Comparison of accuracy and stability between disposable arterial blood syringes and pre-heparinized syringe in arterial blood gas analysis: a retrospective study

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Abstract

Background Arterial blood gas (ABG) analysis is vital in the emergency department. However, the accuracy and stability of some indicators in ABG analysis are debatable compared with venous ones. Disposable arterial blood syringe (DABS) usage is increasing in clinical practice. To compare the accuracy and stability of venous versus arterial blood results and newly emerging DABS versus traditionally used pre-heparinized syringe (PHS) results, we performed this study.Methods This retrospective study was performed at the emergency department of the Third Xiangya Hospital of Central South University. Participants were divided into two groups PHS and DABS, from which venous and arterial blood was drawn and analyzed either in laboratory or ABG-analyzer. Blood sample results were compared by the Pearson correlation coefficient and t-test. By removing extreme results, the sensitivity analysis was conducted.Results A total of 500 patients (64.80% male, mean age 63.55±16.82) and 400 patients (65.25% male, mean age 62.86±15.65) were enrolled in PHS and DABS groups, respectively. Compared with PHS group, DABS had a quite higher correlation coefficient in K + (0.923 vs. 0.855), Na + (0.911 vs. 0.850) and the differences between venous and arterial of all indicators (K + 0.202mmol/L vs. 0.318mmol/L, P<0.0001; Na + 1.187mmol/L vs. 2.902mmol/L, P<0.0001; Cl - -5.336mmol/L vs. –7.598mmol/L, P<0.0001; Hb -0.898g/L vs. 2.212g/L, P<0.0001; HCT -0.659% vs. 1.269%, P<0.0001) were significantly smaller in DABS group.Conclusion High accuracy was seen in arterial blood results irrespective of the usage of PHS or DABS for sample collection. DABS showed more accurate and stable results, suggesting its role for future medical use.

Background

As an important examination for emergency and critical patients, arterial blood gas (ABG) plays an important role in judging patients' oxygen saturation, electrolyte, hemoglobin (Hb), acid-base balance, and other indicators in a fast manner.

In cases where the patient's condition changes suddenly, ABG analysis can provide clinicians with immediate vital results rather than waiting for the venous blood results to return from the laboratory and delaying the first-aid. ABG analysis is the gold standard method for the assessment of oxygenation and acid-base analysis [1]. In addition, other biochemical indicators, such as blood potassium, sodium, Hb, and hematocrit (HCT), also have important reference values.

In the past, syringe prepared by 0.4% heparin sodium solution (pre-heparinized syringe, PHS) was often used to collect ABG. Due to various factors, such as heparin saline, the accuracy and stability of blood results in ABG analysis, such as electrolyte, Hb, and HCT, were often debatable. In clinical work, different doctors still debate on this matter, and in some studies, different scholars also raised different opinions [2-4].

With the development of science and technology, disposable arterial blood syringe (DABS) has been gradually applied in clinical practice. Without the influence of heparin saline, it remains unknown whether

the accuracy and stability of ABG analysis will be significantly improved. Therefore, the object of this study is comparing the accuracy and stability of indicators in ABG analysis collected by different methods (PHS or DABS) for which one is better.

Methods

The whole research process followed the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) statement. ABG was collected by PHS or DABS *(BD Preset^{TM}, 3 ml)* and analyzed by blood gas analyzer *(ABL 800 FLEX),* which calibrated automatically in every 1 hour. Venous blood was sent to a central laboratory where blood routine was analyzed by blood routine analyzer *(XE-5000),* and the electrolyte was analyzed by the automatic biochemical analyzer *(Hitachi 7600).*

Study population

All patients attending the emergency department of the Third Xiangya Hospital of Central South University between February 01, 2018 and May 30, 2019 were adaptive in the study.

Inclusion criteria

1. Patients from whom arterial blood samples were drawn for ABG analysis and venous blood samples were drawn for the analysis of serum electrolyte and blood routine (Hb, HCT), which can be gained from the results record in the Hospital Information System (HIS) of emergency department of our hospital;
2. Patients from whom both venous and arterial blood samples were drawn in less than 10 minutes difference [3], regarded as almost the same time, which can be identified from the doctor's advice and nursing record in the HIS of emergency department of our hospital.

Exclusion criteria

1. Patients whose interval time between venous and arterial blood sample collection was more than ten minutes or not known.
2. Patients whose method for collecting arterial blood (i.e., PHS or DABS) was unknown, which can be known from the list of expenses of patients recorded in the HIS of emergency department of our hospital.

Grouping method

This is a retrospective study, so only one method would be used to collect artery blood for every patient. Patients were divided into 2 groups according to the different methods of collecting artery blood. In the

PHS group, artery blood was collected using PHS for ABG analyzing and at almost the same time, the venous blood of the same patient was collected using common blood collector for blood routing and electrolyte detecting. In the DABS group, artery blood was collected using DABS for ABG analyzing and at the same time, the venous blood of the same patient was collected using common blood collector for blood routing and electrolyte detecting.

Estimation of sample size

One hundred cases of data were collected in each PHS group and DABS group, and the sample size required for each indicator (potassium, sodium, chlorine, Hb, HCT) was calculated by Power Analysis Sample Size ***(PASS, Version 11.0.7)*** with parameters α=0.05 and β=0.1 (YYW). The target sample size was achieved by expanding the maximum estimated sample size among all indicators by 20%. Finally, 500 cases in the PHS group and 400 cases in DABS group were decided to be collected.

Random sampling method

In the emergency room of our hospital, we began to use DABS instead of PHS for ABG collection since July 2018. Before that time, we only used PHS for artery blood collection and after that time, we used DABS for artery blood collection. To avoid the influence of season and temperature on the ABG analysis results [5], we selected the cases from February to June 2018 for PHS group and February to May 2019 for DABS group, and collected the first 100 cases of every month that met the requirements according to the admission criteria in a consecutive manner [6]. The flow chat for including eligible patients can be seen in Figure 1.

Data collection

Patients' demographic information, such as patients' ID, gender, age, admission time, type of admission, admission scores and blood sample results, such as blood potassium (K^+), sodium (Na^+), chlorine (Cl^-), Hb, HCT, from artery and vein were collected, as well as the method of collecting ABG. Data were collected by two researchers independently (HTT, HLC) in manual from the HIS of emergency department of hospital, and inconsistencies after data checking were confirmed by a third person (JWW). Abnormal and extreme values found in the data analysis process were further confirmed by a fourth person (JYL).

Data analysis

Two indexes, accuracy and stability were used to assess which is better for ABG analysis between PHS and DABS. We regarded the venous results as the gold standard when comparing the two methods for ABG analysis. The difference between arterial and venous results indicates the accuracy. If the mean difference is small, the accuracy of this method is high, vice versa. Standard deviation (SD) of the mean difference indicates the stability. If the SD is small, the stability of this method is high, vice versa.

Data were recorded in Microsoft Excel Home edition 2016 spreadsheet and exported to Statistical Package for the Social Sciences version 23.0 **(SPSS Inc. Chicago, USA**) for analysis. Continuous variables were presented as mean ± standard deviation (SD), and categorical variables as percentages. Data points more than 1.5 or 3 times the length of the box body from the edge of the box-plot were defined as abnormal values and extreme values, respectively [7]. Pearson's correlation coefficient was used to assess the correlation or accuracy of the results between arterial and venous of the same patient in PHS group or DABS group, respectively. Paired t-test was used to assess whether there is statistical significance between arterial and venous results of the same patient in PHS group or DABS group, respectively. Independent samples t-test was used to compare the results between the PHS group and DABS group for whether there is statistical significance that which method is more accuracy and stable. Chi-square test ($\chi 2$) was used to test differences between enumeration data. A P-value of less than 0.05 was considered significant. Test efficiency is equal to 1-β, which was calculated by Power Analysis Sample Size ***(PASS, Version 11.0.7)*.** When test efficiency is more than 90% or β<0.1, test efficiency is high enough for acceptance.

Results

Basic data characteristics

According to the requirement of sample size, 500 cases were enrolled in the PHS group; 64.80% were men; the mean ± SD age at baseline was 63.55±16.82 and 400 cases were enrolled in the DABS group; 65.25% were men; the mean ± SD age at baseline was 62.86±15.65. Baseline characteristics in the research are presented in Table 1. Comparing PHS and DABS group, the type of admission and admission scores had no statistic difference, as well as most venous results of K^+, Na^+, Hb, HCT, which reminds that the two groups have almost the same baseline. On the contrary, statistic difference existed in all the arterial results of K^+, Na^+, Cl^-, Hb, HCT from the two groups.

Smaller differences between arterial and venous results in DABS

Table 2 shows the difference in blood results between venous blood and arterial blood, which is an important index to reflect the accuracy and stability of ABG analysis. Compared with PHS group, the differences between venous and arterial of all indicators (K^+ 0.202mmol/L vs. 0.318mmol/L, P<0.0001; Na^+ 1.187mmol/L vs. 2.902mmol/L, P<0.0001; Cl^- -5.336mmol/L vs. −7.598mmol/L, P<0.0001; Hb

-0.898g/L vs. 2.212g/L, P<0.0001; HCT -0.659% vs. 1.269%, P<0.0001) were significantly smaller in DABS group.

Correlation of biochemical indicators between venous and arterial blood results

Table 3 shows the correlation coefficient of venous and arterial blood results in PHS group or DABS group, respectively. No matter in which way for ABG collection, the correlation coefficient with venous results was quite high. Compared with PHS group, DABS had a little higher correlation coefficient in K^+ (0.923 vs. 0.855), Na^+ (0.911 vs. 0.850).

Sensitivity analysis

Through the analysis of box-plot (Figure 2), some abnormal values and extreme values were found, and some extreme values were quite different. However, to minimize the possibility of data entry errors, data were rechecked by multiple people. The possible reasons were measurement errors, special conditions of patients, or other accidental error. These abnormal and extreme values may have a great impact on the results. So, a sensitivity analysis was conducted by removing all the extreme values.

By comparison, there were 17 extreme values in the PHS group and 31 extreme values in the DABS group. After removing them, the average difference of the relative indicators between venous results and ABG collected by PHS or DABS was almost unaffected, but the standard deviation was obviously reduced. The results are shown in Table 4. At the same time, the adjusted correlation coefficient between venous and arterial blood samples also increased. No matter in which way for ABG collection, the correlation coefficient with venous results was high. Compared with PHS group, DABS had a higher correlation coefficient in all indicators K^+(0.933 vs. 0.916), Na^+(0.921 vs. 0.852), Cl- (0.819 vs. 0.793), Hb (0.986 vs 0.981), HCT (0.978 vs. 0.969) (Table 5).

Discussion

ABG analysis is a very important examination in acute and critical cases. In the past, PHS was used to collect ABG. However, its consistency with venous blood was often questioned by the clinicians [8]. Our study explored the accuracy and stability of indicators of venous blood and ABG collected by PHS and DABS in retrospective research and found that irrespective of the method used for collecting ABG blood sample, the consistency was high, especially ABG collected by DABS.

From the basic characteristics, there was almost no statistical difference in age, gender, type of admission, admission scores and venous blood results between PHS group and DABS group, suggesting that the population composition of the two groups was comparable though the collection duration was

different. Because of the different ways of collecting arterial blood, the difference in arterial biochemical indicators between the two groups is what our study explored.

The qualitative analysis revealed that the correlation coefficient of the blood results between ABG and venous blood was markedly high, no matter which method, PHS or DABS, was used to collect ABG. It is worth mentioning that DABS had a significantly higher consistency in K^+ and Na^+, while PHS seemed to have a higher consistency in Cl^-, Hb, and HCT. But after the sensitivity analysis, all five blood results had higher correlation coefficients in DABS after removing the extreme values.

The quantitative analysis, that is, from the difference of related indicators between venous blood and arterial blood, showed that all the results of arterial blood collected with DABS had less mean differences compared with the venous blood, especially in Hb, whose mean difference was too small to have a statistical difference, suggesting that DABS had a higher accuracy in collecting ABG. Regarding standard deviation, DABS had a smaller standard deviation in K^+ and Na^+. While PHS appeared to have a smaller standard deviation in Cl^-, Hb, and HCT. But after the sensitivity analysis, all five blood results had a smaller standard deviation in DABS after removing the extreme values, suggesting that DABS had higher stability (Table 4).

The possible reasons for the difference in arteriovenous blood samples are as follows: Firstly, the use of heparin sodium saline dilutes the arterial blood samples in different degrees at each time of ABG collection. Therefore, the blood results of the arterial blood samples taken with PHS are generally lower than those of the venous blood samples. At the same time, the amount of heparin saline attached to the syringe tube wall is uncertain each time. This results in fluctuations with true value, which is consistent with the conclusion of this study. As a result, using DABS to collect ABG avoids such an error, so DABS is more accurate and stable. Secondly, there may be inherent differences in the biochemical indicators of arteriovenous blood [9], such as blood potassium. After capillary microcirculation, metabolites, such as lactic acid, entered the vein, making the PH of venous blood more acidic, affecting H^+-K^+ exchange, and resulting in higher potassium in venous blood than that in arterial blood. Further experiments are needed to analyze the arteriovenous blood on the same instrument at the same time. Thirdly, there could be accidental errors in the arteriovenous blood detection instrument, which might be the reason why our findings are some kind of different from other researches [2, 3] where sodium and potassium showed no significant difference between venous and arterial but Hb did. Fourthly, hemolysis may occur during blood collection [10]. Fifthly, potassium will release from platelets during coagulation [11]. Lastly, heparin sodium itself can bind positive ions. Heparin molecule contains sulfate groups and carboxyl groups, which is a strong acidic polyanion, and is capable of reacting with a cationic salt, including Ca^{2+}, Na^+, K^+, etc. [12], thus reducing the corresponding cationic concentration.

It is strange that there are more extreme values in DABS group than in the PHS group. But it is not difficult to understand that the DABS group's data is more stable, so the quartile spacing is smaller, and the data falling three times out the quartile spacing naturally increases.

It is worth noting that when sensitivity analysis was conducted by removing the extreme values, Hb and HCT changed greatly, even reversing the previous conclusions. It attracted our attention on how extreme values affect Hb and HCT. Therefore, we further analyzed the extreme values of Hb and HCT. We found that the extreme values of Hb and HCT were highly consistent in both PHS and DABS groups (Figure 2a, 2b, 2d, 2e). For the extreme values, whether in PHS or DABS group, annihilation and gastrointestinal hemorrhage were the main common characteristics of these abnormal values. Chest pain, uremia, and others were also the common characteristics of the abnormal values (Figure 2c, 2f). Among them, the differences in Hb between venous blood and arterial in patients with gastrointestinal hemorrhage was obvious, which had never been reported before. We speculate that in the course of acute hemorrhage, the microcirculation of the body compensates for the replenishment of fluid in the blood vessels to dilute the venous blood, especially, the red blood cells could not pass through the blood vessel wall. As a result, Hb and HCT in the arteriovenous blood are quite different even though they are sampled at the same time. We call for a more in-depth study of the causes and mechanisms of extreme values in blood gas. It also suggests that when patients suffered from annihilation, gastrointestinal hemorrhage, chest pain, uremia, the indicators in ABG might have obviously deviated from the true value.

Limitation

In the study, values tested from venous blood were regarded as the golden standard, but there may be measurement errors in venous blood itself, which inevitably leads to bias. This is a real-world retrospective analysis, in which ABG and venous values are common emergency indicators, so it could not achieve absolute control like arterial-arterial comparison or venous-venous comparison. Some studies pointed out that venous blood gas could be used to replace ABG [13], but it could not judge the oxygen and carbon dioxide indicators. Although those studies have given the relevant formula [14, 15], the calculation is relatively complicated, and the results were not visualized. So, the accuracy and stability between ABG and venous blood indicators need to be further confirmed by prospective multi-center research.

Conclusions

There is a high correlation of results in venous and ABG blood samples collected in PHS or DABS groups, although the difference is statistically significant. In some indicators (such as Hb, HCT), these differences may be ignored and regarded as of no clinical significance. It might be easy to estimate intravenous blood results only by the average values of ABG results. However, what confuses clinicians is the deviation of values. The reason for such deviations is still debatable. However, DABS is more accurate and stable than PHS and may become a consensus method in judging the patients' condition of acute diseases in the future. We still need to pay attention to special conditions, such as gastrointestinal bleeding, annihilation, chest pain, uremia, etc., that may have an extreme impact on ABG outcomes.

List Of Abbreviations

ABG, arterial blood gas; PHS, pre-heparinized syringe; DABS, disposable arterial blood syringe; SD, standard deviation; CI, confidence interval

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and material

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

XXZ for the research design and writing the article, JDS for data analysis and writing the article, HLC and HTT for data collection, JWW and JYL for data checking, YYW for sample size estimating, NNY and XYZ for data analysis, XGL and WHJ for quality control and final approval of the version to be published. All authors read and approved the final manuscript.

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Tables

Table 1. Characteristics of basic indicators by two methods for ABG.

		PHS	DABS	P
Number(n)		500	400	-
Male (%)		64.80	65.25	0.944
Age (years)		63.55±16.82	62.86±15.65	0.532
Type of admission (%)	Anhelation	15.20	14.50	0.778
	Gastrointestinal Hemorrhage	15.60	14.00	0.511
	Chest pain	12.80	14.25	0.556
	Uremia	11.40	12.00	0.835
	Fever	13.60	11.25	0.312
	Hemoptysis	7.60	8.00	0.900
	Unconsciousness	7.00	8.75	0.381
	Others	16.80	17.25	0.859
Admission Scores*		3.77±0.653	3.83±0.524	0.157
AK^+(mmol/L)		3.79±0.75	3.89±0.70	0.035
VK^+(mmol/L)		4.11±0.72	4.09±0.71	0.773
ANa^+(mmol/L)		135.19±5.02	136.80±5.69	<0.0001
VNa^+(mmol/L)		138.09±4.87	137.99±5.13	0.749
ACl^-(mmol/L)		108.74±7.42	107.62±8.38	0.033
VCl^-(mmol/L)		101.15±6.42	102.28±6.45	0.009
AHb(g/L)		113.93±31.10	119.62±32.28	0.007
VHb(g/L)		116.14±31.04	118.73±30.82	0.213
AHCT (%)		35.12±9.36	36.84±9.72	0.007
VHCT (%)		36.39±9.59	36.18±9.22	0.742

*Admission Score is assessed by guidance nurses according to the patients' condition. Patients with stable vital signs score 1 and patients with unstable vital signs and critical conditions score 4. If patients' condition is between the two extremes, 2 or 3 will be scored. Mean ± standard deviation was showed for quantitative data. A P-value of less than 0.05 was considered significant. ABG, arterial blood gas; PHS, pre-heparinized syringe; DABS, disposable arterial blood syringe; VK^+, Venous potassium; AK^+, Arterial potassium; VNa^+,

Venous sodium; ANa^+, Arterial sodium; VCl^-, Venous chlorine; ACl^-, Arterial chlorine; VHb, Venous hemoglobin; AHb, Arterial hemoglobin; VHCT, Venous hematocrit; AHCT, Arterial hematocrit.

Table 2. Differences of biochemical indicators between venous results and ABG by two methods.

Indicator	Method for ABG	Mean	SD	95%CI	P
DK^+ (mmol/L)	PHS	0.318	0.396	0.283-0.353	P<0.0001
	DABS	0.202	0.276	0.174-0.229	
DNa^+ (mmol/L)	PHS	2.902	2.709	2.664-3.140	P<0.0001
	DABS	1.187	2.346	0.956-1.418	
DCl^- (mmol/L)	PHS	-7.598	5.060	-8.042--7.153	P<0.0001
	DABS	-5.336	6.116	-5.937--4.735	
DHb (g/L)	PHS	2.212	7.992	1.510-2.914	P<0.0001
	DABS	-0.898	9.998	-1.880-0.085	
DHCT (%)	PHS	1.269	2.861	1.017-1.520	P<0.0001
	DABS	-0.659	3.228	-0.986--0.341	

A P-value of less than 0.05 was considered significant. ABG, arterial blood gas; PHS, pre-heparinized syringe; DABS, disposable arterial blood syringe; SD, standard deviation; CI, confidence interval; DK^+, differences of potassium between venous results and ABG(venous minus arterial); DNa^+, differences of sodium between venous results and ABG(venous minus arterial); DCl^-, differences of chlorine between venous results and ABG(venous minus arterial); DHb, differences of hemoglobin between venous results and ABG(venous minus arterial); DHCT, differences of hematocrit between venous results and ABG(venous minus arterial).

Table 3. Correlation of biochemical indicators between venous results and ABG by two methods.

Indicator	Method for ABG	Correlation coefficient	P
K^+	PHS	0.855	<0.0001
	DABS	0.923	<0.0001
Na^+	PHS	0.850	<0.0001
	DABS	0.911	<0.0001
Cl^-	PHS	0.742	<0.0001
	DABS	0.688	<0.0001
Hb	PHS	0.967	<0.0001
	DABS	0.951	<0.0001
HCT	PHS	0.955	<0.0001
	DABS	0.943	<0.0001

A P-value of less than 0.05 was considered significant. ABG, arterial blood gas; PHS, pre-heparinized syringe; DABS, disposable arterial blood syringe; Hb, hemoglobin; HCT, hematocrit.

Table 4. Adjusted differences of biochemical indicators between venous results and ABG by two methods after removing extreme value.

Indicator	Method for ABG	n	Mean	SD	95%CI	P
DK^+ (mmol/L)	PHS	483	0.334	0.284	0.308-0.359	P<0.0001
	DABS	369	0.193	0.255	0.167-0.219	
DNa^+ (mmol/L)	PHS	483	2.899	2.646	2.662-3.136	P<0.0001
	DABS	369	1.158	2.219	0.930-1.385	
DCl^- (mmol/L)	PHS	483	-7.359	4.542	-7.766--6.953	P<0.0001
	DABS	369	-5.620	4.213	-6.051--5.189	
DHb (g/L)	PHS	483	2.211	6.018	1.673-2.749	P<0.0001
	DABS	369	-0.404	5.242	-0.940-0.133	
DHCT (%)	PHS	483	1.250	2.371	1.038-1.462	P<0.0001
	DABS	369	-0.434	1.953	-0.634--0.235	

Data points more than three times the length of the box body from the edge of the box -plot are defined as extreme values.17 and 31 pieces of data were removed as extreme value in PHS and DABS group, respectively. A P-value of less than 0.05 was considered significant. ABG, arterial blood gas; PHS, pre-heparinized syringe; DABS, disposable arterial blood syringe; SD, standard deviation; CI, confidence interval; DK^+, differences of potassium between venous results and ABG(venous minus arterial); DNa^+, differences of sodium between venous results and ABG(venous minus arterial); DCl^-, differences of chlorine between venous results and ABG(venous minus arterial); DHb, differences of hemoglobin between venous results and ABG(venous minus arterial); DHCT, differences of hematocrit between venous results and ABG (venous minus arterial).

Table 5. Adjusted correlation of biochemical indicators between venous results and ABG by two methods after removing extreme value.

Indicator	Method for ABG	n	Correlation coefficient	P
K^+	PHS	483	0.916	<0.0001
	DABS	369	0.933	<0.0001
Na^+	PHS	483	0.852	<0.0001
	DABS	369	0.921	<0.0001
Cl^-	PHS	483	0.793	<0.0001
	DABS	369	0.819	<0.0001
Hb	PHS	483	0.981	<0.0001
	DABS	369	0.986	<0.0001
HCT	PHS	483	0.969	<0.0001
	DABS	369	0.978	<0.0001

Data points more than three times the length of the box body from the edge of the box -plot are defined as extreme values.17 and 31 pieces of data were removed as extreme value in PHS and DABS group respectively. Pearson's correlation coefficient was shown and a P-value of less than 0.05 was considered significant. ABG, arterial blood gas; PHS, pre-heparinized syringe; DABS, disposable arterial blood syringe; Hb, hemoglobin; HCT, hematocrit.

Figures

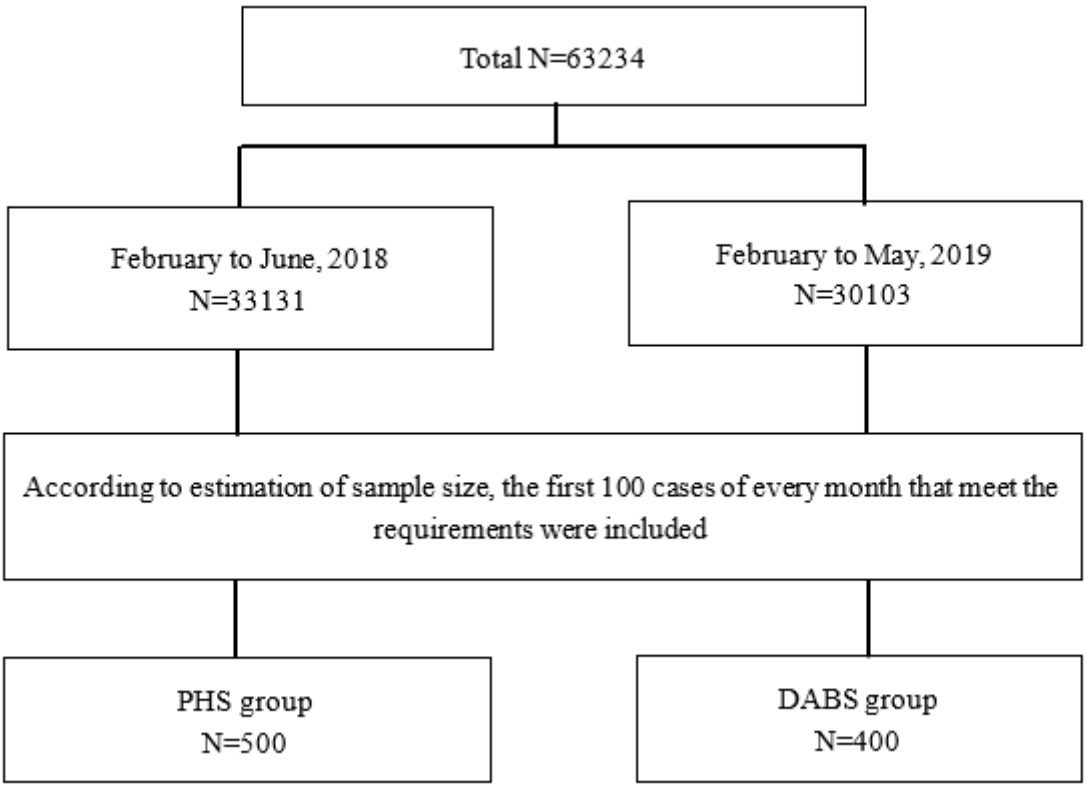

Figure 1

Flow-chat of the retrospective study. PHS, pre-heparinized syringe; DABS, Disposable arterial blood syringe.

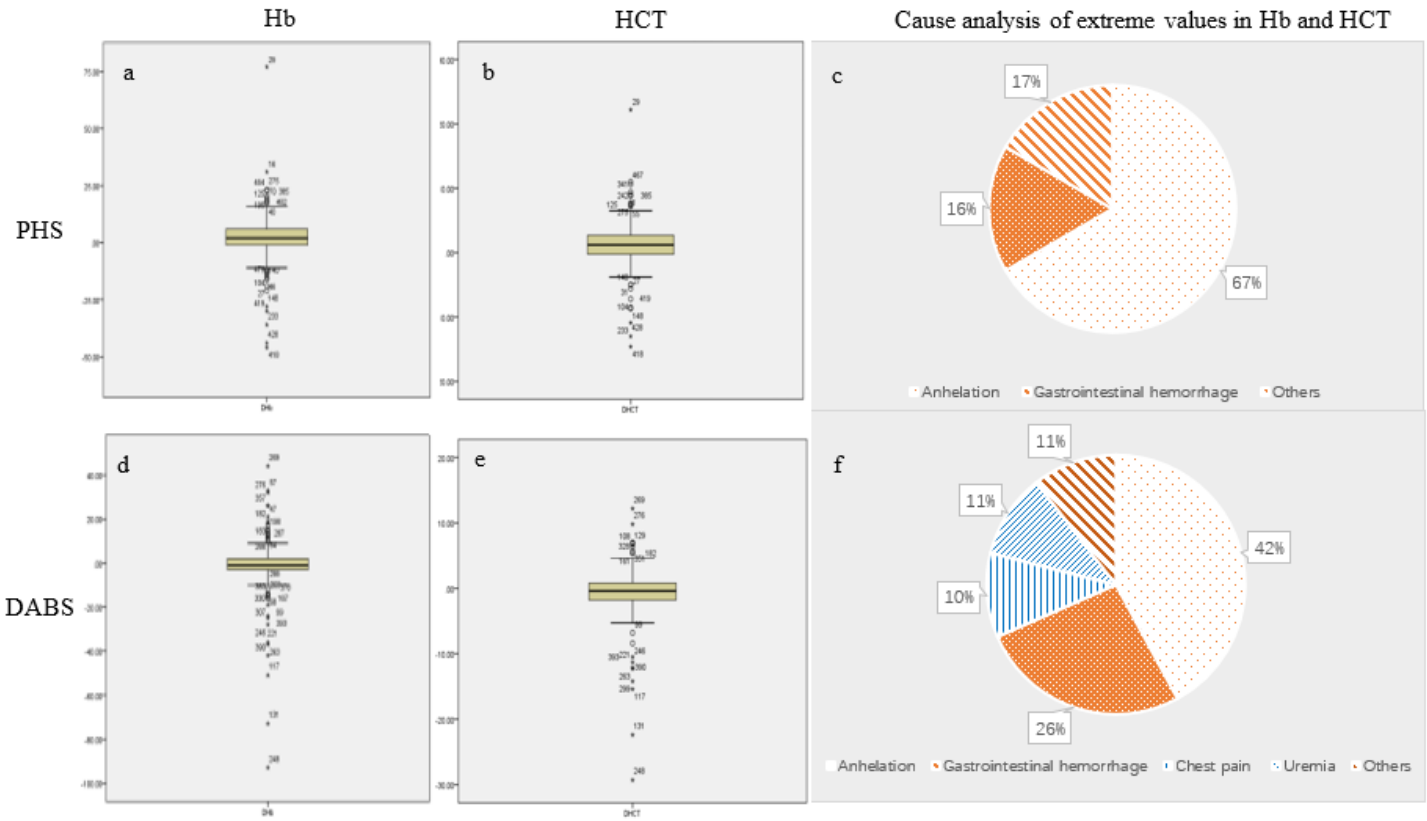

Figure 2

Analysis of extreme values in Hb and HCT from ABG by two methods.