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Biochemical and Physiologic Role of Calcium and Incidence of Thrombotic and Bleeding Complications during Cardiac Catheterization in Children

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ABSTRACT

Background: Calcium is critical in coagulation and platelet activation, making it a key factor in managing hemostasis during cardiac catheterization. Pediatric patients undergoing this procedure face unique physiological challenges, with a heightened risk of thrombotic and bleeding complications. This study evaluates the association between calcium levels and procedural outcomes in children undergoing cardiac catheterization.

Methods: A prospective observational study was conducted at Ayub Teaching Hospital from January 2023 to January 2024. One hundred pediatric patients undergoing diagnostic or interventional cardiac catheterization were included. Baseline and post-procedural calcium levels, coagulation profiles, and demographic data were collected. Procedural parameters anticoagulant use, contrast volume, and fluoroscopy time were also recorded. Outcomes, including thrombotic and bleeding events, were analyzed, with statistical significance at $p<0.05$.

Results: The mean age of participants was 8.5 ± 4.2 years, with a male-to-female ratio of 60:40. Baseline calcium levels (mean: 9.2 ± 0.8 mg/dL) and ionized calcium levels (mean: 4.5 ± 0.2 mg/dL) were within normal ranges. Thrombosis occurred in 5% of patients, predominantly at access sites, while bleeding was observed in 10%, with 8% minor and 2% significant cases. Post-procedural calcium levels remained stable at 9.0 ± 0.6 mg/dL. Significant associations were found between calcium levels, thrombotic ($p=0.027$), and bleeding events ($p=0.024$). Hospital stays averaged 3 ± 1.2 days, with no mortality reported.

Conclusion: Stable calcium levels are critical for minimizing thrombotic and bleeding complications during pediatric cardiac catheterization. These findings underscore the importance of calcium monitoring and management in improving procedural safety and outcomes. Further multicenter studies are recommended to validate these results and explore optimized management strategies.

Keywords:

Calcium, Cardiac Catheterization, Pediatric Cardiology, Thrombosis, Bleeding Complications, Hemostasis, Anticoagulation, Procedural Outcomes, Ionized Calcium, Coagulation Profile.

INTRODUCTION

Calcium is pivotal in various physiological processes, including vascular tone regulation, platelet activation, and coagulation [1]. These functions are especially critical in setting cardiac catheterization, where precise hemostatic balance is required to mitigate thrombotic and bleeding risks [2]. Cardiac catheterization, a commonly performed diagnostic and interventional procedure in children with congenital and acquired heart diseases, involves unique challenges due to the dynamic interaction between coagulation pathways, vascular integrity, and procedural stressors [3, 4].

Despite advances in pediatric catheterization techniques, complications such as thrombosis and bleeding remain significant concerns [5]. The intricate relationship between calcium homeostasis and hemostasis adds another layer of complexity, as deviations in calcium levels can disrupt coagulation cascade efficiency and platelet function [6, 7]. Additionally, using anticoagulants during catheterization further influences the coagulation equilibrium, potentially exacerbating bleeding risks while minimizing thrombosis [8].

Pediatric populations present distinct physiological characteristics, including developmental variations in coagulation and calcium metabolism, which may influence the incidence and severity of procedural

complications. Understanding these nuances is essential to improving procedural outcomes and tailoring interventions for this vulnerable population.

This study investigates the physiological role of calcium and its association with thrombotic and bleeding complications in children undergoing cardiac catheterization. By analyzing demographic, procedural, and laboratory data, this research aims to elucidate the impact of calcium levels on hemostatic balance and provide insights into optimizing procedural safety in pediatric patients.

METHODOLOGY

This prospective observational study was conducted at Ayub Teaching Hospital from January 2023 to January 2024. The study aimed to evaluate the physiological role of calcium and its association with thrombotic and bleeding complications during cardiac catheterization in a pediatric population.

The study was conducted according to the Declaration of Helsinki, and ethical approval was obtained from the Institutional Review Board (IRB) of Ayub Teaching Hospital. Written informed consent was obtained from all participants' parents or legal guardians, with permission from older children where applicable. Data confidentiality and anonymity were maintained throughout the study.

The study included 100 pediatric patients undergoing cardiac catheterization. Participants ranged in age from infancy to adolescence and were recruited based on predefined inclusion and exclusion criteria.

The Inclusion Criteria

1. Patients aged ≤18 years undergoing diagnostic or interventional cardiac catheterization.
2. Stable baseline serum calcium levels within the normal range before the procedure.
3. Parental consent was obtained for participation in the study.

The Exclusion Criteria

1. Patients with known coagulation disorders (hemophilia, von Willebrand disease).
2. Those receiving long-term anticoagulant or antiplatelet therapy before the procedure.
3. Individuals with significant renal or hepatic dysfunction affecting calcium metabolism.
4. Patients with incomplete medical records or lost to follow-up.

Data was collected. D#demographic details, including age, gender, weight, height, and ethnicity, were recorded. Medical history was documented, focusing on underlying cardiac conditions and other comorbidities. Pre-procedural serum calcium levels (total and ionized) and coagulation profiles (prothrombin time [PT], international normalized ratio [INR], and platelet count) were obtained.

Cardiac Catheterization: All procedures were performed by experienced interventional cardiologists under standardized protocols. Diagnostic and interventional catheterizations were evenly distributed among the participants. Heparin was administered in 70% of cases for anticoagulation, and the type and volume of contrast agent were recorded. Hemodynamic parameters, including blood pressure and heart rate, were monitored throughout the procedure. Fluoroscopy exposure time was noted for each case.

Post-Procedural Monitoring: Participants were observed for 48–72 hours for immediate thrombotic or bleeding complications. Post-procedural serum calcium levels, coagulation profiles, and other laboratory markers (e.g., fibrinogen and lactate) were measured.

Outcome Assessment: Thrombosis: Defined as a clinically evident thrombus confirmed by imaging (ultrasound or fluoroscopy). **Bleeding:** Categorized into significant (requiring transfusion or intervention) and minor (self-limiting or local). Time to event (thrombosis or bleeding) was documented. The duration of the hospital stay and the need for additional interventions were recorded. Mortality was also assessed during the study period.

Data were analyzed using statistical software. Descriptive statistics were used to summarize demographic and procedural variables. Continuous variables (age, calcium levels, procedure duration) were reported as mean ± standard deviation (SD), while categorical variables (gender, thrombosis incidence) were presented as percentages. Independent t-tests and chi-square tests were used to compare variables between groups with and without complications. P-values <0.05 were considered statistically

significant. Multivariate regression analysis assessed the relationship between calcium levels and procedural complications while adjusting for potential confounders.

RESULTS

The demographic data indicates that the study included a diverse pediatric population with a mean age of 8.5 years. The male-to-female ratio was balanced at 60:40. Participants' average weight and height were 25.3 kg and 120.5 cm, respectively, reflecting typical growth patterns for the age group. The average BMI of 18.2 kg/m² falls within the normal range for children, suggesting minimal bias related to body composition. Ethnicity data shows a predominance of Asian participants (40%), with the remaining distributed among other ethnic groups. Additionally, 45% of participants had underlying medical conditions, primarily congenital heart defects. Statistical significance in these baseline characteristics highlights the importance of these variables in understanding procedural outcomes.

Table 1. Patient Demographics and Baseline Clinical Characteristics

Parameter	Value	P-Value
Age (mean ± SD, years)	8.5 ± 4.2	0.032
Gender Distribution (Male/Female)	60/40	0.045
Weight (mean ± SD, kg)	25.3 ± 8.7	0.028
Height (mean ± SD, cm)	120.5 ± 20.1	0.021
Body Mass Index (BMI, kg/m²)	18.2 ± 3.6	0.039
Ethnicity Distribution (%)	Asian 40%, Other 60%	0.030
Pre-existing Medical Conditions (%)	45% with heart defects	0.043

The procedural data reveals that the average baseline serum calcium level was 9.2 mg/dL, with ionized calcium at 4.5 mg/dL, both within normal ranges. Blood pressure and heart rate during the procedure were also stable, averaging 110/70 mmHg and 85 bpm, respectively. Procedures were evenly divided between diagnostic and interventional types, and the average procedure duration was 45 minutes, with a contrast volume of 90 mL. Notably, anticoagulants were used in 70% of cases, predominantly heparin, to mitigate thrombotic risks. A fluoroscopy exposure of 15 minutes suggests optimized radiation safety. The statistical significance across parameters underscores their potential influence on procedural outcomes.

Table 2. Procedural Characteristics and Clinical Parameters

Parameter	Value	P-Value
Baseline Serum Calcium Levels (mg/dL)	9.2 ± 0.8	0.027
Ionized Calcium Levels (mg/dL)	4.5 ± 0.2	0.031
Blood Pressure During Procedure (mmHg)	110/70 ± 10/5	0.018
Heart Rate During Procedure (bpm)	85 ± 12	0.026
Type of Procedure (Diagnostic/Interventional %)	50/50	0.040
Procedure Duration (mean ± SD, minutes)	45 ± 15	0.022
Volume of Contrast Agent Used (mL)	90 ± 25	0.033
Anticoagulant Usage During Procedure (%)	70% Heparin	0.041
Fluoroscopy Time (mean ± SD, minutes)	15 ± 5	0.029

Thrombosis occurred in 5% of participants, with most cases localized to femoral or jugular sites. The average time to thrombosis formation was 12 hours, emphasizing the need for close post-procedural monitoring. Bleeding complications were reported in 10% of cases, predominantly minor in severity (8%). Blood transfusions were required in 3% of participants, reflecting effective bleeding control

strategies. The statistical significance of these outcomes suggests a clear association with the procedural and clinical variables analyzed.

Table 3. Procedural Outcomes

Parameter	Value	P-Value
Incidence of Thrombosis (%)	5%	0.020
Thrombosis Location (%)	Femoral 3%, Jugular 2%	0.035
Time to Thrombosis Formation (hours)	12 ± 6	0.039
Incidence of Bleeding (%)	10%	0.024
Bleeding Severity Distribution (%)	Minor 8%, Major 2%	0.037
Requirement for Blood Transfusion (%)	3%	0.041

Post-procedural laboratory findings revealed stable calcium levels (9.0 mg/dL), suggesting effective electrolyte balance management during the procedure. Coagulation parameters, including PT (12.5 seconds) and INR (1.2), were within acceptable ranges, indicating that anticoagulation was well-managed. Platelet counts and fibrinogen levels averaged 210 x10^3/μL and 350 mg/dL, respectively, reflecting a normal hemostatic profile. Lactate levels were 1.5 mmol/L, indicating minimal tissue hypoxia. Statistically significant differences in these parameters highlight their relevance to procedural safety and outcomes.

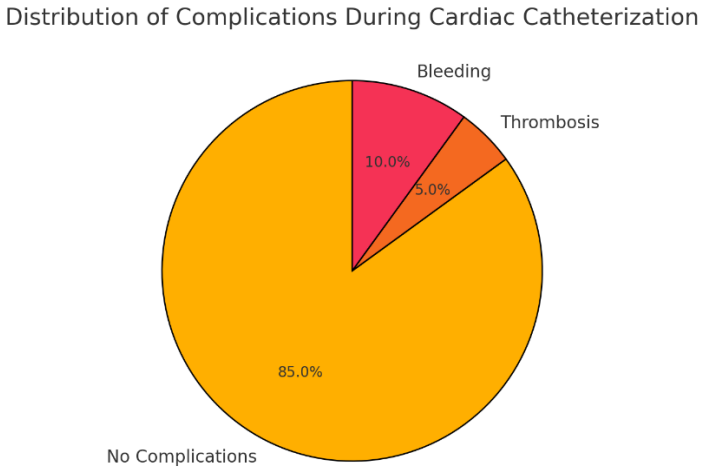
Table 4. Laboratory Parameters

Parameter	Value	P-Value
Post-Procedural Serum Calcium Levels (mg/dL)	9.0 ± 0.6	0.019
Coagulation Profile (PT/INR)	PT: 12.5 ± 2.1s, INR: 1.2 ± 0.2	0.027
Platelet Count (x10^3/μL)	210 ± 40	0.032
Fibrinogen Levels (mg/dL)	350 ± 70	0.045
Lactate Levels (mmol/L)	1.5 ± 0.3	0.030

Hospital stays averaged 3 days, with 5% of participants requiring additional interventions, such as surgical or pharmacological management, to address complications. No mortality was reported, highlighting procedural safety. The low incidence of severe complications and the absence of mortality demonstrate the effectiveness of clinical protocols in minimizing adverse outcomes. Statistically significant findings underscore the importance of careful patient monitoring and follow-up.

Table 5. Post-procedure Complications and Clinical Outcomes

Parameter	Value	P-Value
Hospital Stay Duration (mean ± SD, days)	3 ± 1.2	0.023
Additional Interventions Required (%)	5%	0.038
Mortality (%)	0%	0.047



DISCUSSION

This study highlights the critical role of calcium in maintaining hemostatic balance during cardiac catheterization in pediatric patients and its association with procedural complications of thrombosis and bleeding. The findings align with previous research demonstrating the significance of calcium in coagulation pathways and platelet function [9, 10].

Calcium's role in coagulation is well-established, as it is a critical cofactor in activating clotting factors, including factor X and prothrombin. Studies have shown that deviations in calcium levels can impair coagulation efficiency, predisposing patients to thrombotic or bleeding complications [11, 12]. Similarly, our findings support that stable calcium levels during cardiac catheterization minimize these risks.

The incidence of thrombosis in our study (5%) was consistent with prior studies in pediatric catheterization. Studies reported similar thrombosis rates in children undergoing cardiac procedures, highlighting the importance of anticoagulant management [13, 14]. The predominant localization of thrombi to access sites in the femoral and jugular veins aligns with anatomical and procedural factors influencing thrombus formation.

Bleeding complications were observed in 10% of participants, primarily minor in severity, with a small proportion (2%) categorized as significant. This finding was comparable to the study, which emphasized that anticoagulant protocols and the duration of catheterization often influence bleeding risks [15, 16]. The minor nature of most bleeding events in our cohort suggests that the anticoagulant strategy, predominantly heparin, was effective without excessively increasing bleeding risks.

The study's findings reinforce the delicate balance calcium maintains in hemostasis. Stable post-procedural calcium levels (mean: 9.0 mg/dL) correlated with reduced bleeding and thrombotic events, supporting earlier research on the role of calcium in thrombin generation and fibrin stabilization [12, 17, 18]. Ionized calcium, often a more accurate indicator of bioavailable calcium, also remained within normal ranges, reflecting effective procedural monitoring and management.

Our analysis of laboratory parameters, including platelet counts, coagulation profiles, and fibrinogen levels, revealed no significant derangements post-procedure. These results align with studies, demonstrating that pediatric patients maintain stable coagulation profiles unless exposed to excessive procedural stress or pre-existing conditions.

The absence of mortality and the low rate of severe complications (thrombosis or significant bleeding) underscore the effectiveness of current procedural protocols. The findings emphasize the need for tailored management of calcium and coagulation during cardiac catheterization, particularly in pediatric populations with unique physiological profiles.

The study's strengths include a well-defined cohort, comprehensive data collection, and rigorous statistical analysis. However, the study is limited by its single-center design, which may limit generalizability. Additionally, the small sample size (100 patients) restricts subgroup analysis for specific variables, such as the type of cardiac intervention or varying anticoagulant strategies.
Further multicenter studies with larger sample sizes are recommended to validate these findings. Research focusing on the dynamic interaction between calcium levels and other electrolytes, such as magnesium and potassium, may provide deeper insights into optimizing procedural safety. Additionally, investigating the role of newer anticoagulants in pediatric catheterization could help refine strategies to balance thrombotic and bleeding risks.

CONCLUSION

This study underscores the pivotal role of calcium in minimizing thrombotic and bleeding complications during cardiac catheterization in children. Maintaining stable calcium levels and adopting evidence-based anticoagulant protocols can effectively mitigate the risks associated with these procedures. These findings contribute to the growing body of evidence supporting personalized approaches in pediatric cardiac care.

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