



EFFECTS OF BLOOD COLLECTION AND PROCESSING VARIABLES ON HEMATOLOGICAL QUALITY OF PACKED RED CELLS

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Abstract

This study aimed to analyze the relationship between blood bag type, blood collection duration, and processing time with the quality of Packed Red Cells (PRC) to support transfusion safety. An observational analytic study with a cross-sectional design was conducted at the Blood Transfusion Unit of PMI Bantul. A total of 50 PRC units collected from male voluntary donors were analyzed. Variables included blood collection duration, processing delay, blood bag type, and processing method, while PRC quality was assessed based on hemoglobin concentration, hematocrit, and physical appearance. Data were analyzed using Spearman correlation and Mann-Whitney tests. The results showed that blood collection duration and processing delay had no significant effect on PRC hemoglobin levels. However, both factors demonstrated a significant negative correlation with PRC hematocrit, indicating that longer collection and delayed processing reduced hematocrit values. Processing method significantly affected hematocrit, with centrifugation producing higher hematocrit compared to sedimentation, while blood bag type showed no significant influence. All PRC units met quality standards with clear plasma and no clot formation. This study highlights the importance of timely blood processing and appropriate processing methods to maintain PRC quality, thereby contributing to improved transfusion safety and blood bank quality management.

Keywords: *Packed Red Cells (PRC) ; Blood Collection Time ; Blood Processing Method ; Hematological Quality ; Blood Transfusion Safety*

1. Introduction

Blood transfusion is essential for managing severe anemia, massive hemorrhage, trauma, and major surgery (Nelma & Adiratna, 2023). (Nelma & Martha Adiratna, 2023). Blood transfusion services require strict quality control procedures from donor recruitment, blood collection, component processing, and storage to ensure transfusion safety and blood product quality (Astuti et al., 2025). Transfusion safety and efficacy depend on blood component quality in blood banks. Packed Red Cells (PRC), the most transfused component, must meet standards for volume (179 – 257 mL), hemoglobin (minimum 45 g/unit),

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hematocrit (65-75%), hemolysis (<0.8%), and appearance (clear plasma, no clots) (Zhang et al., 2018 ; Permenkes RI, 2015).

Several factors during blood collection and processing may affect PRC quality. CPDA-1 blood bags maintain red cell viability during collection and storage ((Nelma & Adiratna, 2023); Zhang et al., 2018). Nelma & Martha Adiratna, 2023; Zhang et al., 2018 In addition, the duration of blood collection may influence blood quality, as prolonged collection time can increase the risk of early coagulation and mechanical stress on erythrocytes (Permenkes RI, 2015b). Processing delays promote degradation, hemolysis, and poor separation (Permenkes No. 91, 2015; Subekti et al., 2024) (Subekti, Wijaya, et al., 2024)

Previous studies have mainly focused on the effect of storage duration on PRC quality, reporting changes in hemoglobin levels, hematocrit values, and hemolysis during prolonged storage periods (Subekti, Wijaya, et al., 2024; Danarsih et al., 2023). However, few examine collection duration or processing delay, especially in Indonesian blood banks. Furthermore, evidence regarding the influence of blood bag type and processing method on hematological parameters of PRC remains insufficient, particularly in routine blood bank practice.

Accurate assessment of hemoglobin and hematocrit levels is essential to ensure blood component quality and transfusion safety. Aran et al. emphasized that standardized and validated quality control methods are important to maintain compliance with blood component specifications (Aran et al., 2026). Hemoglobin and hematocrit assessments are important parameters in blood donor selection and blood component quality evaluation because they reflect the adequacy and safety of blood products for transfusion (Astuti & Artini, 2019). This study evaluates associations between collection duration, processing delay, bag type, method, and PRC quality (hemoglobin, hematocrit, appearance). The findings of this study are expected to contribute to improved blood bank quality control and support transfusion safety.

2. Method

This cross-sectional observational study was conducted at PMI Bantul Blood Transfusion Unit, Indonesia (October 2025). Ethics approval was obtained from Universitas Jenderal Achmad Yani Yogyakarta, No. Skep/517/KEP/VIII/2025. The study population consisted of blood donation units collected at the facility, with a total of 50 Packed Red Cell (PRC) units included as samples. All PRC units were obtained from male voluntary donors who met the inclusion criteria.

The independent variables were blood collection duration, processing delay, blood bag type (double or triple), and blood processing method (sedimentation or centrifugation). The dependent variables were PRC quality parameters, including hemoglobin concentration, hematocrit value, and physical characteristics (plasma clarity and presence of clots). Blood collection duration was recorded from the start to the completion of blood flow into the collection bag, while processing delay was defined as the time interval between blood collection and component processing. PRC hemoglobin and hematocrit levels were analyzed using standard laboratory procedures. Physical quality was assessed by visual inspection. Blood collection duration was recorded from the start to the completion of blood flow into the collection bag, while processing delay was defined as the time interval between blood collection and component processing. PRC hemoglobin and hematocrit levels were analyzed using standard laboratory procedures. Physical quality was assessed by visual inspection.

This study was conducted in accordance with the Blood Transfusion Service Standards stipulated in the Regulation of the Minister of Health of the Republic of Indonesia No. 91 of 2015. These standards served as references for blood collection, processing, and handling procedures, including the processing time implemented at the PMI Bantul Blood Transfusion Unit. No specific reference blood bag (gold standard bag) was used; however, the study results were evaluated based on the quality parameters defined in the regulation. Statistical analyses were performed using tests appropriate to the type and distribution of the data.

Non-parametric tests (Spearman rho, Mann-Whitney U; due to non-normality [Shapiro-Wilk]) were performed using SPSS version 27. A p-value < 0.05 was considered statistically significant after Bonferroni adjustment.

3. Result and Discussion

We analyzed 50 PRC units from male voluntary donors at PMI Bantul (Table 1). The donors were predominantly within the productive age range (31–50 years), and most were repeat donors, indicating a stable donor population. All PRC units demonstrated acceptable physical quality, characterized by clear plasma and absence of clots (Table 1). The mean blood collection duration was 7.6 minutes (range: 6–8 minutes), which falls within the recommended standard for whole blood donation. The average processing delay was 20.1 hours, with wide variability among samples. No significant correlations were observed with hemoglobin levels (collection duration: $\rho = 0.10$, $p = 0.946$; processing delay: $\rho = -0.10$, $p = 0.510$; Table 2). Similarly, blood bag type (double vs. triple) did not significantly affect PRC hemoglobin, or hematocrit values. Hematocrit negatively correlated with collection duration ($\rho = -0.31$, $p = 0.027$) and processing delay ($\rho = -0.36$, $p = 0.011$; Table 2), indicating that longer collection and delayed processing resulted in lower hematocrit values. In addition, processing method significantly influenced hematocrit, with centrifugation producing higher hematocrit compared to sedimentation ($p = 0.002$) (Table 3). PRC met the quality standards for hemoglobin, hematocrit, and appearance (clear plasma and absence of clots) according to Permenkes RI (2015).

Hemoglobin Content of PRC

This study found no significant relationship between blood collection duration, processing delay, processing method, or blood bag type and hemoglobin content of PRC. These findings reinforce existing evidence that hemoglobin levels in PRC are primarily determined by the donor's baseline hemoglobin concentration and the efficiency of red cell retention during processing (Hanifah et al., 2022; Sepvianti et al., 2019). Previous studies have shown that standardized processing methods yield consistent hemoglobin levels regardless of minor variations in collection or processing time, provided standard operating procedures are followed (Danarsih, Kusumawardani, et al., 2023; Danarsih, Artini, et al., 2023). Furthermore, international studies comparing centrifugation and sedimentation methods have reported no significant differences in hemoglobin concentration of PRC, despite minor differences in early hemolysis rates (17). This supports the conclusion that both processing methods are capable of producing PRC with adequate hemoglobin content when performed under controlled conditions.

Hematocrit and Pre-analytical Factors

The most notable finding of this study is the significant negative correlation between blood collection duration and PRC hematocrit, as well as between processing delay and PRC hematocrit. Longer collection times were associated with lower hematocrit values, suggesting that prolonged blood flow during donation may increase mechanical stress on erythrocytes and promote early coagulation, leading to reduced red cell concentration in the final PRC product (Cahyani & Ihtiarintyas, 2020); Permenkes RI, 2015b). The negative correlation between processing delay and hematocrit levels observed in this study may be related to biochemical and structural changes in erythrocytes during blood storage and handling. Previous studies have reported that prolonged storage and delayed processing may alter erythrocyte integrity and affect hematological parameters, including hemoglobin and hematocrit levels (Harisanti et al., 2021).

Similarly, extended delays before processing were associated with decreased PRC hematocrit. Delayed processing may allow erythrocytes to undergo sedimentation, morphological changes, or partial hemolysis, thereby reducing the proportion of intact red blood cells available for concentration during component separation (Made et al., 2023). Several hematology studies have reported that delayed blood analysis or processing is associated with reduced hematocrit values due to progressive erythrocyte damage and membrane instability (Syuhada et al., 2020; Yanti & Astuti, 2025). These findings are consistent with literature on blood "holding time," which emphasizes that prolonged intervals between collection and processing can adversely affect the biochemical and cellular integrity of blood components (van der Meer & de Korte, 2015). Although international guidelines do not always specify strict maximum holding times, they stress the importance of minimizing delays to maintain component quality and transfusion safety (World Health Organization (WHO), 2025).

Effect of Processing Method on Hematocrit

The processing method significantly influenced PRC hematocrit, with centrifugation producing higher hematocrit values compared to sedimentation. This finding is consistent with the fundamental principles of component separation, where centrifugation applies greater centrifugal force to effectively separate erythrocytes from plasma based on density differences (Maurer et al., 2022). As a result, PRC produced by centrifugation contains a higher concentration of red blood cells and less residual plasma.

Previous studies have consistently demonstrated that centrifugation yields PRC with hematocrit values within the optimal range of 65–75%, whereas sedimentation tends to produce less concentrated PRC due to incomplete plasma removal (Permenkes RI, 2015b), (Sawadogo et al., 2021). Therefore, centrifugation should be prioritized when higher hematocrit PRC is clinically required. The higher hematocrit levels observed in the centrifugation group compared with the sedimentation group may be explained by the stronger centrifugal force, which promotes more efficient separation and packing of erythrocytes from plasma. Quirynen et al. reported that red blood cells have the highest density among blood components; therefore, during centrifugation, erythrocytes are pushed deeper toward the bottom layer, resulting in better component separation and higher hematocrit concentration (Quirynen et al., 2025).

In this study, PRC hemoglobin and hematocrit values remained within acceptable quality standards. Similar findings were reported by Aran et al., who demonstrated that blood component quality control parameters, including hemoglobin and hematocrit, remained within established specifications despite methodological differences in blood component analysis (Aran et al., 2026). Likewise, Astutiningtiyas et al. reported that most PRC products met hemoglobin and hematocrit quality control criteria according to the Indonesian Blood Transfusion Service Standards (Permenkes No. 91 of 2015). The negative correlation between processing delay and hematocrit levels observed in this study may indicate that prolonged handling and processing affect erythrocyte concentration and PRC quality. In addition, higher hematocrit values in the centrifugation group may reflect more effective erythrocyte separation during component preparation. Previous studies have emphasized that blood processing and storage conditions may influence hematological quality parameters, including hemoglobin and hematocrit values (Astutiningtiyas et al., 2022).

Table 1. Results of Descriptive Analysis of Research Variables

Variable	Mean	Standard Deviation	Range
Blood Collection Duration (minutes)	7.60	0.535	6 - 8
Blood Processing Time Interval (hours)	20.10	35.670	1 - 168
Donor Hemoglobin (g/dL)	14.8220	0.95496	13 - 16.7
Donor Hematocrit (%)	43.4400	3.21451	37 - 53
PRC Hemoglobin (g/unit)	51.8139	3.33728	41.17 - 57.86
PRC Hematocrit (%)	66.2000	3.56857	55 - 74
PRC Plasma Color	All PRC plasma was clear		
Blood Clots	No blood clots were found in any PRC		

The mean blood collection duration was 7.60 ± 0.54 minutes, ranging from 6 to 8 minutes. The interval between blood collection and processing averaged 20.10 ± 35.67 hours, with a range of 1 to 168 hours. Donor hemoglobin levels had a mean value of 14.82 ± 0.95 g/dL, while donor hematocrit averaged $43.44 \pm 3.21\%$. For the PRC products, the mean hemoglobin content was 51.81 ± 3.34 g/unit, ranging from 41.17 to 57.86 g/unit. The mean PRC hematocrit was $66.20 \pm 3.57\%$, with values ranging from 55% to 74%. Visual quality assessment showed that all PRC units had clear plasma, and no blood clots were detected in any sample.

Table 2. Relationship of Blood Collection Duration and Processing Delay with PRC Hemoglobin and Hematocrit Levels

Variable	Hemoglobin PRC		Hematokrit PRC	
	r	P-Value*	r	P-Value*
Blood Collection Duration	0.10	0.946	-0.312	0.027

Blood Processing Time Interval	-0.095	0.510	-0.357	0.011
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*Data analysis was performed using the Spearman Rank test.

Spearman correlation analysis demonstrated no significant relationship between blood collection duration and PRC hemoglobin levels ($r = 0.10$, $p = 0.946$). However, blood collection duration showed a significant negative correlation with PRC hematocrit levels ($r = -0.312$, $p = 0.027$). Similarly, no significant correlation was observed between the blood processing time interval and PRC hemoglobin levels ($r = -0.095$, $p = 0.510$). In contrast, a significant negative correlation was found between the processing time interval and PRC hematocrit levels ($r = -0.357$, $p = 0.011$). These findings indicate that longer blood collection duration and longer processing delays were associated with lower hematocrit levels in PRC products, whereas hemoglobin levels remained unaffected.

Table 3. Relationship of Blood Processing Methods and Blood Bag Types with PRC Hemoglobin and Hematocrit Levels

Variable	Category	n	PRC Hemoglobin		PRC Hematocrit	
			Mean (SD)	P-value*	Mean (SD)	P-value*
Blood Processing Method	Sedimentation	20	51.80 $\pm$ 3.34	0.81	64.70 $\pm$ 1.75	0.002
	Centrifugation	30	51.82 $\pm$ 3.39		67.2 $\pm$ 4.11	
Type of Blood Bag	Double	37	51.39 $\pm$ 3.50	0.114	66.03 $\pm$ 3.83	0.510
	Triple	13	53.01 $\pm$ 2.28		66.69 $\pm$ 2.78	

*Data were analyzed using the Mann-Whitney U test. Significant p-values are shown in bold.

The comparison of blood processing methods revealed no significant difference in PRC hemoglobin levels between the sedimentation and centrifugation methods ($p = 0.810$). However, PRC hematocrit levels differed significantly between the two methods ($p = 0.002$). The centrifugation method produced a higher mean hematocrit value ($67.2 \pm 4.11\%$) compared with the sedimentation method ($64.70 \pm 1.75\%$). Regarding blood bag type, no significant differences were observed in either PRC hemoglobin levels ($p = 0.114$) or PRC hematocrit levels ($p = 0.510$) between double and triple blood bags. The mean hemoglobin and hematocrit values were comparable across both blood bag categories.

4. Conclusion and Suggestion

PRC from 50 male donors at PMI Bantul met quality standards, with hemoglobin and hematocrit levels within the acceptable range, clear plasma, and no clots observed (Table 1).. The duration of blood collection and the interval before blood processing did not have a significant effect on PRC volume or hemoglobin; however, both factors affected PRC hematocrit, with longer times tending to reduce hematocrit values. Centrifugation yielded higher hematocrit levels than sedimentation (67% vs 65%, $p = 0.002$; Table 3). Overall, PRC quality was more strongly influenced by the efficiency of component separation and the timeliness of processing than by donor characteristics or the type of blood bag used.

Based on the study results, it is recommended that blood processing be carried out as soon as possible after donation to prevent a decline in PRC hematocrit quality, and that blood collection time remains within an optimal range so as not to affect red blood cell concentration. The centrifugation method may be prioritized when PRC with higher hematocrit is required, while improved adherence to standard operating procedures (SOPs) and regular staff training are essential to maintain consistent blood component quality. In addition, future studies are expected to involve larger sample sizes and consider additional variables such as storage conditions or donor physiological characteristics in order to obtain a more comprehensive understanding.

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