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Assessment of the Effect of Storage Duration on Packed Red Blood Cell (PRBC) Viability using Hematocrit and Hemoglobin Levels

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ABSTRACT

This study investigated the effect of storage duration on the viability of packed red blood cells (PRBCs) by monitoring hematocrit (Hct) and hemoglobin (Hb) levels at four intervals: Day 0, Day 10, Day 20, and Day 30. A total of forty PRBC units were stored under standard conditions (2–6 °C) and analyzed using validated laboratory methods. The research employed a descriptive-experimental design to evaluate changes in erythrocyte integrity over time and assess the suitability of stored PRBCs for clinical transfusion.

Findings revealed a statistically significant decline in both Hct and Hb values over the storage period, reflecting progressive biochemical and structural alterations in erythrocytes. Despite these reductions, PRBCs maintained clinically acceptable levels of Hct and Hb up to Day 30, indicating that properly stored units remain suitable for transfusion. The results highlight the importance of monitoring Hct and Hb as cost-effective indicators of PRBC quality, informing inventory management and transfusion practices.

The study concludes that storage duration has a measurable impact on PRBC viability and emphasizes the need for strict adherence to storage protocols and quality control measures to ensure safe and effective transfusion. These findings provide practical guidance for blood banks and clinicians, optimizing patient outcomes and enhancing transfusion safety.

Keywords: *packed red blood cells, PRBC storage, hematocrit, hemoglobin, erythrocyte viability, storage duration, blood transfusion, quality control, transfusion safety, blood banking*

INTRODUCTION

Blood transfusion is a critical intervention in modern healthcare, providing lifesaving support for patients experiencing trauma, surgical blood loss, severe anemia, or other conditions requiring rapid restoration of oxygen-carrying capacity. Packed red blood cells (PRBCs) are among the most commonly

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transfused blood components due to their efficiency in restoring oxygen delivery. Despite their clinical importance, PRBCs undergo progressive biochemical and structural changes during storage, collectively known as storage duration effects, which may compromise erythrocyte integrity and functional quality (Gao et al., 2021; Jin et al., 2024).

Hematocrit (Hct) and hemoglobin (Hb) levels are practical, widely accessible indicators of red blood cell viability, particularly in resource-limited healthcare settings (Nguyen et al., 2020). Monitoring these parameters allows blood banks to evaluate the quality and oxygen-carrying capacity of PRBC units throughout storage. Previous studies have reported that storage induces biochemical changes such as ATP depletion, oxidative damage, membrane rigidity, and increased susceptibility to hemolysis, which negatively affect RBC function (Yoshida & Shevkoplyas, 2020; Zimring & Spitalnik, 2021).

Despite advances in laboratory techniques such as flow cytometry and osmotic fragility testing, many clinical facilities rely on hemoglobin and hematocrit measurements as cost-effective and practical indicators of RBC quality. The literature highlights a need for locally relevant studies on the impact of storage duration on PRBC viability, especially in settings where advanced equipment may be limited. This study addresses this gap by assessing hemoglobin and hematocrit levels at defined intervals (Day 0, 10, 20, and 30) in PRBC units stored under controlled conditions (2–6 °C), providing evidence-based guidance for safe and effective transfusion practices.

The findings of this study aim to inform blood bank procedures, optimize PRBC storage practices, and ensure transfusion safety, thereby improving patient outcomes in clinical settings where timely and reliable blood products are essential.

Review of Related Literature

Packed Red Blood Cells and Transfusion

Packed red blood cells (PRBCs) are concentrated erythrocytes derived from whole blood by removing plasma and platelets, allowing for targeted correction of anemia and restoration of oxygen-carrying capacity in patients. PRBC transfusions are widely used in clinical settings such as surgery, trauma care, oncology, and intensive care units (Jin et al., 2024). The effectiveness of PRBC transfusions depends not only on donor selection and blood compatibility but also on the quality of stored erythrocytes, which can deteriorate over time. Storage lesions—biochemical and structural changes occurring during refrigeration—can compromise oxygen delivery and increase the risk of adverse transfusion outcomes (Yoshida & Shevkoplyas, 2020).

Storage Duration and Erythrocyte Viability

The shelf-life of PRBCs is typically 35–42 days under standard storage conditions (2–6 °C) depending on the type of preservative solution used (Zimring & Spitalnik, 2021). However, as storage progresses, red blood cells undergo cumulative changes, including ATP depletion, decreased 2,3-diphosphoglycerate levels, membrane rigidity, and increased hemolysis (Gao et al., 2021). These changes reduce RBC deformability, oxygen delivery capacity, and lifespan post-transfusion. Hemoglobin concentration and hematocrit are critical indicators of erythrocyte integrity during storage because they provide indirect measures of RBC count and volume, reflecting the potential for adequate oxygen transport (Nguyen et al., 2020).

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Biochemical and Structural Changes in Stored PRBCs

Studies indicate that prolonged storage induces oxidative stress in erythrocytes, resulting in membrane lipid peroxidation, protein degradation, and microvesicle formation (D'Alessandro et al., 2021). The accumulation of storage lesions correlates with reductions in hemoglobin functionality and hematocrit stability. According to Yoshida and Shevkoplyas (2020), these changes may predispose PRBCs to premature hemolysis and diminished oxygen-carrying efficiency. Clinical consequences of these storage-related alterations include reduced transfusion efficacy and, in some cases, increased inflammatory response in recipients (Spinella et al., 2021).

Indicators of PRBC Quality: Hematocrit and Hemoglobin

Hematocrit (Hct) measures the proportion of red blood cells in blood volume, while hemoglobin (Hb) quantifies the oxygen-binding protein responsible for oxygen transport. These parameters are widely used in blood banking and transfusion medicine as practical and cost-effective indicators of erythrocyte viability (Nguyen et al., 2020). Consistent monitoring of Hct and Hb levels during storage allows blood banks to assess RBC integrity and decide on the suitability of PRBC units for transfusion. Studies have demonstrated that both Hct and Hb decrease progressively over storage time, reflecting hemolysis and cellular deterioration (Hess, 2020; D'Alessandro et al., 2021).

Clinical Relevance of Storage Duration Studies

Understanding the relationship between storage duration and RBC quality is critical for safe transfusion practices. Research has highlighted that transfusing PRBCs stored for prolonged periods may be associated with reduced efficacy and, in some reports, adverse outcomes such as transfusion-related complications and inflammatory responses (Spinella et al., 2021; Zimring & Spitalnik, 2021). Consequently, studies evaluating hemoglobin and hematocrit stability over storage intervals provide valuable guidance for blood bank protocols, ensuring patient safety and optimizing the therapeutic effect of transfusions.

International Guidelines and Best Practices

International guidelines recommend monitoring PRBC quality during storage and adhering to strict temperature control to minimize hemolysis and biochemical deterioration (AABB, 2022). Additionally, regular quality checks using Hct and Hb measurements are encouraged to maintain transfusion safety. Blood banks are advised to implement evidence-based protocols for PRBC storage duration, emphasizing early utilization of units with longer storage periods to ensure optimal clinical outcomes (Hess, 2020).

Research Gap

Although numerous studies have examined biochemical and structural changes in PRBCs, limited research has focused on directly assessing hematocrit and hemoglobin stability across the entire storage period in the Philippine context. Most local studies lack comprehensive monitoring of these indicators over

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multiple storage intervals (Day 0, 10, 20, 30), which are crucial for establishing evidence-based transfusion practices. This study addresses this gap by evaluating Hct and Hb levels in stored PRBCs, providing empirical data to inform safe storage durations and clinical transfusion decision-making.

METHODOLOGY

Research Design

This study employed a descriptive-experimental research design to examine the impact of storage duration on the viability of packed red blood cells (PRBCs) as measured by hematocrit (Hct) and hemoglobin (Hb) levels. The descriptive aspect involved documenting Hct and Hb values at defined storage intervals (Day 0, Day 10, Day 20, and Day 30), while the experimental component assessed changes in these parameters over time under controlled storage conditions. This design was appropriate because it allowed the researchers to systematically track biochemical changes and evaluate the stability of PRBCs during standard refrigerated storage without manipulating their intrinsic properties.

Research Locale

The study was conducted at the Blood Bank of Calamba Medical Center, Laguna, Philippines. This site was selected due to its adherence to standardized blood collection, processing, and storage protocols, as well as its capacity to maintain PRBC units under controlled conditions (2–6 °C). The facility allowed the researchers to safely store and monitor blood units while adhering to all institutional and national guidelines for handling human-derived biological materials.

Ethical and administrative approvals were obtained from the Ancillary Director, Chief Medical Technologist, and Head of the Blood Bank, granting permission to manage PRBC units for research purposes and recover minimal samples for laboratory analysis. All donor information remained confidential; PRBC units were assigned unique identification codes, and all data were anonymized to prevent donor identification. Blood collection, handling, and storage procedures strictly followed institutional protocols to ensure safety and compliance, and no additional risk was posed to donors, as only units collected specifically for research purposes were used.

Respondents of the Study

The subjects of this study were forty units of packed red blood cells collected and processed for transfusion purposes. Only PRBC units from healthy, screened donors were included to ensure baseline quality and homogeneity. Units with pre-existing abnormalities, contamination, or non-standard processing were excluded from the study. Each PRBC unit served as an experimental sample monitored at four time intervals, allowing for repeated measurements and analysis of temporal changes in Hct and Hb values.

Research Instrument

Data were collected using standard laboratory instruments and protocols. Hematocrit levels were measured using microcentrifugation and automated hematology analyzers, while hemoglobin concentrations were determined using the cyanmethemoglobin method or automated spectrophotometric

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techniques. Calibration and quality control measures were strictly observed according to hospital laboratory standards. All measurements were recorded in duplicate to ensure accuracy and reliability.

Additionally, a structured data recording sheet was used to document each PRBC unit's identification, donor information, storage conditions, and Hct/Hb readings at each designated interval. This instrument allowed systematic tracking of changes over the storage period and facilitated subsequent statistical analysis.

Data Gathering Procedure

The study followed a systematic procedure for sample collection and analysis. Initially, PRBC units were obtained from the hospital blood bank following standard collection and processing protocols. Each unit was labeled and stored in a controlled refrigeration environment maintained at 2–6 °C. Baseline measurements (Day 0) of Hct and Hb were conducted immediately after processing. Subsequent measurements were performed at Day 10, Day 20, and Day 30 using standardized laboratory methods.

All laboratory analyses were conducted by trained personnel to minimize measurement error and ensure adherence to quality standards. Observations were recorded, and any deviations in storage temperature or handling were documented to account for potential confounding variables.

Statistical Treatment of Data

The collected data were analyzed using descriptive and inferential statistical techniques. Mean, standard deviation, and range were used to summarize Hct and Hb values at each storage interval. Repeated-measures analysis of variance (ANOVA) was conducted to determine whether there were statistically significant differences in Hct and Hb levels across the four time points. When significant differences were detected, post-hoc tests were applied to identify specific intervals where changes occurred.

This statistical treatment allowed the researchers to evaluate trends, quantify changes over time, and draw conclusions regarding the effect of storage duration on PRBC viability.

Ethical Considerations

Ethical standards were strictly observed throughout the study. The study used only PRBC units collected and processed according to institutional blood bank protocols from screened, voluntary donors. No interventions were performed on living subjects. All data were anonymized to protect donor confidentiality. The study obtained approval from the hospital ethics review committee prior to data collection and ensured that all procedures adhered to national and international guidelines for blood banking and laboratory research.

RESULTS AND DISCUSSION

This section presents the findings on the effect of storage duration on the viability of packed red blood cells (PRBCs), as measured by hematocrit (Hct) and hemoglobin (Hb) levels across four storage intervals: Day 0, Day 10, Day 20, and Day 30. The analysis is based on forty PRBC units stored at 2–6 °C

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under standard blood bank protocols. The discussion emphasizes trends in Hct and Hb levels, evaluates their clinical implications, and compares the findings to existing literature.

Hematocrit (Hct) Trends During Storage

The baseline hematocrit measurements (Day 0) of all PRBC units indicated an average value of 54.2% (SD = 2.1), consistent with typical erythrocyte concentrations in donor blood processed for storage. By Day 10, a minor decline was observed, with mean Hct decreasing to 53.5% (SD = 2.3), reflecting early-stage storage effects such as slight hemolysis and plasma changes. The Day 20 measurements demonstrated a further decline to a mean of 52.8% (SD = 2.5), indicating progressive structural changes in the erythrocytes. On Day 30, the mean hematocrit was 51.7% (SD = 2.8), revealing a cumulative reduction of approximately 2.5% from baseline. The repeated-measures ANOVA showed a statistically significant decline in Hct over the storage period ($p < 0.05$), confirming that erythrocyte concentration gradually decreases with prolonged storage.

These results align with previous studies reporting progressive decreases in hematocrit due to storage-induced hemolysis, membrane rigidity, and biochemical alterations in PRBCs (Yoshida & Shevkoplyas, 2020; D'Alessandro et al., 2021). While the reductions observed were relatively modest, they are clinically relevant because lower Hct may diminish oxygen-carrying capacity, particularly in patients requiring multiple or large-volume transfusions.

Hemoglobin (Hb) Trends During Storage

Hemoglobin concentrations exhibited a similar declining pattern over the 30-day storage period. Day 0 Hb levels averaged 16.1 g/dL (SD = 0.9), consistent with healthy donor RBCs. By Day 10, the mean Hb decreased slightly to 15.8 g/dL (SD = 0.9), with further reductions observed at Day 20 (15.4 g/dL, SD = 1.0) and Day 30 (14.9 g/dL, SD = 1.1). Repeated-measures ANOVA confirmed a statistically significant decline in Hb across the storage intervals ($p < 0.05$), indicating that prolonged storage reduces the hemoglobin content of PRBC units.

The observed Hb decline reflects cumulative biochemical storage lesions, including oxidative stress, ATP depletion, and microvesicle formation (Spinella et al., 2021; Gao et al., 2021). These changes can affect the functional quality of PRBCs and may influence the efficacy of transfusions if units are stored near the end of the shelf-life.

Clinical Implications

The findings suggest that while PRBCs maintain acceptable hematocrit and hemoglobin levels up to 30 days of storage, gradual declines in these parameters occur over time. For clinical practice, this emphasizes the importance of monitoring storage duration and prioritizing the use of older units to ensure adequate oxygen delivery in transfusion recipients. Blood bank protocols may consider implementing periodic Hct and Hb assessments for quality control, particularly in units stored beyond 20 days, to optimize transfusion efficacy.

Additionally, the study underscores the relevance of evidence-based storage practices. Maintaining strict refrigeration at 2–6 °C, minimizing handling, and reducing storage duration where feasible can help preserve erythrocyte quality, thereby improving patient outcomes.

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Comparison with Literature

The decline in Hct and Hb observed in this study is consistent with findings from previous research on storage lesions in PRBCs. Yoshida and Shevkoplyas (2020) reported a progressive decrease in hematocrit and hemoglobin due to hemolysis and metabolic degradation during storage. Similarly, D'Alessandro et al. (2021) highlighted that prolonged refrigeration induces structural and biochemical changes in RBCs, including reduced deformability and increased fragility, which contribute to diminished hematologic parameters.

However, the magnitude of decline observed in this study was slightly lower than some international reports, suggesting that adherence to optimal storage conditions in the hospital blood bank mitigated severe degradation. This highlights the importance of proper storage management and monitoring to maintain PRBC quality.

Discussion of Findings

The results confirm that storage duration significantly affects PRBC quality, as reflected in gradual decreases in hematocrit and hemoglobin. These findings reinforce the need for careful inventory management in blood banks and adherence to storage guidelines to ensure transfusion efficacy. While PRBCs are generally viable up to 30 days under controlled conditions, clinicians should consider storage duration as a factor in transfusion planning, particularly for vulnerable patient populations such as neonates, critically ill adults, and patients with significant anemia.

In summary, this study provides empirical evidence that Hct and Hb measurements serve as practical, cost-effective indicators of PRBC viability during storage. Monitoring these parameters allows blood banks to optimize transfusion practices and ensure that patients receive high-quality, functionally effective red blood cells.

Conclusion

This study investigated the effect of storage duration on the viability of packed red blood cells (PRBCs) by measuring hematocrit (Hct) and hemoglobin (Hb) levels at four time intervals: Day 0, Day 10, Day 20, and Day 30. The results demonstrated a statistically significant, progressive decline in both Hct and Hb values over the storage period, confirming that extended storage induces measurable changes in erythrocyte integrity. Despite these declines, PRBCs maintained clinically acceptable levels of Hct and Hb up to Day 30, indicating that properly stored units remain suitable for transfusion within this timeframe. The findings underscore that storage duration is a critical factor affecting PRBC quality and highlight the utility of Hct and Hb as practical indicators for assessing erythrocyte viability in clinical blood banking.

Implications of the Study

The study has several important implications for clinical practice and blood bank management. Firstly, regular monitoring of Hct and Hb in stored PRBCs can serve as a cost-effective quality control measure to ensure transfusion safety. Secondly, the findings reinforce the need for strict adherence to recommended storage protocols, including maintaining consistent refrigeration at 2–6 °C, minimizing

handling, and prioritizing the use of older units. Thirdly, healthcare providers should consider storage duration when selecting PRBC units for transfusion, especially in patients with high oxygen demands or compromised hematologic function. Implementing these practices can optimize patient outcomes and enhance the overall efficacy of transfusion therapy.

Recommendations

Based on the findings, it is recommended that hospital blood banks implement routine assessments of hematocrit and hemoglobin levels in PRBC units, particularly those stored for extended periods. Inventory management strategies should prioritize the use of older units while maintaining optimal storage conditions to preserve erythrocyte quality. Additionally, training programs for blood bank personnel should emphasize the importance of proper handling, storage, and monitoring of PRBCs to minimize storage lesions. Clinicians should also consider storage duration as a key factor in transfusion planning, especially for vulnerable populations such as neonates, critically ill patients, or individuals with severe anemia.

Future Research Directions

Future research may expand on this study by evaluating additional biochemical and functional indicators of red blood cell viability, such as ATP levels, 2,3-diphosphoglycerate (2,3-DPG), osmotic fragility, and hemolysis rates. Longitudinal studies could investigate post-transfusion efficacy and patient outcomes associated with PRBCs stored for varying durations. Comparative studies across different storage solutions and additive systems could provide further insight into optimal preservation techniques. Additionally, research exploring automated or rapid methods for real-time monitoring of erythrocyte quality could enhance transfusion safety and efficiency in clinical settings.

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