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A comparative study on coagulation and hematologic laboratory techniques for blood sampling using the push-pull method from a CVC versus venipuncture

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Abstract

Objectives: To demonstrate the equivalence and substitutability of two blood collection methods: the push-pull method from a CVC and direct venous puncture (DVP).

Methods: A comparative, within-subject study was conducted between September 2021 and December 2021 at a hospital in NanTong city. The sample comprised critically ill patients aged 18 and older in critical care units such as general, emergent, cardiac, respiratory, and neurological units. A total of 154 paired blood samples were collected via a CVC and direct venous puncture. This study focused on the laboratory results of the coagulation and hematologic tests. The reproducibility and reliability of the results were calculated by the mean of the coefficient of variation (CV) and the intraclass correlation coefficient (ICC). Bland–Altman statistics were used to analyze the substitutability of the two blood collection methods.

Results: The difference in the means between the two methods ranged from −1.61 to 0.09, and the coefficients of variation for both methods were similar. The ICCs of the two methods were all above 0.90, which indicated excellent reliability. In the Bland–Altman plots, all of the blood samples that obtained by the push-pull method were within clinically acceptable ranges compared to the samples obtained by direct venous puncture.

Conclusion: The push-pull method of collecting blood specimens from a CVC should be acceptable for coagulation and hematologic laboratory tests.

Keywords

Blood specimen collection, push-pull method, central venous catheterization, peripherally inserted central catheter, centrally inserted central catheters, hematologic tests, blood coagulation tests

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Introduction

Critically ill patients are often subjected to numerous invasive procedures, among which the most frequent is blood collection by direct venous puncture (DVP) for laboratory tests, and DVP may cause acute pain, skin or nerve damage and provoke anxiety or patient dissatisfaction.[1] However, the placement of a central venous access device (CVAD) is revolutionary because accurate placement ensures that blood samples can be obtained without the trauma associated with venipuncture. The existing literature has described the methods of blood sampling from a

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CVAD, which mainly including the discard method, reinfusion method and push–pull method, and the discard method is the most common technique, however, when drawing blood specimens in this manner, an adequate volume of blood is usually discarded to avoid altering the test results because of the presence of infusion substances in the discarded sample. For the discard method, studies reported that discard volumes ranging from 2 to 25 mL,[2] and this wide variation could produce hospital-acquired anemia.[3,4] The reinfusion method is similar to the discard method, but the original discard sample is reinfused in the end. Although this method can minimize blood loss, it can increase the risk of blood clot formation or contamination.[5] As a result of these risks, the reinfusion method has no longer been widely used in the clinic.

The 2021 guideline of infusion therapy standards of practice recommend that blood can be returned to the patient when use closed-loop blood collection system for venous catheters, but do not reinfuse the discard sample in a disconnected syringe.[6] The cycle of aspiration and repeated returns of the blood without disconnecting the syringe is the push-pull technique, in such a closed system, it is beneficial to clear the catheter before specimen collection and reduce the risk of contamination and blood clot formation.[8] In recent years, the push-pull method has gained wider acceptance because of its advantages, such as producing clinically reliable patient laboratory values while limiting blood loss and exposure to pathogens.[7,8]

Some researchers are concerned that the push-pull method may increase risk of specimen hemolysis due to agitation or turbulence, however, this disadvantage has not been found in most literature. Holmes[9] reported that, in an adult study comparing the push–pull method with the reinfusion and discard method, no evidence of hemolysis based on the potassium level was found, and then this conclusion was also reconfirmed by Adlard[10] and Byrne[8] again, only a pediatric study reported hemolysis of one push-pull sample form a CVC, and it was not identified as a statistically significant risk due to a small sample.[11] In some review articles, researchers have summarized the advantages and disadvantages of the above methods, but there has been insufficient evidence to support the superiority of one method over the others. Several studies have compared various blood sampling methods from CVADs, a study[12] that compared the reinfusion method with the push-pull method in adult patients reported that there was no significant difference in hematocrit values between the methods. Some studies compared the push–pull method with the discard method in adult[8,9] and pediatric patients,[10,11,13] they found no significant difference in most of the laboratory results in their studies and no evidence of hemolysis, hemodilution or bloodstream infections in the samples based on either of the techniques. A pediatric study[7] reported that the push–pull method was a reliable and safe option for determination of plasma gentamicin concentrations from samples collected via implantable CVC. However, the best method for blood sampling has not been established, and whether the push-pull method could be an alternative to other methods needs further examination.

In the relevant literature, the laboratory assays focused largely on biochemical parameters, hematologic tests and drug concentrations, although the differences in a few of the lab results were statistically significant, they were not clinically significant. Two studies previously evaluated the differences in the coagulation test results obtained while comparing the push-pull method with the discard method[11] and venipuncture.[14] These studies demonstrated that the push-pull method could provide reliable coagulation test results from samples obtained from a catheter containing heparin and without the need for any discard. While some studies have supported the push-pull method for sampling using CVADs in patients, more evidence is needed to demonstrate the reliability and superiority of this method in obtaining blood samples for laboratory tests, especially in common tests such as hematological, biochemical and coagulation tests.

However, in China, direct venous puncture for blood collection continues to be the most widely used method in the clinical setting. Some clinical staff question the necessity of blood collection via a CVAD, especially when considering the accuracy of the test results, risk of catheter blockages or bloodstream infections, but this approach has been reaffirmed as an acceptable technique in the latest guideline of the infusion therapy standards of practice.[6] In particular, the push-pull method has been recommended as an acceptable blood sampling method. At present, in our hospital, a small amount of heparin (10 units/mL) is used to lock the CVADs to maintain the patency, the results of the coagulation test may be affected, and there is a lack of studies on this issue. Therefore, in our study patients who had blood samples taken by the venipuncture method were selected as the control group, and the concordance and equivalence between the two techniques, including DVP (control) and the push-pull method via CVADs, were be analyzed.

Methods

Design

A cross-sectional observational study using a simple crossover design and a within-subject design was conducted. A total of 154 patients with a CVC were prospectively included in this study. After obtaining informed consent, paired blood sample specimens were obtained via direct venous puncture and via catheters by the push-pull method at the same time.

Study setting and samples

This project was implemented in the affiliated hospital of Nantong University, and blood samples were obtained from adult inpatients. The inclusion criteria included the

Table 1. Detailed protocol that was used for obtaining blood samples from a CVC by the push-pull method.

1. The equipment was collected: Two 20 mL prefilled 0.9% sodium chloride syringe (10 units/mL heparin if needed), alcohol prep pads, one pair of sterile gloves, one treatment towel, a needleless connector, a sterile cap and a three-way stopcock, two sets of labeled blood tubes, and a blood transfer device.
2. The patient's name and age were verbally identified, and the patient's identification was verified by checking the identification band.
3. The infusing solutions were stopped for 2 min, and all lumens were clamped.
4. Hand hygiene was performed, and the phlebotomist wore sterile gloves and spread a treatment towel.
5. The needleless connector was removed and discarded, the infusion tube was removed, and a sterile cap was placed on the end of tube. The tubing connection was cleansed with an alcohol prep pad by rubbing vigorously for 15 s and allowing it to dry.
6. The first prefilled 20-mL 0.9% sodium chloride syringe with a three-way stopcock was attached to the catheter, open the stopcock to the syringe and catheter, opened and flushed the lumen with 10 mL of saline.
7. Keep the 20-mL syringe attached, first confirmed the return of blood and then obtained 6 mL of blood through the catheter, the push-pull cycles were repeated for a total of four cycles.
8. A blood transfer device was attached to the stopcock, opened the stopcock to the blood transfer device, inserted an evacuated blood collection tube into the blood transfer device, transferred blood to the lab tube using the tube's vacuum.
9. Another prefilled 20-mL 0.9% sodium chloride syringe (10 units/mL heparin if needed) was attached to the stopcock, then the catheter was flushed with 10 mL sodium chloride using the push-pause technique, the catheter was clamped and then the syringe and stopcock were both removed.
10. The tube connection was cleansed with an alcohol prep pad by rubbing vigorously for 15 s, and a new needleless connector was attached until it had fully dried.
11. All of the previous steps of the infusion were restarted.

following: (1) inpatient status, (2) aged 18 and older, and (3) the types of catheters were PICCs (4 Fr and greater) and CICCs (14/18-gauge double lumen or 16-gauge single lumen). The exclusion criteria were as follows: (1) patients with PICCs smaller than 4.0 Fr or implantable ports, (2) patients who refused to participate, (3) patients with a malfunctioning catheter, and (4) patients whose drug infusion could not be paused due to illness. The project was approved by the Human Research Ethics Committee, and informed consent was obtained from each patient (2021-K070-01).

Procedures

Each clinical department appointed a nurse to obtain specimens, and all nurses were educated and trained about the details and attention points of this protocol. A detailed protocol for obtaining blood samples from CVCs was developed and then followed by the nurses (Table 1). For each blood draw, the designated nurse obtained specimens from the CVCs and then blood samples were obtained by venous puncture 5 min later. The paired samples were attached and carried to the laboratory by a specially assigned person, and all of the blood specimens were processed in the same laboratory using the same machine.

Matters that need attention to standardizing the protocol

1. Blood samples should be drawn from the appropriate lumen of the catheter.
2. Blood samples were taken using a central catheter without the needleless connector.
3. Blood collection from a CVC should be discontinued if there is no blood return or if the phlebotomist is unable to withdraw 6 mL of blood.
4. Using push-pull technique: The plunger should be pulled back at a uniform speed, using slow and gentle force, so that the blood fills the syringe at the same rate that the plunger is pulled back, to avoid hemolysis of the blood specimens. A push-pull cycle lasted 15 s, including slowly pulling 6 mL blood from the line for 5 s duration, gently pushing the blood back into the line for 5 s, and then waiting for 5 s before the next push-pull cycle.

This study protocol selected coagulation and hematologic tests for the analysis, and the coagulation tests included D-dimer, prothrombin time, activated partial thromboplastin time, fibrinogen, international normalized ratio, and thrombin time. The hematological tests included the white blood cell count, red blood cell count, hemoglobin, hematocrit, mean corpuscular volume, mean corpuscular hemoglobin, mean corpuscular hemoglobin concentration, and platelet count.

Patient and public involvement

The research question and study design were discussed with patients and relatives, and they also shared the idea and experience about the two methods. The findings of this study may be disseminated to the public by sharing information on public media.

Statistical analysis

Statistical analysis was performed using SPSS 25.0, MedCalc software version 20.1.15 and an online statistical tool (SPSSAU 21.0, http://www.spssau.com).

The reproducibility of the results was calculated by the mean of the coefficient of variation (CV = (SD/mean) × 100%). The absolute agreement of the results from the two methods was assessed by the intraclass correlation coefficient (ICC).[15]

The results of the coagulation and hematological results of the paired blood samples that were taken either via direct venous puncture or the push-pull method from CVCs were compared using Bland Altman analysis.[16] The mean difference (MD) was calculated as the mean of the push-pull method-direct venous puncture, and the limits of agreement (LOA) were expressed as MD ± 1.96 × standard deviation (SD), with confidence intervals (CI) around each LOA.

Before performing the Bland–Altman analysis, it was necessary to judge the characteristics of the data, including the data's normality, proportional bias and heteroscedasticity.[17] The normality of the data distribution was assessed using the Kolmogorov-Smirnov test, the proportional bias was assessed by ordinary least squares regression (OLS), and heteroscedasticity was assessed using the Breusch–Pagan test.

In this study, the clinically acceptable limit (CAL) was defined by the external quality assessment standard of the clinical laboratory center of the National Center for Clinical Laboratories in China (2021).

Results

In this study, 154 paired blood samples were collected from 154 patients; there were more males (66.2%) than females (33.8%); the mean age of the patients was 66.98 ± 14.56 years; and the most common diagnoses were cancer (26.6%) and hematological disease (19.5%); the types of catheters were mainly 14/18-gauge double lumen CICCs (56.5%) and 4 Fr PICCs (37%); the mean indwelling time of the catheter was 23.73 ± 44.26 days; and the most common locations for the catheter were the internal jugular vein (41.6%) and the basilic vein (30.5%). In addition, 49.4% of the patients were not receiving infusions when the blood samples were collected (Table 2).

Table 3 shows the mean, CV and ICC of the 154 paired blood samples. The difference in the means between the two blood collection methods ranged from −1.61 to 0.09. The coefficients of variation for both methods were similar. All of the ICCs of the two methods were above 0.90, indicating excellent reliability.

In the consistency evaluation of the two quantitative measurement methods, the behavior of the data mainly depends on normality, proportional bias and heteroscedasticity. The standard Bland Altman analysis must evaluate data that follow a normal distribution, have no proportional bias and have an equal variance. Under such circumstances, the data behavior could be defined as well behaved. The data in our study do not satisfy the necessary conditions mentioned above, which are considered to be poorly behaved data (Table 4). In this case, we processed the data accordingly. In the Bland–Altman plots, the value of the direct venous puncture method was plotted on the X-axis, which was the gold standard in this research, and the ratio of the two methods (venous puncture method/push-pull method) was plotted on the Y-axis.

Table 5 shows the ratio means of the two methods, the 95% LOAs and their upper and lower limits, and the clinically acceptable limits in the Bland–Altman plots. The upper and lower limits of the 95% LOAs were included in the clinically acceptable limits of all the laboratory variables; this supports the conclusion that the two methods in this study were clinically acceptable and interchangeable; and the conclusions were exactly the same for the hematological tests (Figures 1 and 2).

Table 2. Demographic of 154 patients ($n = 154$).

Variable	Number	Percent (%)
Sex		
Male	102	66.2
Female	52	33.8
Age (year) (range)	66.98 ± 14.56 (18–94)	
Diagnosis		
Cardiorespiratory	25	16.2
Cerebrovascular	22	14.3
Digestive	13	8.4
Hematologic	30	19.5
Cancer	41	26.6
Other	23	14.9
CVC types		
4 Fr PICC	57	37.0
14/18-gauge double lumen CICC	87	56.5
16-gauge single lumen CICC	10	6.5
Catheter indwelling time(day) (range)	23.73 ± 44.26 (1–218)	
Location of catheter		
Brachial vein	3	1.9
Femoral vein	22	14.3
Basilic vein	47	30.5
Internal jugular vein	64	41.6
Subclavian vein	17	11.0
Axillary vein	1	0.6
Heparinized catheters		
Yes	96	62.3
No	58	37.7
Infusion		
No	76	49.4
Saline solution	19	12.3
5% Glucose solution	9	5.8
Medication	25	16.2
TPN	25	16.2

TPN: total parenteral nutrition.

Table 3. Mean and variance coefficient of 154 paired blood samples ($n = 154$).

Determination	Variable	Mean DVP (gold standard)	CV_{DVP} (%)	Mean CVCs (push-pull method)	CV_{CVCs} (%)	Mean difference (push-pull method vs gold standard)	ICC
Coagulation	D-dimer	4.74	114.68	4.74	114.50	0.00	0.997*
	PT	13.04	17.77	13.13	17.73	0.09	0.994*
	aPTT	30.39	15.89	30.11	15.97	−0.28	0.966*
	Fib	4.07	38.10	4.07	38.76	0.00	0.988*
	INR	1.14	19.11	1.15	19.09	0.01	0.994*
	Antithrombin III	76.68	24.62	76.44	24.93	−0.24	0.990*
	TT	17.07	8.64	16.93	8.74	−0.14	0.934*
Hematology	WBC	9.72	66.45	9.64	67.25	−0.08	0.997*
	RBC	3.43	20.25	3.38	20.03	−0.05	0.995*
	Hgb	102.73	19.99	101.12	19.92	−1.61	0.996*
	Hct	0.31	19.52	0.31	19.20	0.00	0.992*
	MCV	90.98	6.93	91.06	6.98	0.08	0.998*
	MCH	30.05	7.23	29.99	7.29	−0.06	0.985*
	MCHC	330.48	3.97	329.47	3.88	−1.01	0.937*
	Plt	178.59	55.69	178.64	56.43	0.05	0.995*

DVP: direct venous puncture; CVAD: central venous access device; PT: prothrombin time; aPTT: activated partial thromboplastin time; Fib: fibrinogen; INR: international normalized ratio; TT: thrombin time; WBC: white blood cell count; RBC: red blood count; Hgb: hemoglobin; Hct: hematocrit; MCV: mean corpuscular volume; MCH: mean corpuscular hemoglobin; MCHC: mean corpuscular hemoglobin concentration; Plt: platelets count.
*$p < 0.001$.

Table 4. Data behavior analysis result of 154 paired blood samples ($n = 154$).

Variable	Normality (K-S test)			Proportional bias (OLS)			Heteroscedasticity (B-P test)			Data behavior
	Z	*p*	Result	*B*	*p*	Result	χ^2	*p*	Result	
D-dimer	0.211	0.000	No	0.008	0.253	No	31.696	0.000	Yes	×
PT	0.136	0.000	No	0.028	0.617	No	18.438	0.000	Yes	×
aPTT	0.074	0.039	No	−0.170	0.858	No	7.214	0.007	Yes	×
Fib	0.166	0.000	No	−0.070	0.164	No	24.250	0.000	Yes	×
INR	0.176	0.000	No	0.002	0.283	No	15.919	0.000	Yes	×
Antithrombin III	0.164	0.127	Yes	−0.489	0.403	No	6.893	0.009	Yes	×
TT	0.091	0.003	No	−0.188	0.926	No	1.255	0.263	No	×
WBC	0.123	0.000	No	−0.117	0.522	No	10.019	0.002	Yes	×
RBC	0.070	0.610	Yes	0.037	0.002	Yes	3.062	0.080	No	×
Hgb	0.140	0.000	No	0.392	0.008	Yes	0.174	0.677	No	×
Hct	0.245	0.000	No	0.005	0.006	Yes	0.997	0.318	No	×
MCV	0.129	0.000	No	−0.641	0.148	No	4.546	0.033	Yes	×
MCH	0.065	0.120	Yes	−0.243	0.670	No	0.001	0.976	No	×
MCHC	0.077	0.025	No	8.046	0.348	No	0.407	0.523	No	×
Plt	0.113	0.000	No	−2.364	0.101	No	16.986	0.000	Yes	×

K-S test: Kolmogorov-Smirnov test; OLS: ordinary least squares regression; B-P test: Breusch-Pagan test; ×: means badly-behaved data.

Discussion

The main finding of this study was that all the results of the hematological and coagulation tests obtained via a CVC by the push-pull method in patients aged 18 and older showed excellent agreement and were within clinically acceptable ranges when compared with the samples obtained by direct venous puncture. Combining the results of ICC and Bland Altman analysis, we can conclude that the push-pull method provides reliable laboratory results without increasing the loss of blood and pain, and there was no hemolysis observed in the paired samples. These

Table 5. Summary of Bland-Altman analysis for 154 paired blood samples ($n = 154$).

Variable	Ratio mean (95% CI)	Lower 95% LoA (95% CI)	Upper 95% LoA (95% CI)	CAL (%)
D-dimer	1.00 (0.99, 1.02)	0.83 (0.81, 0.84)	1.21 (1.18, 1.24)	±50
PT	0.99 (0.99, 0.10)	0.96 (0.95, 0.96)	1.03 (1.03, 1.04)	±15
aPTT	1.01 (1.00, 1.02)	0.93 (0.92, 0.94)	1.09 (1.08, 1.11)	±15
Fib	1.00 (0.99, 1.01)	0.90 (0.89, 0.91)	1.12 (1.10, 1.13)	±20
INR	0.99 (0.98, 0.10)	0.95 (0.95, 0.96)	1.03 (1.03, 1.04)	±15
Antithrombin III	1.00 (1.00, 1.01)	0.94 (0.93, 0.95)	1.08 (1.07, 1.09)	±20
TT	1.01 (1.00, 1.01)	0.95 (0.94, 0.96)	1.07 (1.06, 1.08)	±20
WBC	1.01 (1.00, 1.02)	0.92 (0.90, 0.93)	1.12 (1.10, 1.13)	±15
RBC	1.01 (1.01, 1.02)	0.97 (0.97, 0.98)	1.05 (1.05, 1.06)	±6
Hgb	1.02 (1.01, 1.02)	0.98 (0.97, 0.98)	1.05 (1.05, 1.06)	±6
Hct	1.01 (1.01, 1.02)	0.96 (0.96, 0.97)	1.06 (1.05, 1.07)	±9
MCV	1.00 (0.99, 1.00)	0.99 (0.98, 0.99)	1.00 (1.000.10.01)	±7
MCH	1.00 (1.00, 1.00)	0.98 (0.97, 0.98)	1.03 (1.02, 1.03)	±7
MCHC	1.00 (1.000.10.01)	0.98 (0.97, 0.98)	1.03 (1.02, 1.03)	±8
Plt	1.00 (0.99, 1.01)	0.88 (0.87, 0.90)	1.13 (1.11, 1.15)	±20

PT: prothrombin time; aPTT: activated partial thromboplastin time; Fib: fibrinogen; INR: international normalized ratio; TT: thrombin time; WBC: white blood cell count; RBC: red blood count; Hgb: hemoglobin; Hct: hematocrit; MCV: mean corpuscular volume; MCH: mean corpuscular hemoglobin; MCHC: mean corpuscular hemoglobin concentration; Plt: platelets count; CAL: clinically acceptable limit.

results are consistent with previous research,[10,11] and these findings are beneficial to patients who need multiple consecutive samples taken for blood testing.[18]

In our study, the hematological laboratory results were similar to those of many other studies,[8,11] and there was no significant difference in the Hct levels based on the blood collecting method or infusion status. It seems that the push-pull method did not increase the incidence of hemodilution. However, in some previous studies, coagulation testing was excluded,[8] at the authors' institution, double-cavity CICCs and PICCs were most frequently used for adult patients, and a heparin solution (10 units/mL) was still used to lock catheters in some patients with special situations, such as a high coagulation state. Therefore, blood sampling for coagulation testing via heparin-locked central catheters has the risk of heparin contamination, and the accuracy for the results of coagulation tests have been inconclusive.[19] It is controversial whether coagulation tests can be drawn from heparinized catheters. At present, studies on the coagulation tests mainly focus on the discard method, the results of which support the equivalency in partial coagulation tests by the discard method.[20,21] Therefore, in the present stage the discard method is the most frequently accepted technique that ensures a sample free of contaminants, such as saline or heparin. However, the discard method is a risky procedure in terms of acquired anemia, in addition, the lack of standard for the discard volume could also lead to difficulties in clinical application. The results of this study showed that the push-pull method was considered a reliable method based on comparisons to direct venous puncture, and all coagulation values were within the clinically expected limits, which also supports the reliability of the samples drawn using this method, the same results were obtained in a study by Penwarden et al.[15]

In our study, we selected 4 Fr PICCs, 14/18-gauge double lumen and 16-gauge single lumen CICCs for research, and a 6 mL withdraw and return volume was determined to remove catheter substances, there was no significant difference in the laboratory results based on the type of catheter. A pediatric study selected 2.6 Fr to 4 Fr catheters and determined a 4 mL withdraw and return volume, which showed that the method was equivalent to the discard method when drawing samples for coagulation tests via CVADs.[13] A study conducted by Lokeskrawee[22] selected a 16/16-gauge double lumen CICC and a 10 mL withdraw and return volume, this study took blood samples after successful CICC insertion, and the line was flushed the line with 10 mL of normal saline and three push-pull sessions were performed, the accuracy was more than 90% for almost all the laboratory values except aPTT (85.5%) and aPTT ratio (86.7%), but those errors were still within the allowable range. In conclusion, although similar studies have been published, either the study population, type of catheters or withdraw and return volume was different, but the results all possessed some clinical meaning, and we need data on the best method for blood sampling using a central catheter in a further study.

In addition, according to the related expert consensus in China, removing and replacing the used needleless connector is recommended after collecting blood samples from the CVADs. Meanwhile, given that the needleless connector might increase turbulence and could lead to hemolysis, the connector can be more polluted by blood because of the push-pull method, so different from other

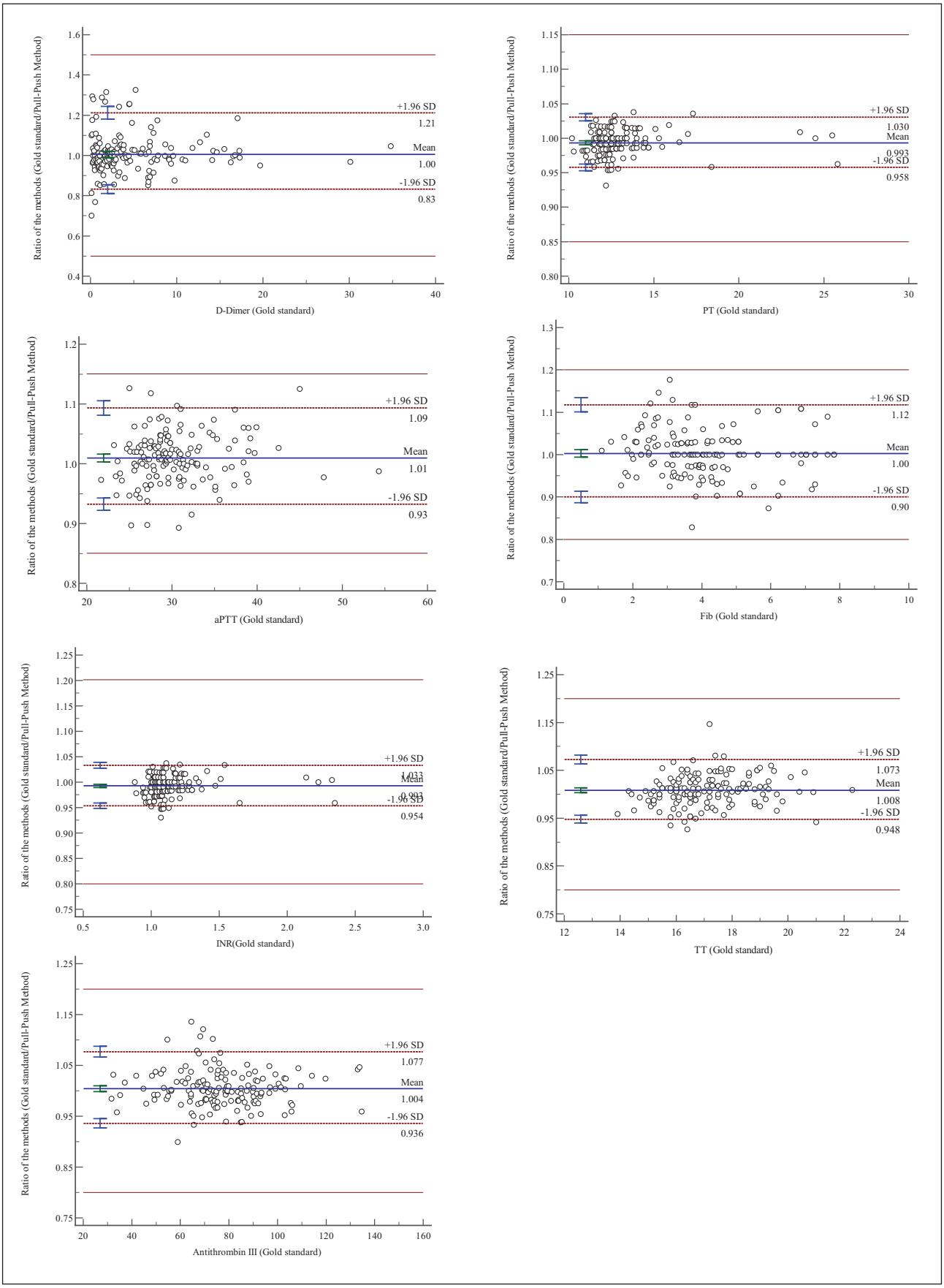

Figure 1. Ratio Bland-Altman plots of coagulation.

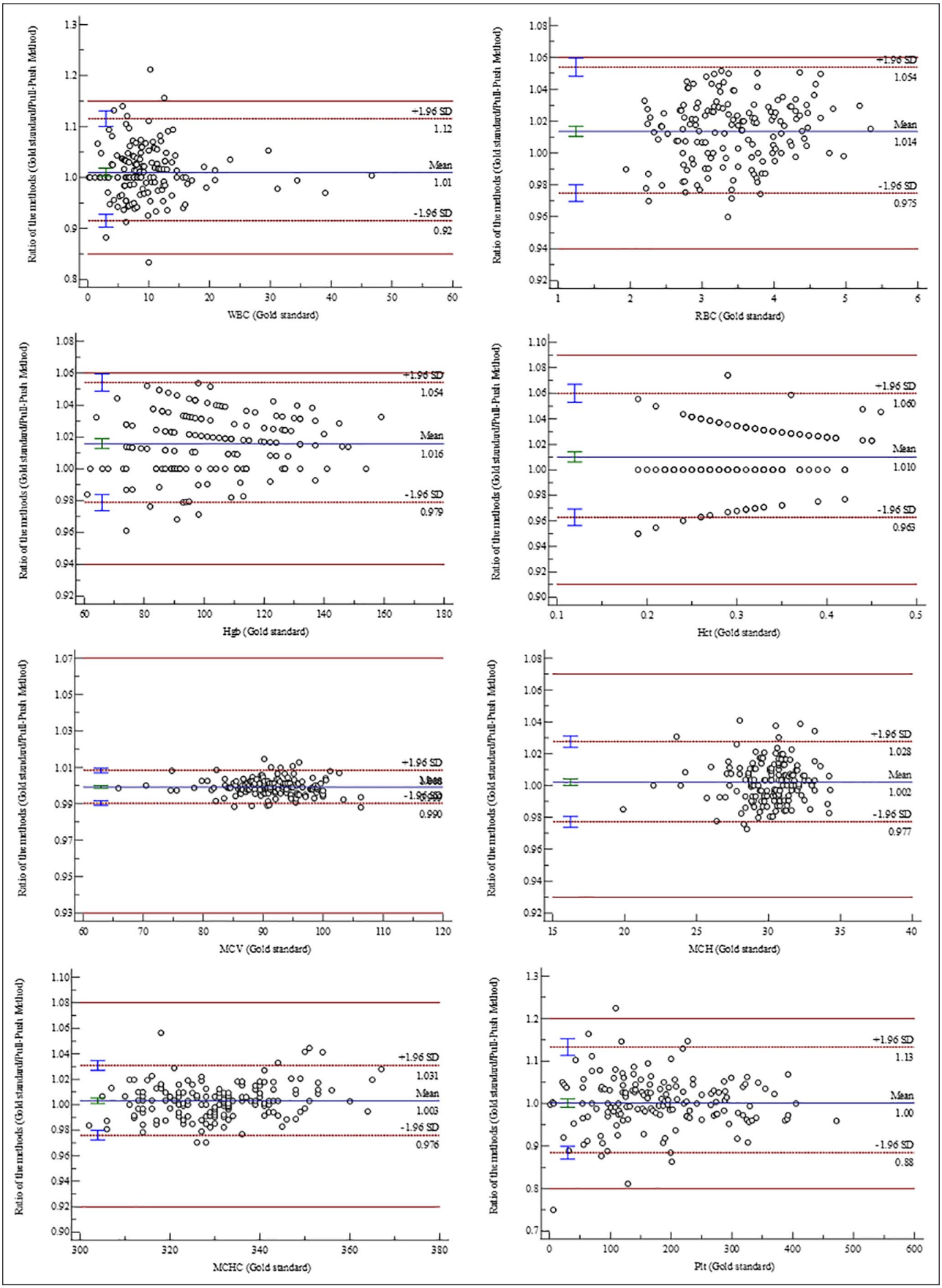

Figure 2. Ratio Bland-Altman plots of hematology.

studies, our blood collection protocol used a central catheter without a needle free connector. However, in our study, we did not assess the infection risk of this method, on the one hand, the study did not exclude patients with fever, on the other hand, in this study each patient only underwent a blood collection behavior via a catheter, and we could not determine whether the patient's infection was related to the behavior. In the related existing study, most push-pull sampling techniques adopted needleless connector or injection cap, only two pediatric studies have reported infection results, and no infections were identified probably because the sample sizes were all small.[10,11] Moreover, every time we collected blood samples by this method, a needleless connector will be discarded, which would cost RMB 30.2 (€ 4.29) and was unquestionably expensive. This is a limitation of our study, therefore, in the future, we will continue working on an optimized and economical push-pull sampling procedure, and it is more necessary to conduct a prospective study on infection risk related to this method.

This study had several limitations. First, the study only focused on laboratory values of hematologic and coagulation tests. Although other laboratory results were not reported in this study, the blood ionogram, renal and liver function tests and plasma gentamicin concentrations have been reported in past studies, but it is impossible to generalize this method to all laboratory tests due to the differences between studies. Second, this study also failed to compare the hemolysis of samples between the two blood collection methods, because the probability of hemolysis is very low, and it is impossible to make an effective statistical comparison. Third, compared to the venipuncture or discard method for blood collection, the current study is a high-cost technique, and we will continue to work to perfect the pull-push technology from the perspective of cost-effective improvement.

In conclusion, our study focused on two laboratory tests of coagulation and hematologic in patients aged 18 and older, and we took blood samples via a central catheter without the needle free connector by push-pull method. The results confirmed that the push-pull method is a safe and reliable method for blood collection without discarding any of the blood, and shows substitutability and reliability when compared with the laboratory results of samples obtained by direct venous puncture. Therefore, the push-pull method is recommended for clinical use, especially in the intensive care unit. Meanwhile, we emphasize that physicians should prescribe blood sampling in a more logical manner when a central line is available in order to save the patient's blood.

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Contributors

Yi Qin, Lingli Wang, and Xiaomei Zhang contributed to the design of the study, analysis and interpretation of results, the first draft of the paper, revision of draft and approval of the final manuscript. Yan Hu and Yu Chen contributed to interpretation of the statistical analysis and revision of draft. Feng Wang, Ming Cui, and Yingjuan Shi contributed to laboratory inspection work and the statistical analyses. We would also like to thank Xiaohong Jin, Xiaoqin Liu, Hailan Qian, Xiaoyan Chen, Huifen Xu, Yunlan JI, Ping Yi, and Ya Wang for their help with blood specimen collection.

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