detection Kit, Bioscience, China) against the receptor-binding domain (RBD) of the SARS-CoV-2 spike protein. The determination of positivity relied on the sample S/CO ratio (sample luminescence value/cut-off), with a result considered positive if the S/CO ratio was ≥1.0. For antibody titre testing, plasma samples were diluted 10-, 20-, 40-, 80-, 160-, 320-, 640-, and 1,280-fold, and the highest dilutions for positive results were reported as titres. Previous studies have confirmed a high correlation between neutralizing and SARS-CoV-2 spike protein RBD-specific antibody titres [22, 23].

In China, the "COVID-19 Convalescent Plasma Clinical Treatment Protocol (Trial Version 3)" mandates that the IgG titre of CCP must be at least 160, as determined by ELISA or chemiluminescence assays [24]. Given the documented enhancement in therapeutic outcomes when CCP with high antibody titres is administered early in COVID-19 treatment [8], and referencing the European Union's recommendations on CCP antibody titres [25], this study established a minimum CCP IgG antibody titre of 1:320 to characterize high antibody levels.

General statistical analysis

Descriptive statistics were conducted using SPSS 27.0, while other statistical analyses were performed using R software (version 4.3.1). The CCP antibody titre was transformed as follows: $log_2 \frac{IgG}{10}$ for statistical analysis purposes (two cases with undetectable antibody titres due to low levels were defined as −1). Multiple imputation was used to fill missing questionnaire data, and Kolmogorov–Smirnov was employed to analyse the normality of continuous variables. Mann–Whitney U test, Kruskal–Wallis test, and RCS model analyses were used to explore the association between different variables and CCP antibody titres. Friedman tests were utilized to analyse changes in CCP antibody titres before and after storage. Categorized variables were described by their frequency and percentage, non-normal variables were reported as median (Q1, Q3), and mean ± standard deviation was also reported to better express the content of the data. All tests were two-tailed, and $P < 0.05$ was considered statistically significant.

Prediction model

Initially, restricted cubic spline (RCS) models analyzed the relationship between continuous variables and high antibody titres. The results led to transforming continuous variables into categorical ones, and due to the study's limited sample size, certain

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categorical variables were merged. Variable selection involved a univariate binary logistic regression model (0 = low antibody titre, 1 = high antibody titre) and mean decrease Gini (MDG) from a random forest model to assess each variable's importance in predicting high antibody titres. Six optimal variables were chosen for the nomogram based on these analyses. Nomogram effectiveness was measured by the area under the receiver operating characteristic curve (AUC). Model precision was evaluated through a calibration curve using a 1,000-bootstrap resampling method. Practical clinical utility was assessed with decision curve analysis (DCA) to quantify net benefits across various threshold probabilities.

The MDG is a metric used in random forest models to assess the importance of each variable. It measures a variable's contribution to the model's overall predictive accuracy by evaluating the reduction in Gini impurity when the variable is used to split data at a node, providing a quantitative measure of its significance in decision making [26]. The nomogram is constructed as follows: 'days after symptom onset (41–150 days)' is used as the reference variable and assigned 100 points. The score for each variable is calculated based on its regression coefficient relative to the regression coefficient of reference variable, using the following formula: Score for variable = $\beta_i \times X_i$ / ($\beta_{ref} \times X_{ref}$) × 100. Here, β_i is the raw regression coefficient of the variable, and X_i is the difference between the observed value and either the minimum (if $\beta_i > 0$) or maximum (if $\beta_i < 0$) value (for categorical variables with multiple levels, they are converted into binary (0/1) variables using dummy coding). β_{ref} is the coefficient of the reference variable and X_{ref} is the difference between the maximum and minimum values (or vice versa), depending on the sign of β_{ref}. Individual scores are then summed to produce a total score for each individual. Finally, this total score is mapped to a corresponding predicted probability using a predefined mapping function.

Results

Baseline characteristics and plasma antibody titres among different groups

This study included a total of 75 participants, consisting of 44 males (58.7%) and 31 females (41.3%), with an average age of 36.17 ± 10.14 years. The mean duration from COVID-19 symptoms onset to blood donation was 141.68 ± 69.39 days. Among all participants, the average antibody titres were 3.89 ± 1.79. Additional characteristics are outlined in Table 1.

Figure 1 illustrates the relationship between continuous variables (age, days after symptom onset) and antibody titres in this study. Specifically, the correlation between age and CCP antibody titres displayed a "U"-shaped pattern, while the relationship between days after symptom onset and CCP antibody titres exhibited a nearly inverted "U"-shaped pattern. Plasma antibody titres were found to peak approximately 95 days after symptom onset. Moreover, individuals around the age of 36 presented the lowest plasma antibody titres.

Identification of predictive factors

The RCS analysis of age and days after symptom onset with high antibody titres is illustrated in Figure 2, while the univariate analysis and random forest outcomes for high antibody titres are detailed in Table 2. In this phase of analysis, the RCS indicated a "U"-shaped

Table 1. Participant characteristics and plasma COVID-19 antibody titre features among different groups

Variables	Groups	All(n,%)	Median (Q1, Q3)	Mean ± SD	Z/H	*P* value
Gender	Male	44(58.7)	4.00(3.00, 5.00)	3.75 ± 1.52	−1.126	0.260[a]
	Female	31(41.3)	4.00(3.00, 5.00)	4.10 ± 2.12		
Blood type	A	23(30.7)	4.00(2.00, 4.00)	3.35 ± 1.72	6.000	0.112[b]
	B	17(22.7)	4.00(3.00, 4.50)	3.76 ± 1.52		
	AB	2(2.7)	3.00(1.00, 5.00)	3.00 ± 2.83		
	O	33(44.0)	5.00(4.00, 5.50)	4.39 ± 1.85		
Vaccination history	1	2(2.7)	3.50(0.00, 7.00)	3.50 ± 4.95	3.006	0.391[b]
	2	23(30.7)	5.00(4.00, 5.00)	4.35 ± 1.67		
	3	45(60.0)	4.00(3.00, 5.00)	3.62 ± 1.74		
	4	5(6.7)	4.00(3.50, 5.50)	4.40 ± 1.52		
Number of COVID–19 infections	1	58(77.3)	4.00(3.00, 5.00)	3.72 ± 1.88	−0.963	0.336[a]
	2	17(22.7)	4.00(3.50, 5.50)	4.47 ± 1.33		
Number of symptoms	0	3(4.0)	6.00(4.00, 7.00)	5.67 ± 1.53	6.748	0.240[b]
	1	25(33.3)	4.00(3.00, 4.00)	3.76 ± 1.39		
	2	29(38.7)	4.00(3.00, 5.00)	4.10 ± 1.88		
	3	13(17.3)	3.00(3.00, 5.00)	3.69 ± 1.84		
	4	4(5.3)	4.50(1.75, 5.00)	3.75 ± 1.89		
	5	1(1.3)	−1.00(−1.00, −1.00)	−1		

Note:
[a]represents Mann–Whitney U test.
[b]represents Kruskal–Wallis test.

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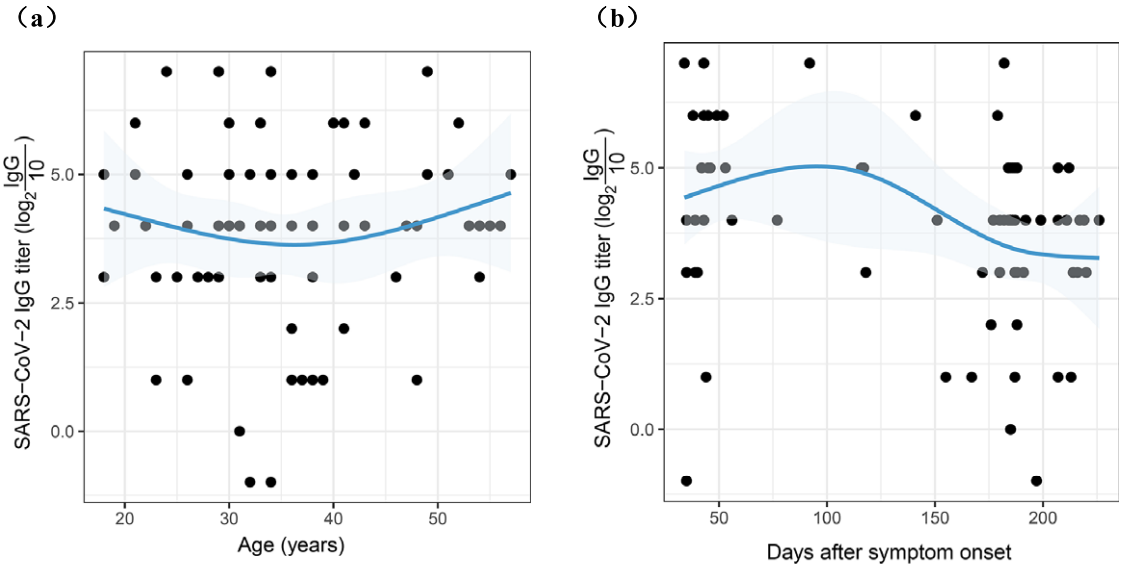

Figure 1. Restricted cubic spline plots of participant age, days after symptom onset, and COVID-19 antibody titres, for: (a) age and CCP antibody titres, (b) days after symptom onset, and CCP antibody titres.
Note: The black dots in the figures represent the samples fitted in the restricted cubic spline model, while the blue lines depict the dose–response relationship between the fitted independent variables and the dependent variable. The blue shaded area represents the 95% confidence interval.

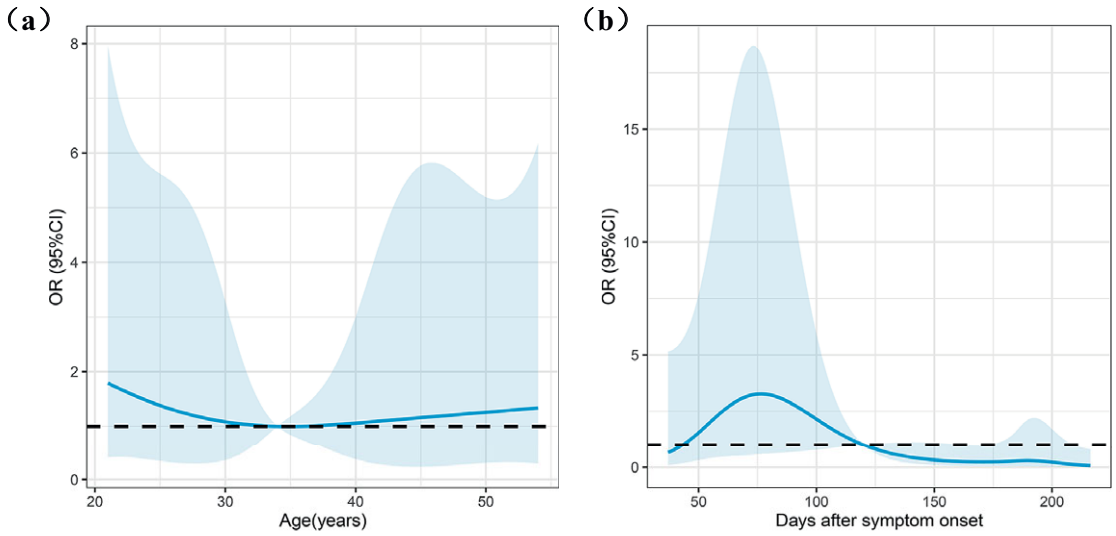

Figure 2. Restricted cubic spline analysis on the association between age, days after symptom onset and high antibody titre, for: (a) age and high antibody titre, reference knot set at 34 and (b) days after symptom onset and high antibody titre, reference knot set at 120.
Note: The blue line and shaded area indicate the estimated Odds Ratio and its respective 95% confidence interval.

relationship between age and high antibody titres, and an inverted "U"-shaped relationship between days after symptom onset and high antibody titres. Based on the results in Figure 2, age and days after symptom onset were transformed into three-category variables (dividing the points on the graph with 2 identical y-axis values but different x-axis values), where age was transformed into 18 ~ 26, 27 ~ 50, and ≥ 51, and days after symptom onset were transformed into ≤40, 41 ~ 150, and ≥ 151 for further analysis.

Within the random forest model, following testing and adjustments, the lowest estimation error rate for out-of-bag samples (OOB = 26.67%) was observed when ntree = 2 and mtry = 3. The 3 most significant feature variables in the random forest were identified as days after symptom onset, blood type, and the number of symptoms. Univariate logistic regression analysis indicates that compared to participants with a days after symptom onset ranging from 41 to 150 days, those ≤40 days (OR = 0.11, 95% CI = 0.02 ~ 0.74) or ≥ 151 days (OR = 0.09, 95% CI = 0.03 ~ 0.31) had a lower likelihood of high antibody titres. Furthermore, compared to individuals with blood type O, those with blood type A (OR = 0.26, 95% CI = 0.08 ~ 0.87), B (OR = 0.29, 95% CI = 0.08 ~ 1.08) or AB (OR = 0.94, 95% CI = 0.05 ~ 16.35) showed a decreased likelihood of high antibody titres. Further details can be found in Table 2. Finally, considering the results from univariate analysis and random forest, the frequency of COVID-19 infection was excluded from further analysis.

Establishment of predictive model

By selecting 6 predictive variables, a nomogram for high antibody titres was constructed, as depicted in Figure 3. Each variable's

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Table 2. Results of univariate analysis and random forest (n = 75)

Variables	Groups	Univariate logistic regression Odds ratio (95% CI)	*P* value	Random forest MDG
Gender	Male	Ref		2.406
	Female	1.96(0.75 ~ 5.12)	0.168	
Age	27 ~ 50	Ref		3.378
	18 ~ 26	1.54(0.46 ~ 5.16)	0.480	
	≥51	1.65(0.39 ~ 6.93)	0.496	
Blood type	O	Ref		4.566
	A	0.26(0.08 ~ 0.87)	0.029	
	B	0.29(0.08 ~ 1.08)	0.064	
	AB	0.94(0.05 ~ 16.35)	0.967	
Vaccination history	1 ~ 2	Ref		3.259
	3	0.38(0.14 ~ 1.04)	0.058	
	4	0.23 (0.02 ~ 2.37)	0.217	
Number of symptoms	0 ~ 1	Ref		3.807
	2	2.12(0.68 ~ 6.56)	0.193	
	≥3	2.40(0.68 ~ 8.49)	0.174	
Number of COVID–19 infections	1	Ref		1.088
	2	0.96(0.31 ~ 2.97)	0.935	
Days after symptom onset	41 ~ 150	Ref		9.077
	≤40	0.11(0.02 ~ 0.74)	0.023	
	≥151	0.09 (0.03 ~ 0.31)	<0.001	

Note: MDG, Mean Decrease Gini; Ref, Reference.

options corresponded to respective scores, and the total score was obtained by summing the options for the 6 variables. At the bottom of Figure 3, predicted probabilities corresponding to different total scores are provided. A higher total score indicates a greater likelihood of high antibody titres. For instance, consider a potential CCP donor meeting inclusion criteria: a female aged 30 with blood type A, having received 3 doses of COVID-19 vaccine, experienced 2 symptoms during the infection, and donated plasma 50 days after contracting the virus. Their corresponding scores would be 29, 15, 3, 19, 46, and 100, resulting in a total score of 212. This suggests an estimated probability of approximately 80% for high antibody titres.

Performance of the nomogram

The AUC of the nomogram was 0.853 (95% CI: 0.767 ~ 0.939), with sensitivity and specificity of 0.646 and 0.926, respectively. The Youden index was 0.572, with a cutoff value of 0.211 (Figure 4). The calibration curve displayed relatively good consistency between predicted and observed high antibody titres (Figure 4). Additionally, the Nagelkerke R^2 value of 0.442 indicated a satisfactory model fit, while the DCA revealed a higher net benefit using the nomogram for threshold probabilities between 9% ~ 90% (Figure 4). These findings suggest that the nomogram generated for this study exhibits good discriminative ability, calibration, and clinical applicability.

Quality characteristics and storage changes of CCP

According to the "Quality Requirements for Whole Blood and Blood Components (18469–2012)" in China, fresh frozen plasma should have a plasma protein content ≥50 g/L and factor VIII content ≥70 IU/L. In this study, all samples successfully met the requirements for plasma protein and VIII factor content standards,

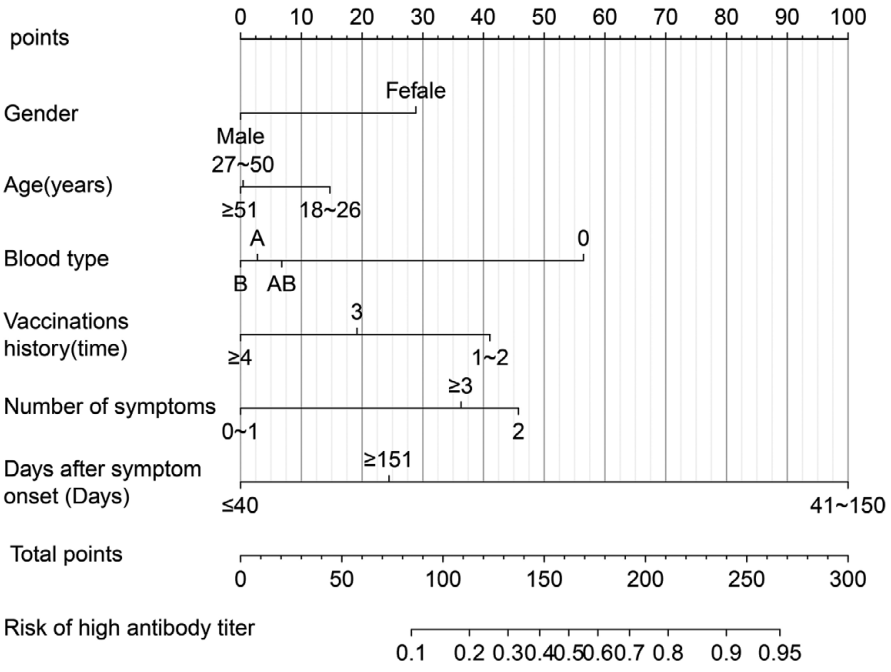

Figure 3. Proposed nomogram for high antibody titre.

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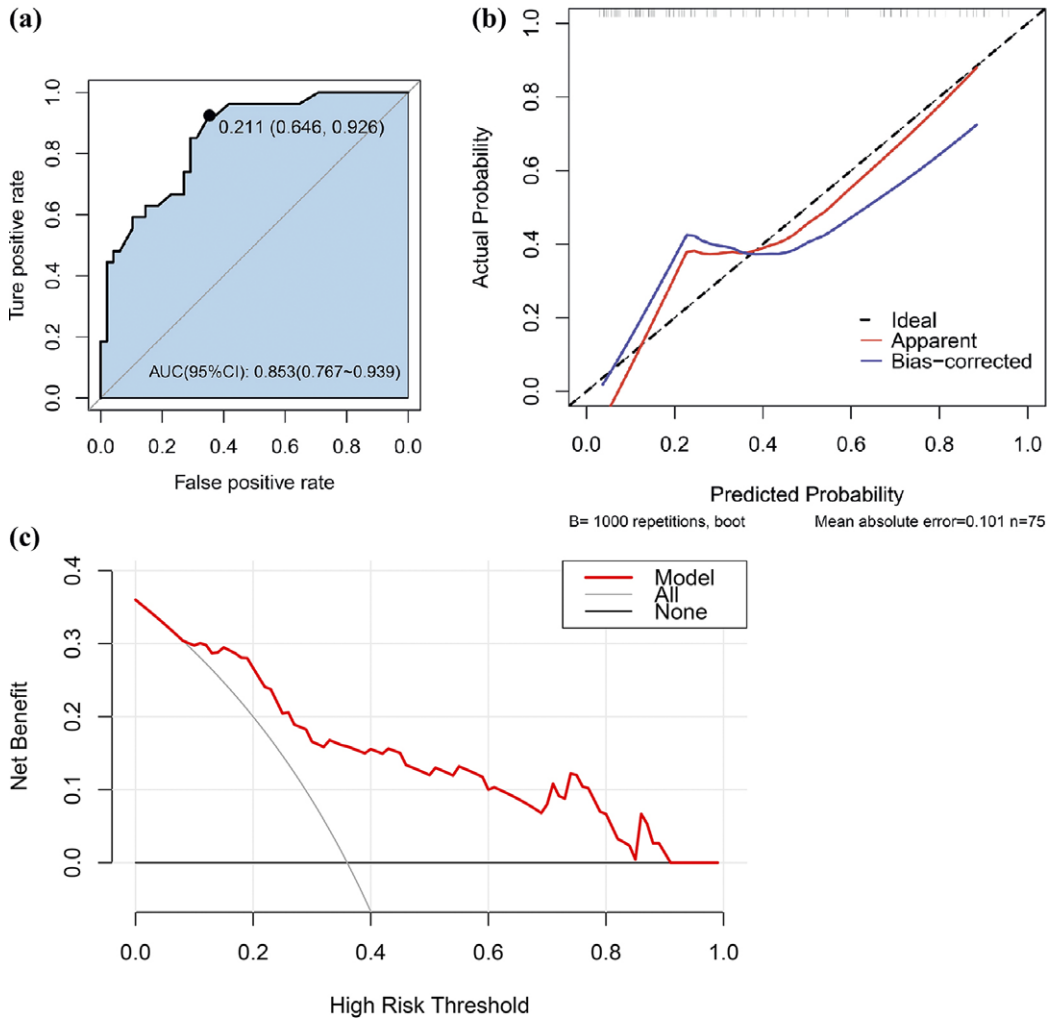

Figure 4. Performance of the study's generated nomogram in the study, for (a) receiver operating characteristic curve of the nomogram, (b) calibration curves of the nomogram, and (c) decision curve analysis of the nomogram.

with the lowest plasma protein content being 54.80 g/L and the lowest factor VIII content being 72.10 IU/L (Figure 5a,b).

These CCP were inactivated and frozen stored, and the results indicated no statistically significant changes in SARS-CoV-2 IgG plasma antibody titres before and after inactivation or during 6-month storage period ($P > 0.05$), as detailed in Figure 5c.

Discussion

Identifying crucial indicators for high antibody titre CCP is beneficial for recruiting CCP donors and benefits clinical COVID-19 patients [8, 27, 28]. This study conducted a cross-sectional survey, using a combination of univariate logistic regression analysis and random forest to evaluate the predictive performance of single variables. Additionally, the study analyzed the quality and storage characteristics of CCP. The results of this study have implications for recruiting high antibody titre plasma donors for other diseases' convalescents, aiding in managing new major infectious diseases more effectively.

The nomogram in this study selected variables from 3 aspects: individual-related, infection-related, and blood collection-related factors, making it more comprehensive in predicting high antibody titres.

Regarding individual characteristics, the nomogram incorporated gender, age, and blood type. Prior research suggests that individuals with blood type O are less susceptible to COVID-19 [29]. Our findings indicate that among those infected population, individuals with blood type O have a higher likelihood of exhibiting high antibody titres. This result is inconsistent with findings from another study [14], and the differences could be primarily attributed to variations in the sample populations, such as ethnicity and vaccination status [14, 30]. Furthermore, the small sample size in our study may lead to unstable results. Moreover, the nomogram's results only represent score differences and cannot directly imply statistical significance. Lastly, it is noteworthy that interpreting the association between CCP antibodies and individual characteristics is challenging because some scholars argue that humoral immunity might be protective but could, in certain cases, exacerbate inflammation, leading to harm [31]. This implies that higher antibody titres could indicate better immune functionality, yet they might also represent a more severe disease state. Regarding gender, females showed higher scores in the nomogram, which is consistent with Schlickeiser's findings [32]. This might be

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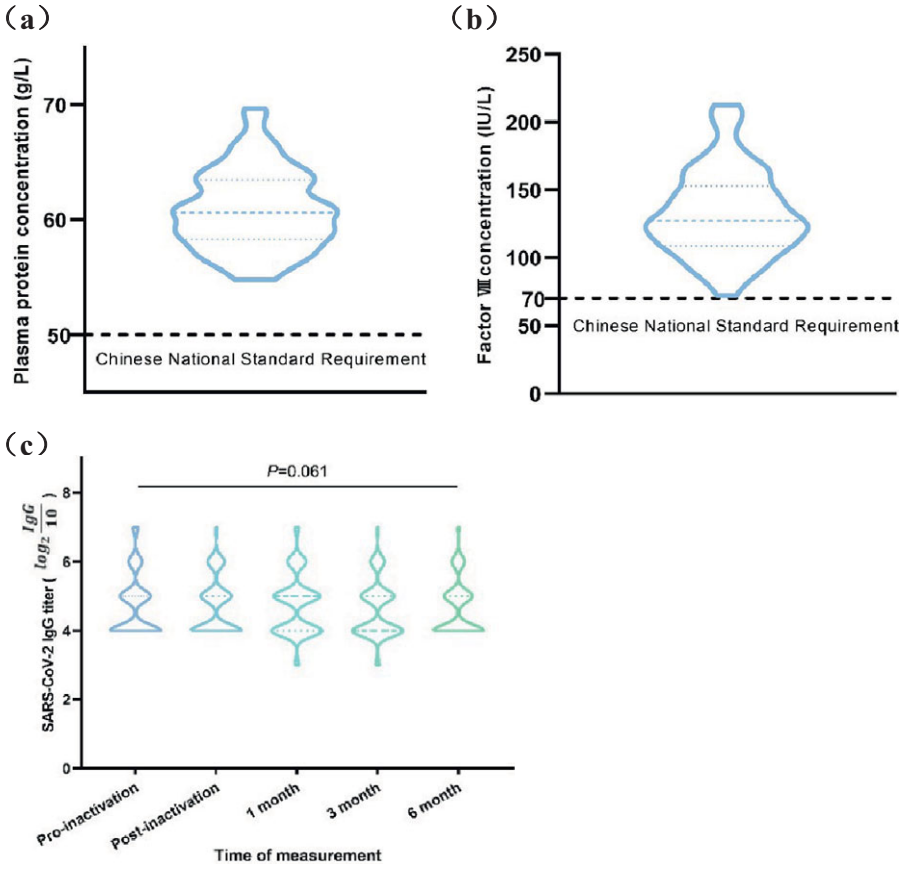

Figure 5. Quality characteristics and storage changes of COVID-19 convalescent plasma, for (a) Violin plot representing the plasma protein content (n = 61); (b) Violin plot representing the factor VIII content (n = 60). (c) Violin plot displaying changes in plasma antibody titres during storage (n = 63). Statistical significance was assessed with the Friedman test.

explained by females having a stronger innate humoral immune response compared to males [33]. Additionally, research indicates that gender is also related to the evolution of humoral responses, males exhibiting faster antibody declines than females [34]. In the age analysis, different age groups displayed minor differences in antibody levels, contrary to observations in CCP from hospitalized patients [35]. In our nomogram results, the age group of 18 ~ 26 exhibited higher scores, possibly related to age-associated immunosenescence [36, 37].

Concerning infection related factors, the nomogram indicated that individuals with 0 ~ 1 symptoms showed a lower likelihood of high antibody titres, as expected, since more severe illness leads to a greater antibody production [15]. Regarding vaccination history, the nomogram demonstrated that individuals who received 1 ~ 2 dose had the highest likelihood of high antibody titres post-COVID-19 infection, possibly due to the protective effect of the vaccine, reducing exposure (decreasing the viral load within the individual) [38]. It is noteworthy that the type of vaccine administered is another potential factor influencing antibody titres. In China, the majority of the population has been vaccinated with inactivated vaccines. Compared to the antibody patterns induced by administering two doses of an inactivated vaccine, as commonly observed [39], the antibody patterns in our study appear to be more durable.

Regarding blood collection related factors, our earlier analyses —univariate logistic regression, random forest, and nomogram— consistently highlighted the interval between blood collection and symptom onset as the most critical predictive factor. According to the RCS analysis of the antibody titre concerning days after symptom onset (Figure 1, Figure 2), the highest antibody titres were observed approximately 95 days after symptom onset. At 78 days after symptom onset, the high antibody titres were the greatest. Current studies have identified varying trends in CCP antibody levels over time, with moderate differences in peak antibody levels [20, 38], possibly due to differences in antibody measurement methods and participant characteristics. Our results are similar to those of Ortega et al. [38].

This study boasts several strengths and practical implications. Firstly, it is the inaugural effort to construct a nomogram for predicting high antibody titres in CCP, offering a valuable tool to identify individuals with high antibody titres. Secondly, rigorous statistical analysis methods were employed, incorporating comprehensive predictive factors. RCS analysis was applied to antibody titres with age and days after symptom onset, leading to more reasonable subgroup divisions and improved predictive model performance. Univariate analysis and random forest screening for predictive factors further enhanced scientific accuracy. However, the study faces certain limitations. The primary limitation is the small sample size of only 75 participants, coupled with the short collection period, both of which impact the stability and generalizability of the results. The limited number of cases may introduce substantial bias and might not adequately represent broader population characteristics. Consequently, the conclusions of this study may require validation in a larger cohort to verify their applicability. Additionally, the study includes a limited number of variables for

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screening and assessment. For example, we did not consider factors such as BMI and the timing of vaccinations, which could influence the antibody titre of CCP. Moreover, its cross-sectional nature limits the ability to infer causality. Finally, the reliance on self-reported data introduces potential recall and reporting biases.

Conclusions

This study, combining univariate logistic analysis and random forest, identified 6 predictive factors for high antibody titres in CCP from COVID-19 survivors and constructed a nomogram for predicting high antibody titres. Among these factors, females aged 18 to 26 years, with blood type O, receiving 1 to 2 doses of COVID-19 vaccines, experiencing 2 symptoms during COVID-19 infection, and donating plasma 41 to 150 days after symptom onset were identified as risk factors affecting high antibody titres in CCP. The nomogram performed well in identification, calibration, and clinical applicability, possessing the capability to assist recruitment personnel in identifying individuals with high antibody titres in CCP, enabling them to devise effective recruitment policies for COVID-19 survivors.

Data availability statement. The data that support the findings of this study are available upon request.

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Author contribution. Conceptualization: S.C.W, Z.R.X, Y.C.Y.; Funding acquisition: Y.C.Y, S.C.W.; Investigation: S.C.W, R.H.D, Z.R.W, Q.L, Q.Y.R, J.Y.; Methodology: M.S., S.C.W, Z.R.X, Z.R.W, R.H.D, Q.L, Q.Y.R.; Formal Analysis: S.C.W, J.Y, Y.C.Y.; Project administration: S.C.W.; Visualization: J.Y.; Writing—original draft preparation: J.Y, S.C.W, Y.C.Y.; Writing—review and editing: Y.C.Y, S.C.W, J.Y.; All authors have read and agreed to the published version of the manuscript.

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Competing interest. The authors declare none.

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