Published in final edited form as:

J Infus Nurs. 2018 ; 41(3): 189–197. doi:10.1097/NAN.0000000000000279.

A Standard Push-Pull Protocol for Waste-Free Sampling in the PICU

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Abstract

Blood sampling is a major source of blood loss in the pediatric intensive care unit (PICU). Blood-sparing sampling techniques such as the push-pull method can significantly reduce sampling-related blood loss and protect patients from anemia and blood transfusions. The push-pull method is supported by research evidence for central venous catheter (CVC) sampling, but research protocols differ and not all CVCs and laboratory tests have been studied. A standard push-pull protocol for the PICU was developed, implemented, and evaluated in this evidence-based practice project. Results show that the protocol can be used safely and reliably as a standard waste-free sampling method in the PICU.

Keywords

push-pull; pediatric; blood sampling; central venous catheter; CVC; peripherally inserted central catheter; PICC; blood conservation

Patients in the pediatric intensive care unit (PICU) are significantly burdened by sampling-related blood loss and anemia. In a multicenter study of anemia in the PICU, Bateman and colleagues¹ found that nearly three-quarters of patients were anemic, with the majority becoming anemic after admission. Patients sustained almost 3 times more blood loss from sampling in the PICU than from all other causes combined, making blood sampling by far the greatest contributor to hospital-acquired anemia, as well as a predictive factor for blood transfusions. Both anemia and blood transfusions in Bateman's study had a negative impact on patients' recovery; patients who acquired anemia spent more days both in the PICU and on the ventilator, while patients who received blood transfusions had a higher risk of complications and death.

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The authors of this article have no conflicts of interest to disclose.

A study by Valentine and Bateman² showed that patients with central venous catheters (CVCs) had significantly more sampling-related blood loss than other PICU patients. Sampling from CVCs is often preferred to venipunctures in the PICU because it is easy and painless for patients who have frequent laboratory tests or limited venipuncture sites; however, CVC sampling is not without risks, including bloodstream infection, catheter occlusion, hemolysis of sample, and sample dilution or contamination. Blood loss in Valentine's study was largely due to blood that was wasted from CVCs before sampling, which is a standard practice for removing solutions that could dilute or contaminate the sample. The amount of waste or discard needed for an accurate sample can depend on the size of the CVC, as well as the potential for infusions in the CVC to affect the laboratory test being drawn; coagulation tests, for example, require a larger discard if drawn from a catheter containing heparin. Evidence-based recommendations for discard amounts are limited, but a review of research including adult CVC and arterial catheter studies shows that a discard volume of 3 to 6 times the volume of the catheter (approximately 2-5 mL for pediatric CVCs) is appropriate for most scenarios in the PICU.³⁻⁵ Valentine evaluated the impact of discard volumes and found that even with a conservative volume of 2 mL, discards more than doubled patients' sampling-related blood loss.²

Push-pull is a method of sampling from CVCs without wasting blood. Instead of taking a discard, the method repeatedly withdraws and returns the patient's blood to clear the catheter before sampling. The push-pull method is a closed system, meaning that blood is withdrawn and returned without being disconnected from the catheter. By protecting blood from exposure to air and pathogens, closed systems reduce the risk of returning clotted or contaminated blood and are recommended by the Infusion Nurses Society's *Infusion Therapy Standards of Practice* (the *Standards*).⁶ Push-pull sampling and closed-system setups for discard returns are the only blood-sparing sampling methods included in the *Standards*.^{6(S86-S87)} Although research evidence for returning discards is limited to the adult intensive care population, studies show that it can reduce sampling-related blood loss by half and blood transfusions by nearly half.⁷⁻¹⁰ Compared to closed-system setups for discard returns, push-pull sampling is less costly in its use of equipment and nursing time, but has a similar blood-sparing benefit for patients.

While research evidence supports the push-pull method for CVC sampling in both adult and pediatric populations, some common CVCs and laboratory tests have not been specifically studied. More evidence is needed to demonstrate the suitability of the push-pull method for drawing coagulation tests and blood gases, as well as for sampling from nontunneled CVCs and peripherally inserted central catheters (PICCs). Especially for pediatric PICCs with lumens smaller than 3 Fr, there is a lack of research on blood sampling in general and a need for studies supporting push-pull and other sampling methods.

PURPOSE

The goal of this evidence-based practice project was to:

- Standardize a push-pull protocol for the majority of laboratory tests and CVCs in the PICU setting, and

- Determine if a standardized push-pull protocol could be safely and reliably used in the PICU as a routine sampling method.

LITERATURE REVIEW

In studies by Holmes et al,¹¹ Barton et al,¹² and Adlard et al,¹³ push-pull sampling is supported for drawing metabolic panels and complete blood counts (CBCs) from adult and pediatric patients with implanted ports and tunneled CVCs. The volume of blood withdrawn and returned in these protocols ranges from 3 to 6 mL, and the number of times that blood is withdrawn and returned before sampling varies from 3 to 5 times; push-pull sampling was not associated with any risk of catheter occlusion or infection in the 2 studies that monitored catheter complications.

Studies by Chen et al,¹⁴ Skolnik et al,¹⁵ and Kontny et al,¹⁶ support push-pull sampling for drawing drug levels from pediatric patients with implanted ports and tunneled CVCs using the dosing lumen (the lumen used for drug infusion). Withdrawn and returned volumes in these studies are 4 to 5 mL and are withdrawn and returned 4 to 5 times before sampling. Catheter occlusions and infections were monitored in Chen's study and were not identified as risks of push-pull sampling.¹⁴ Skolnik's study measured how much drug was removed from the dosing lumen by different flushing solutions and volumes, as well as by different withdrawn and returned volumes and repetitions. Of note, the study found that blood and albumin were more effective flushing agents than 0.9% sodium chloride and that a 3- to 6-mL flush of 0.9% sodium chloride was as effective as a 9-mL flush. A push-pull protocol of 5 mL withdrawn and returned 5 times was the only protocol tested by the study in vivo, but an in-vitro protocol of 5 mL withdrawn and returned 3 times was found to be effective, clearing 99% or more of drug from the catheter.¹⁵

A study by Penwarden¹⁷ supports the push-pull method for drawing prothrombin time (PT) and international normalized ratio (INR) samples from adult patients with nonheparinized implanted ports. It is the only study to look at coagulation tests and uses a push-pull protocol of withdrawing and returning 6 mL 4 times.

The infection risk of returning blood to a patient through a CVC is a common concern, although it is a risk that has not been well researched or confirmed. Evidence in the literature is limited to an older study by Hinds et al¹⁸ in which discarded blood from CVCs of nonneutropenic pediatric oncology patients was subjected to both clean and unclean conditions and then cultured for the presence of fungal or bacterial microbes. The authors found no microbial growth in any of the cultures and concluded that blood returned through CVCs using aseptic technique was not a risk for infection.

Another concern that has not been researched adequately is the risk of introducing clots to a patient when returning blood through a CVC. Only 1 study by Cosca et al¹⁹ has investigated this risk, but the study is older and has some significant limitations. The authors acknowledged that while clots were present in blood withdrawn from CVCs, the implications for returning blood are unclear because the filter (40 micron) used to identify clots was much smaller than a standard blood product filter (170 micron), and because clots

could have been preexisting in the catheter and introduced to the patient any time the catheter was used. Another limitation is the excessive time (5 minutes) the blood was sitting outside the patient before being filtered.

IMPLEMENTATION

A standardized push-pull protocol for this project was determined by taking the average withdrawn and returned volume and the average number of repetitions, 4 mL 4 times, from a review of protocols in the literature. A 4 mL withdraw and return volume was also 6 times the average deadspace (priming volume) of most CVCs used in the project, which is a recommended discard volume for drawing coagulation tests from heparinized catheters.⁵

Standardized push-pull protocol (Figure 1):

1. Attach a 10-mL syringe with 3 to 5 mL 0.9% sodium chloride to the catheter and flush using push-pause technique (a pulsatile flushing motion that helps clear the catheter by creating turbulence in the lumen).
2. Keep the 10-mL syringe attached and use to withdraw and return 4 mL through the catheter a total of 4 times.
3. Attach a new syringe and withdraw sample(s) from the catheter.
4. Attach a 10-mL 0.9% sodium chloride syringe and flush the catheter with 3 to 5 mL using push-pause technique.

This project was implemented as an evidence-based practice initiative on a 24-bed PICU and a 30-bed acute cardiac unit (ACU) at a quaternary children's hospital in the Southwest. Patient populations in the PICU and ACU were a mix of intermediate-acuity and high-acuity patients, including level 1 traumas, organ transplants, and those receiving medical, surgical, and cardiovascular intensive care. The project was presented to the Institutional Review Board and exempted from oversight.

A convenience sample of PICU and ACU patients was used, with the following demographics and catheter data:

- Sample size: 37 patients, 88 total draws
- Age range: 2 months to 23 years old; median age of 4 years
- Gender: 24 male, 13 female
- CVC types: 15 PICCs (6, 2.6 Fr; 6, 3 Fr; 3, 4 Fr), 19 nontunneled CVCs, 2 tunneled CVCs, 3 implanted ports
- CVC infusions: 51% heparin locked (10 unit/mL), 2% sodium chloride locked, 11% total parenteral nutrition (TPN), 29% heparin-sodium chloride (1 unit/mL), 7% maintenance intravenous (IV) fluids or medications
- CVC approximate dead-space, including extension tubing: 0.4 to 0.8 mL

Patients with the following CVCs and laboratory orders were identified for inclusion in the project:

- PICC
- Nontunneled CVC
- Tunneled CVC
- Implanted port
- CBC
- Basic or comprehensive metabolic panel
- Coagulation test
- Venous blood gas
- Drug level

The following CVCs and laboratory tests were excluded:

- PICCs smaller than 2.6 Fr
- Transthoracic catheters
- Coagulation tests for heparin titration

PICU and ACU nurses were educated about the project and trained in using the push-pull protocol. The following sampling instructions were also given:

- Access the CVC from the needleless connector at the hub; access CVCs infusing continuous IV fluids from the needleless connector on a stopcock very close to the hub (<0.4 mL deadspace between the hub and the access port).
- Flush using push-pause technique.
- Discontinue the push-pull protocol if unable to withdraw and return 4 mL within a minute.

Nurses were given the following trouble-shooting tips for inadequate blood return:

- Reposition extremity where the catheter is located.
- Check for catheter kinks under the dressing.
- Withdraw blood using pull-pause technique: Pull back on the plunger in small increments and pause, so that blood fills the syringe at the same rate that the plunger is pulled back (promotes blood flow into the lumen of smaller-French catheters and prevents hemolysis).

For each draw, nurses filled out a short form indicating the following: patient, date and time of draw, type of laboratory sample(s) drawn, type of CVC, status of CVC (lock or infusion solutions), difficulties or trouble-shooting, and any other comments. Forms were used to follow results and catheters for complications up to 7 days after a push-pull draw; samples were not treated differently. Samples drawn by the push-pull method were collected over a 4-month period. A within-subject design was used, in which laboratory values from push-pull samples were compared to the patient's preceding and following laboratory values

drawn according to standard practice (discard method) using both clinical and statistical analysis.

From a large set of laboratory values, the following were chosen for analysis because of their relevance to treatment and clinical decisions:

- Metabolic: sodium, potassium, blood urea nitrogen, creatinine, glucose, calcium, albumin, magnesium, bilirubin
- Hematology: white blood cell count, hemoglobin, hematocrit, platelets, absolute neutrophil count
- Coagulation: activated partial thromboplastin time, PT, INR, fibrinogen, antifactor-Xa
- Blood gas: pH, partial pressure of carbon dioxide, partial pressure of oxygen, base excess, ionized calcium, lactate
- Other: C-reactive protein

Approximately 76% of coagulation tests were drawn from heparinized catheters, and 7% of metabolic tests were drawn from catheters infusing TPN; these conditions were similar for standard practice samples as well.

ANALYSIS

Results from push-pull method and standard samples were analyzed with statistical tools and evaluated for differences with clinical significance, defined as a potential to affect therapy. For statistical analysis, standard and push-pull samples were compared by taking the average value of each method within each subject and comparing these averages across subjects using a paired *t* test. The repeated nature of the data was also used in a linear mixed effect model that included individual measures, with a binary fixed effect indicating whether the draw was done by standard practice or push-pull method and a random intercept term to account for within-subject correlation. Ninety-five percent confidence intervals were reported for the difference in mean laboratory values and for the binary method effect estimated from the mixed model; the boundaries of these intervals being within a clinically insignificant margin was interpreted as evidence for the equivalence of these methods.

Push-pull and standard practice samples were not drawn at the same time, which makes it harder to establish equivalency between the 2 methods. Standard values were typically drawn and compared to push-pull values within 12 to 24 hours, but for ICU patients there could be significant changes during this time due to acute conditions, organ dysfunction, medications, treatments, and transfusions. However, because these factors had an equal chance of affecting both push-pull and standard samples and for many patients the dataset included multiple samples from both methods, the authors expected that these factors would not bias the results in any systematic way. For unstable ICU patients, the reliability of push-pull values was also evidenced by the consistency of values with clinical history, condition, and treatment.

RESULTS

No significant differences were found in the means within each subject between the 2 methods, as evidenced by *P* values $>.05$ and clinically reasonable confidence intervals and mean differences (Table 1, Figure 2). The mixed model analysis found a statistical difference in glucose that was not clinically significant (Table 2); glucose values from the push-pull technique were an average of 7.5 points lower than standard values with a confidence interval of 1.92 to 13.0 points lower. Push-pull values for antifactor-Xa and drug levels (vancomycin and phenobarbital) were clinically consistent with values from standard draws, but the number of patients with levels was not sufficient for statistical analysis.

No increase in catheter occlusions or infections was associated with the project, as tracked by the hospital's vascular access team. Catheters were followed up to 7 days after a push-pull method draw and continued to be sampled from using standard practice. Over the course of the 4-month project, a total of 8 withdrawal occlusions (resolved when t-PA was used) were identified within this 7-day window, with the majority occurring between 3 to 7 days after a push-pull draw; 6 of the 8 occlusions were in PICCs and were evenly distributed among catheter sizes (2.6 Fr, 3 Fr, and 4 Fr). No catheter-related infections within 7 days of a push-pull draw were identified.

Several sampling errors, analysis errors, and problems with sample integrity occurred for both push-pull and standard practice draws during the project and were excluded from the dataset. The following samples or values were excluded: 2 push-pull samples presumed dilute due to protocol error, 1 hemolyzed push-pull potassium value, 1 standard hemoglobin value presumed critically low due to point-of-care equipment error, 6 standard glucose values presumed critically high due to TPN contamination from the nonsampling lumen, and 1 standard CBC sample presumed clotted.

DISCUSSION

Results of this project are consistent with previous research evidence supporting the safety and reliability of push-pull sampling. Additionally, this project supports the routine use of a standardized push-pull sampling method for most laboratory tests and CVCs, and demonstrates that the push-pull method is comparable to discard method sampling for clearing contaminants such as TPN or heparin from a catheter when drawing metabolic or coagulation laboratory samples. While a statistically significant difference was found between glucose values in this project, the difference did not have clinical significance and was also within the accuracy margin ($\pm 15\%$) required by the US Food and Drug Administration for glucose monitoring.²⁰ Nurses in most cases had positive feedback and were satisfied with the ease of the push-pull method. The effect of push-pull sampling on individual catheter complications could not be differentiated from the effect of standard practice sampling, as both methods were used; however, the overall absence of increased complications during the project suggests that the push-pull method does not increase risks of catheter occlusion or infection. Because hemolysis was noted by the laboratory for only 1 push-pull sample during the project, it was not identified as a statistically significant risk.

A significant finding of this project is that the push-pull method can be used for sampling from pediatric PICCs, which have not been included in previous push-pull method studies and have a limited evidence base for blood sampling in general. Difficulty obtaining adequate blood return from 2.6 Fr PICCs, which are the smallest size used for blood draws, was reported several times and prevented push-pull sampling in 1 case; the ease of withdrawing blood through these small catheters was improved by pull-pause technique, but larger PICCs (3 Fr and greater) may be more suitable for routine push-pull sampling.

This project used coagulation tests drawn from heparinized catheters, which is controversial. Studies comparing coagulation values from heparinized catheters (venous or arterial) and peripheral samples do not agree on whether accurate values can be obtained from heparinized catheters or what discard volume is sufficient to prevent sample contamination.^{21–24} Push-pull coagulation values in this project were considered reliable based on comparisons to samples drawn from CVCs according to standard practice (discard method), not to peripheral draws. However, push-pull values were all within either normal or clinically expected limits, which also supports the reliability of samples drawn using this method.

Limitations

To avoid the negative impact on patients of venipuncture pain or unnecessary blood loss, this project had several limitations including the comparison of push-pull method and standard samples not drawn simultaneously, as well as the comparison of push-pull samples to standard CVC draws versus peripheral venipunctures. Evaluation of catheter complications in this project was limited by the concurrent use of both push-pull and discard-method sampling. Additionally, in gathering data for some laboratory tests and CVCs, the project's small sample size was a limitation.

Research Implications

While the purpose of this project was to determine a standard push-pull protocol for the PICU setting, further research could determine a standardized push-pull protocol for other settings or universal use; a larger withdraw and return volume or more repetitions could be needed for accurate values from CVCs with a greater deadspace, or for levels of drugs highly absorbed by the catheter. For drug levels from dosing lumens and coagulation values from heparinized catheters, additional research comparing the push-pull technique to the gold standard of venipuncture is recommended. The potential to sample from 2.6 Fr PICCs using push-pull method is a finding of this project that merits further investigation with a larger sample size, or a protocol using smaller withdraw and return volumes, to determine if blood return from these small catheters is adequate for routine push-pull sampling.

CONCLUSION

A standard, evidence-based push-pull protocol can be used routinely in the PICU as a simple, safe, and reliable CVC sampling method that protects patients from the negative impact of blood loss and anemia.

Biographies

Clare McBride, BSN, RN, CCRN, is a pediatric intensive care and cardiac nurse at Oregon Health and Science University's Doernbecher Children's Hospital. She previously worked at Rady Children's Hospital in San Diego and presented this evidence-based practice project at the American Association of Critical Care Nurses' annual teaching conference.

Suzan Miller-Hoover, DNP, RN, CCNS, CCRN-K, has been in the nursing profession for more than 35 years. An experienced national speaker and peer-reviewed author, Dr Miller-Hoover is passionate about evidence-based best practice and pediatrics.

James A. Proudfoot, MSc, is a senior statistician at the University of California at San Diego, Altman Clinical and Translational Research Institute. He has consulted on numerous clinical trials and is a coauthor of more than 25 articles.

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1. Attach a 10-mL syringe with 3 to 5 mL 0.9% sodium chloride to the catheter and flush using push-pause technique.

2. Keep the 10-mL syringe attached and use to withdraw and return 4 mL through the catheter a total of 4 times.

3. Attach a new syringe and withdraw sample(s) from the catheter.

4. Attach a 10-mL 0.9% sodium chloride syringe and flush the catheter with 3 to 5 mL using push-pause technique.

Figure 1.
Standardized push-pull protocol.

Figure 2.

Means (standard deviation) of within subject means by technique: push-pull or standard method. Abbreviations: Alb, albumin; ANC, absolute neutrophil count; aPTT, activated partial thromboplastin time; BE, base excess; Bili, bilirubin; BUN, blood urea nitrogen; Ca, calcium; CI, confidence interval; Cr, creatinine; CRP, C-reactive protein; Fib, fibrinogen; Glu, glucose; Hct, hematocrit; Hgb, hemoglobin; iCal, ionized calcium; INR, international normalized ratio; K, potassium; Lac, lactate; Mg, magnesium; Na, sodium; pCO₂, partial

pressure of carbon dioxide; pH, potential hydrogen; Plt, platelets; pO₂, partial pressure of oxygen; PT, prothrombin time; WBC, white blood cell count.

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TABLE 1 Means (Standard Deviation) of Within Subject Means by Technique: Push-Pull or Standard Method^a

NA	Standard (n = 35)	Push-Pull (n = 35)	Difference (95% CI)	<i>P</i> value
	140.96 (8.12)	140.15 (7.34)	0.81 (−0.48, 2.10)	.209
K	Standard (n = 36)	Push-Pull (n = 36)	Difference (95% CI)	<i>P</i> value
	3.88 (0.49)	3.92 (0.64)	−0.04 (−0.18, 0.10)	.587
BUN	Standard (n = 35)	Push-Pull (n = 35)	Difference (95% CI)	<i>P</i> value
	22.34 (17.04)	22.47 (16.65)	−0.12 (−1.11, 0.87)	.805
Cr	Standard (n = 35)	Push-Pull (n = 35)	Difference (95% CI)	<i>P</i> value
	0.58 (0.86)	0.57 (0.83)	0.01 (−0.01, 0.03)	.47
Glu	Standard (n = 35)	Push-Pull (n = 35)	Difference (95% CI)	<i>P</i> value
	108.34 (30.39)	103.41 (27.62)	4.93 (−1.03, 10.89)	.102
Ca	Standard (n = 35)	Push-Pull (n = 35)	Difference (95% CI)	<i>P</i> value
	9.11 (0.73)	9.18 (0.78)	−0.07 (−0.23, 0.09)	.391
Alb	Standard (n = 28)	Push-Pull (n = 28)	Difference (95% CI)	<i>P</i> value
	3.37 (0.55)	3.39 (0.63)	−0.02 (−0.21, 0.17)	.824
Mg	Standard (n = 27)	Push-Pull (n = 26)	Difference (95% CI)	<i>P</i> value
	2.00 (0.28)	2.03 (0.31)	−0.03 (−0.12, 0.06)	.469
Bili	Standard (n = 12)	Push-Pull (n = 11)	Difference (95% CI)	<i>P</i> value
	2.55 (2.84)	2.99 (3.38)	−0.24 (−0.86, 0.37)	.399
WBC	Standard (n = 26)	Push-Pull (n = 27)	Difference (95% CI)	<i>P</i> value
	10.29 (5.88)	10.68 (6.12)	−0.51 (−1.72, 0.70)	.395
Hgb	Standard (n = 28)	Push-Pull (n = 29)	Difference (95% CI)	<i>P</i> value
	11.39 (1.93)	11.49 (1.72)	−0.09 (−0.51, 0.32)	.65
Hct	Standard (n = 26)	Push-Pull (n = 27)	Difference (95% CI)	<i>P</i> value
	33.87 (6.29)	34.10 (5.47)	−0.22 (−1.41, 0.97)	.703
Plt	Standard (n = 26)	Push-Pull (n = 27)	Difference (95% CI)	<i>P</i> value
	183.88 (106.23)	202.81 (124.95)	−8.66 (−23.27, 5.95)	.234
ANC	Standard (n = 24)	Push-Pull (n = 25)	Difference (95% CI)	<i>P</i> value
	6488.45 (4539.21)	7113.56 (4692.35)	−696.50 (−1974.29, 581.29)	.271
aPTT	Standard (n = 10)	Push-Pull (n = 10)	Difference (95% CI)	<i>P</i> value
	44.44 (19.35)	43.49 (18.94)	0.95 (−1.49, 3.39)	.402
PT	Standard (n = 9)	Push-Pull (n = 9)	Difference (95% CI)	<i>P</i> value
	17.57 (4.26)	17.53 (4.83)	0.03 (−0.99, 1.05)	.945
INR	Standard (n = 9)	Push-Pull (n = 9)	Difference (95% CI)	<i>P</i> value
	1.47 (0.42)	1.47 (0.48)	−0.00 (−0.10, 0.10)	.941
Fib	Standard (n = 7)	Push-Pull (n = 7)	Difference (95% CI)	<i>P</i> value
	404.77 (228.80)	429.82 (238.38)	−25.05 (−55.93, 5.82)	.094
pH	Standard (n = 12)	Push-Pull (n = 12)	Difference (95% CI)	<i>P</i> value

	7.39 (0.07)	7.38 (0.05)	0.01 (−0.00, 0.03)	.061
pCO₂	Standard (n = 12)	Push-Pull (n = 12)	Difference (95% CI)	<i>P</i> value
	47.73 (7.72)	47.10 (8.39)	−0.24 (−2.41, 1.93)	.808
pO₂	Standard (n = 12)	Push-Pull (n = 12)	Difference (95% CI)	<i>P</i> value
	39.14 (6.74)	38.26 (5.85)	−0.76 (−4.99, 3.47)	.698
BE	Standard (n = 13)	Push-Pull (n = 12)	Difference (95% CI)	<i>P</i> value
	1.58 (5.01)	1.58 (4.16)	0.63 (−0.51, 1.76)	.250
iCal	Standard (n = 11)	Push-Pull (n = 11)	Difference (95% CI)	<i>P</i> value
	1.25 (0.08)	1.24 (0.05)	0.00 (−0.02, 0.02)	.978
Lac	Standard (n = 5)	Push-Pull (n = 5)	Difference (95% CI)	<i>P</i> value
	1.84 (0.93)	2.05 (0.51)	0.18 (−0.83, 1.18)	.610
CRP	Standard (n = 10)	Push-Pull (n = 10)	Difference (95% CI)	<i>P</i> value
	9.00 (11.51)	8.46 (10.40)	0.55 (−1.66, 2.75)	.589

Abbreviations: Alb, albumin; ANC, absolute neutrophil count; aPTT, activated partial thromboplastin time; BE, base excess; Bili, bilirubin; BUN, blood urea nitrogen; Ca, calcium; CI, confidence interval; Cr, creatinine; CRP, C-reactive protein; Fib, fibrinogen; Glu, glucose; Hct, hematocrit; Hgb, hemoglobin; iCal, ionized calcium; INR, international normalized ratio; K, potassium; Lac, lactate; Mg, magnesium; Na, sodium; pCO₂, partial pressure of carbon dioxide; pH, potential hydrogen; Plt, platelets; pO₂, partial pressure of oxygen; PT, prothrombin time; WBC, white blood cell count.

^aSignificance determined by paired *t* test.

TABLE 2

Regression Results for Univariable Linear Mixed Model Fits for Each Label Outcome^a

		Estimate	Standard Error	95% CI	t value	P value
NA	(Intercept)	140.526	1.275	(138.013, 143.040)	110.217	< .001 ^b
	Push-Pull	0.053	0.570	(-1.071, 1.177)	0.093	.926
K	(Intercept)	3.895	0.091	(3.716, 4.074)	42.969	< .001 ^b
	Push-Pull	0.002	0.062	(-0.119, 0.124)	0.036	.971
BUN	(Intercept)	23.779	3.145	(17.562, 29.996)	7.562	< .001 ^b
	Push-Pull	-1.881	2.206	(-6.243, 2.481)	-0.853	.395
Cr	(Intercept)	0.626	0.156	(0.318, 0.934)	4.018	< .001 ^b
	Push-Pull	-0.078	0.090	(-0.256, 0.100)	-0.864	.389
Glu	(Intercept)	109.613	5.014	(99.727, 119.499)	21.861	< .001 ^b
	Push-Pull	-7.491	2.816	(-13.042, -1.939)	-2.660	.008 ^c
Ca	(Intercept)	9.187	0.121	(8.948, 9.427)	75.833	< .001 ^b
	Push-Pull	-0.030	0.102	(-0.231, 0.172)	-0.292	.770
Alb	(Intercept)	3.405	0.107	(3.193, 3.616)	31.878	< .001 ^b
	Push-Pull	0.019	0.078	(-0.137, 0.174)	0.237	.813
Mg	(Intercept)	2.018	0.053	(1.913, 2.124)	38.012	< .001 ^b
	Push-Pull	0.011	0.033	(-0.055, 0.077)	0.326	.745
Bili	(Intercept)	2.726	0.980	(0.772, 4.680)	2.782	.007 ^c
	Push-Pull	0.285	0.755	(-1.220, 1.790)	0.377	.707
WBC	(Intercept)	10.209	1.144	(7.941, 12.477)	8.924	< .001 ^b
	Push-Pull	0.366	0.512	(-0.648, 1.381)	0.715	.476
Hgb	(Intercept)	11.327	0.324	(10.688, 11.966)	34.984	< .001 ^b
	Push-Pull	0.184	0.181	(-0.174, 0.542)	1.016	.311
Hct	(Intercept)	33.649	1.105	(31.459, 35.839)	30.455	< .001 ^b
	Push-Pull	0.544	0.577	(-0.599, 1.687)	0.943	.348
Plt	(Intercept)	193.935	23.018	(148.305, 239.566)	8.425	< .001 ^b
	Push-Pull	6.875	8.617	(-10.207, 23.956)	0.798	.427
ANC	(Intercept)	6742.008	907.895	(4937.174, 8546.843)	7.426	< .001 ^b
	Push-Pull	218.768	467.05	(-709.696, 1147.233)	0.468	.641
aPTT	(Intercept)	44.615	6.235	(32.058, 57.172)	7.156	< .001 ^b

		Estimate	Standard Error	95% CI	<i>t</i> value	<i>P</i> value
	Push-Pull	−0.336	2.883	(−6.144, 5.471)	−0.117	.908
PT	(Intercept)	17.411	1.562	(14.212, 20.611)	11.147	< .001 ^{<i>b</i>}
	Push-Pull	0.489	0.786	(−1.121, 2.098)	0.622	.539
INR	(Intercept)	1.457	0.154	(1.140, 1.773)	9.432	< .001 ^{<i>b</i>}
	Push-Pull	0.053	0.080	(−0.109, 0.216)	0.672	.507
Fib	(Intercept)	411.126	88.872	(227.281, 594.971)	4.626	< .001 ^{<i>b</i>}
	Push-Pull	8.049	36.617	(−67.699, 83.798)	0.220	.828
pH	(Intercept)	7.386	0.017	(7.353, 7.418)	446.508	< .001 ^{<i>b</i>}
	Push-Pull	−0.007	0.011	(−0.029, 0.016)	−0.594	.554
pCO₂	(Intercept)	47.617	2.357	(42.926, 52.309)	20.202	< .001 ^{<i>b</i>}
	Push-Pull	−0.164	1.568	(−3.285, 2.956)	−0.105	.917
pO₂	(Intercept)	40.067	1.598	(36.887, 43.247)	25.081	< .001 ^{<i>b</i>}
	Push-Pull	−1.292	1.703	(−4.681, 2.097)	−0.759	.450
BE	(Intercept)	1.633	1.261	(−0.875, 4.142)	1.296	.199
	Push-Pull	−0.384	0.496	(−1.372, 0.603)	−0.775	.441
iCal	(Intercept)	1.245	0.019	(1.208, 1.283)	66.183	< .001 ^{<i>b</i>}
	Push-Pull	−0.010	0.016	(−0.042, 0.023)	−0.600	.550
Lac	(Intercept)	1.756	0.309	(1.057, 2.456)	5.683	< .001 ^{<i>b</i>}
	Push-Pull	0.252	0.316	(−0.463, 0.966)	0.797	.446
CRP	(Intercept)	10.713	3.874	(2.959, 18.467)	2.766	.008 ^{<i>c</i>}
	Push-Pull	−3.060	2.167	(−7.398, 1.279)	−1.412	0.163

Abbreviations: Alb, albumin; ANC, absolute neutrophil count; aPTT, activated partial thromboplastin time; BE, base excess; Bili, bilirubin; BUN, blood urea nitrogen; Ca, calcium; CI, confidence interval; Cr, creatinine; CRP, C-reactive protein; Fib, fibrinogen; Glu, glucose; Hct, hematocrit; Hgb, hemoglobin; iCal, ionized calcium; INR, international normalized ratio; K, potassium; Lac, lactate; Mg, magnesium; Na, sodium; pCO₂, partial pressure of carbon dioxide; pH, potential hydrogen; Plt, platelets; pO₂, partial pressure of oxygen; PT, prothrombin time; WBC, white blood cell count.

^{*a*} A random intercept is included to account for within-subject variability.

^{*b*} *P* .001

^{*c*} *P* .01