Capillary blood sampling increases the risk of preanalytical errors in pediatric hospital care: Observational clinical study

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Abstract

Purpose: The blood sampling procedure is complex and prone to failure, as reflected by preanalytical errors in pediatric hospital care. The primary aim was to evaluate if the risk of preanalytical errors was higher with capillary blood sampling than with venous blood sampling, and secondary, explore specific factors associated with preanalytical errors, both overall and stratified by capillary and venous blood sampling.

Design and Methods: This observational pediatric hospital study collected outcomes from medical records and blood sampling surveys from year 2014 to 2016. The risk of preanalytical errors was analyzed with adjusted-odds ratio (adj-OR) by multivariable logistic regression with 95% confidence intervals (CIs).

Results: Overall, 128 (13%) preanalytical errors were identified among 951 blood samples. The proportion and adj-OR of errors was significantly higher in capillary compared with venous blood samples, 72 (20%) of 354 versus 56 (9.4%) of 597, \( p = .001 \), adj-OR 2.88 (CI 1.79–4.64). Blood collection with multiple sample tubes was significantly associated with increased risk of preanalytical errors \( (n = 97 \text{ of } 601, 16\%) \), while log weight (kg) significantly decreased the risk of preanalytical errors adj-OR 0.66 (CI 0.50–0.86), indicating a protective effect of increasing weight. However, stratified analyses indicated a protective effect of increasing log weight for venous blood sampling adj-OR 0.52 (CI 0.38–0.72), but not capillary blood sampling, adj-OR 1.08 (CI 0.76–1.55).

Conclusion: This study indicates that capillary blood sampling collection increases the risk of preanalytical errors. Further, a child's increasing body weight reduced the risk of preanalytical errors, while multiple sample tube collections significantly increased the risk of preanalytical errors.

Practice Implications: This new information may help nurses improve their knowledge concerning blood sampling collection in pediatrics. Altogether, this study also indicates that implementing more venous blood sampling and improve the cases of capillary sampling could reduce the number of preanalytical errors in pediatric hospitals.

KEYWORDS
blood sampling collection, capillary blood sampling, children, nursing, pediatric hospital care, preanalytical errors, risk factors, venous blood sampling

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1 | INTRODUCTION

Blood sampling is one of the most common diagnostic methods for the treatment and assessment of pediatric diseases and conditions (Plebani, 2006). In addition, children may find blood sampling to be the most anxiety-causing procedure experienced during their hospital stay (Hands et al., 2010). The success of blood sampling strongly depends on the technical, psychological, and pedagogical skills of the nurses and laboratory assistants and knowledge of preanalytical pitfalls and guidelines (Harnik & Moreiras, 2014).

This study was executed in a pediatric tertiary hospital in Sweden, but the results may be of interest to nurses and other professionals working with blood sampling collection in other countries.

1.1 | Background

The process of the total laboratory testing can be defined according to the preanalytical, analytical, and postanalytical phases. The preanalytical phase involves submitting electronic requests for the analyses, preparing the patient, sampling the blood, and delivering the samples to the laboratory. Errors in the preanalytical phase account for approximately 60%–70% of all blood sampling errors (Carraro & Plebani, 2007; Lippi et al., 2011). Preanalytical errors (PAE) often lead to rejected samples due to clotting, hemolysis, and unfilled tubes (Lippi et al., 2011). Regarding PAE and associated factors including patient characteristics of age, body weight, underlying medical condition, and nurse and phlebotomist academic education are not well established. In general, avoiding PAE is crucial for sustaining blood sample quality and preventing effects on lab results that will lead to wrong diagnoses and treatments, stressful recollection, as well as economic burdens for hospitals and society (Green, 2013; Lippi et al., 2018).

Previous studies, not stratified to adults and children, have shown that hemolysis is the most common cause of blood sample error (Simundic et al., 2010, 2019). Two-fold higher rates of PAE were reported in pediatric wards compared with adult wards (Salvagno et al., 2008). Collection using capillary blood sampling (CBS) seems particularly problematic in neonatal units due to a high rejection rate of clotting and hemolysis (Phillips et al., 2011). CBS is accomplished by puncturing a finger, heel, toe, or earlobe (Krzeza et al., 2015). Intuitively, CBS is a quick and easy method of choice; however, it cannot be recommended for sampling blood volumes larger than 1 ml (Folk, 2007). The success of CBS depends on securing the blood flow and circulation, usually by warming the puncture area (Becht & Anderson, 1996). We have published data from a laboratory register and found high numbers of PAE, mainly related to clotting, in Swedish pediatric hospitals (Hjelmgren et al., 2019). While the register lacks detailed information of methods used for blood sample collection, we decided to test our hypothesis that clotting errors are associated with CBS due to low blood flow and volumes. Therefore, we designed a clinical investigation comparing PAE between capillary- and venous blood sampling (VBS), as well as in detail evaluate factors affecting the risk of PAE in children treated inward for medical conditions.

1.2 | The study

1.2.1 | Aims

The primary aim of this study was to evaluate if the risk of PAE was higher with CBS compared with VBS, and secondary, explore specific factors with influence on PAE, both overall and stratified by CBS and VBS in pediatric hospital care.

2 | METHODS

2.1 | Study design

This was an open clinical observation study that prospectively combined information on blood sampling from a health professional survey with information of the main outcome of PAE from the medical record.

2.2 | Participants

The study population consisted of all available children with complete information on blood sampling during hospital stays in two pediatric emergency wards in Stockholm Sweden, from January 27, 2014 to October 1, 2016.

2.3 | Data collection and analysis

While VBS and CBS were routinely collected by nurses with bachelor’s or master’s degrees, CBS could regularly be taken by nurse assistants. VBS was retrieved using Microtainer (0.5 ml) or regularly vacuum tubes (4 ml max volume), while CBS was retrieved only by Microtainers. Data regarding blood sampling were retrieved from healthcare professionals who had filled in a survey when the sample was collected. The survey contained information about sampling methods, the sampler’s professional academic level, and the puncture location, needle size, and a number of punctures. The information from each survey was used to collect information about each child’s age, gender, weight, diagnosis/symptoms, PAE, and number of tubes in the electronic medical record (Take Care™ system). All blood samples analyzed at Astrid Lindgren’s Children’s Hospital are registered in the medical record by the Karolinska University Hospital Laboratory, which complies with ISO standard 15189:2012.

In total, 9500 unique children (ward 1: 4866 and ward 2: 4634) at Astrid Lindgren’s Children’s Hospital were treated during the study period, according to data extracted from the hospital information register. The wards treated children aged 0–18 years within general pediatric medicine for approximately 2–3 days, mostly for infectious diseases. Regarding the external validity, the annual number of blood samples collected during the year 2014 was 11,590 at Astrid Lindgren’s Children’s Hospital. Based on data from 2014 and lack of annual
data from 2016 to 2017, we estimate that approximately 32,000 blood samples were collected during the study period.

2.4 Definition of outcomes

The primary outcome PAE was defined by the laboratory due to any of the following specific types of errors: clotting, hemolysis, incorrect filling level, missing sample, or erroneously labeled sample tube as described elsewhere (Hjelmgren et al., 2019). Uncommon PAE represented in the study were defined as "other," and included damaged samples, samples with thrombocyte aggregation, and sample analyses that were not executed. VBS was defined as a blood sample obtained from a vein by a blood collection system (Becton Dickson [BD] Vacutainer®, butterfly collection set, open needle, or a direct draw from a peripheral intravenous catheter [PVC], or central venous line [CVL]). CBS was defined as a blood sample obtained through a finger (BD Microtainer®, contact-activated lancet) or heel (BD Quickheel®). The BD Microtainers sample tubes were used to collect CBS. The child's medical condition was classified based on a review of the medical record and defined accordingly as fever, respiratory, gastroenteritis, oncology, surgical, and other (i.e., pain, infectious disease, possible renal and liver diseases, neurological diseases, metabolic diseases, skin disorders, and eating disorders).

2.5 Statistics

Power estimation was based on analysis of 708 collected blood samples, with a PAE rate of 20% in CBS and 9% in VBS. Attainment of 80% power for detecting a statistically significant difference between CBS and VBS in risk of PAE at a 5% significance level required at least 160 CBS and 160 VBS. The data from the surveys and medical records were compiled in a Microsoft Excel spreadsheet, and the patient identification number was replaced and coded in the statistical data analysis using STATA MP14 (StataCorp LLC). Proportions of children in different categories, for example, female, male, were calculated separately for CBS and VBS, including 95% confidence intervals (CIs). The distribution of weight was evaluated with a histogram and transformed using the natural logarithm (ln) to limit the influence of outliers and provide a better fit for the regression models.

Mixed-effects logistic regression was used with PAE as an outcome variable, with a random intercept per patient, to take into account the dependencies of samples from the same patient. p values of less than .05 were considered to allow for rejection of the null hypothesis of no significant difference. Differences between CBS and VBS in odds ratios (OR) or adjusted OR (adj-OR), adjusting for weight and number of collected tubes, were evaluated by adding an interaction term between the puncture type and the variable of interest (i.e., weight and number of tubes). Weight and age were both closely associated with PAE. To avoid overadjustment in the multivariable model, only weight, the variable showing the strongest correlation with PAE, was included in the model. Since the linearity assumption of the association between weight (kg) and log-odds was violated, the shape of the association between weight (kg) and the probability of PAE was investigated by fitting logistic regression models, with weight transformed using restricted cubic splines (RCS) with four knots, separately for CBS and VBS. RCS is a method for relaxing the linearity assumption in regression models, thereby enabling alternative shapes of the association between an explanatory variable and an outcome variable. The function rcspline.plot in the R package rms in R version 3.6.0 was used (Harrell, 2019).

2.6 Ethical considerations

The study was approved by the Regional Ethical Review Board in Stockholm (Registration number: 2015/206-31/4). Independently of this study, all blood sampling was performed due to child’s health condition.

3 RESULTS

A sample of 1020 surveys was collected with information about blood collection during the study period. Of these 1020 surveys, 69 contained incomplete information due to duplications, missing information, and missing patient IDs. Among the final sample of 951 complete surveys were 645 unique patients identified. The discordant number of filled in surveys and patients was related to repeated blood sampling in some patients during the time of hospitalization.

Table 1 shows detailed information about the 951 blood sample collections across 354 (37%) CBS and 597 (63%) VBS. For laboratory tests requiring one sample tube, a significantly higher proportion was collected using CBS (51% [95% CI, 46–56]) than VBS (29% [95% CI, 25–32]), whereas the proportion of VBS samples was greater for laboratory analyses requiring three or more sample tubes. In children with fever, respiratory symptoms, or other medical conditions according to the study definition, was CBS used more frequently than VBS. Children with oncological conditions were less common in the CBS group. The ways that CBS and VBS were executed are described in Table S2.

The proportional distributions of categorized PAE across CBS and VBS are presented in Figure 1. The overall number of PAE was...
128 (13%) of the 951 investigated blood samples. The most frequent cause of PAE was clotting, at 38% \( (n = 49) \), and the proportion was significantly higher in CBS (33%) than in VBS (5.5%) \( (p < .001) \).

Figure S1 provides proportions of PAE between CBS and VBS in age groups from neonates to adolescents.

Binary logistic regression analyses are presented in Table 1. The distribution of PAE was significantly higher in CBS compared with VBS \( (OR 2.56 [1.69–3.88]) \). Neither the study site nor the child’s gender was statistically significantly associated with PAE. Toddlers and neonates had significantly higher PAE risk than adolescents. Weight less than 11 kg was another factor increasing the risk of PAE \( (OR 2.05 [1.35–3.10]) \). Blood sampling requests for two or more sample tubes compared with one tube were associated with PAE \( (OR: 2.14 [1.32–3.47]) \).

A multivariable logistic regression model showed that CBS and a requirement for two or more sample tubes significantly increased

| TABLE 1 Univariable logistic regression analysis of factors associated with preanalytical blood sample errors, \( n = 951 \) |
|------------------------|------------------|------------------|------------------|
| Blood samples          | Preanalytical    | Odds ratio       |
| n (%)                 | errors n (%)     | 95% CI           |
| Wards                  |                  |                  |
| Ward 1                 | 447 (47)         | 70 (16)          | 1                |
| Ward 2                 | 504 (53)         | 58 (12)          | .070             |
| Gender                 |                  |                  |
| Boys                   | 516 (54)         | 73 (14)          | 1                |
| Girls                  | 435 (46)         | 55 (13)          | .503             |
| Age                    |                  |                  |
| Adolescents (10–18 years) | 253 (27)    | 23 (9.1)         | 1                |
| Childhoods (6–9 years)  | 166 (17)         | 21 (13)          | .247             |
| Pre-schoolers (3–5 years) | 162 (17)   | 19 (12)          | .386             |
| Toddlers (1–2 years)   | 188 (20)         | 31 (16)          | .021             |
| Infants (3–11 months)  | 85 (8-9)         | 13 (15)          | .113             |
| Neonates (0–2 months)  | 97 (10)          | 21 (22)          | .002             |
| Weight                 |                  |                  |
| ≥ 11 kg                | 695 (73)         | 77 (11)          | 1                |
| 0–10 kg                | 256 (27)         | 51 (20)          | <.001            |
| Weight* (ln kg)        |                  |                  |
| Blood sampling         |                  |                  |
| Venous                 | 597 (63)         | 56 (9.4)         | 1                |
| Capillary              | 354 (37)         | 72 (20)          | <.001            |
| - Capillary ward 1     | 221 (23)         | 49 (22)          | .001             |
| - Capillary ward 2     | 133 (14)         | 23 (17)          | .016             |
| Blood amount           |                  |                  |
| One tube               | 350 (37)         | 31 (8.9)         | 1                |
| Two or more tubes      | 601 (63)         | 97 (16)          | .002             |
| Staff–academic level    |                  |                  |
| Nurse Assistant, capillary samples | 130 (37) | 29 (22)         | 1                |
| Nurse Bachelor, capillary samples | 152 (43) | 31 (20)         | .680             |
| Nurse Master Degree, capillary samples | 72 (20) | 12 (17)         | .353             |

Abbreviation: CI, confidence interval.

*Weight transformed by using the natural logarithm to limit the influence of outliers and better fit the regression models.
TABLE 2 Multivariable logistic regression analysis estimating adjusted odds ratios (adj-OR) of factors associated with PAE, n = 951

| Factor                        | Adj-OR (95% confidence interval) | Std. Err | p value |
|-------------------------------|----------------------------------|----------|---------|
| Capillary blood sampling      | 2.88 (1.79–4.64)                 | 0.70     | <.001   |
| Weight in kg                  | 0.66 (0.50–0.86)                 | 0.09     | .002    |
| Two or more sample tubes      | 3.12 (1.84–5.31)                 | 0.85     | <.001   |

Note: The model analyzed independent factors that were significantly associated with PAE in the crude analysis: type of blood sampling collection (capillary vs. venous). Weight was treated as a continuous variable and transformed using the natural logarithm to limit the influence of outliers and to provide a better fit for the regression models. The number of collected blood sample tubes was analyzed as two or more versus one.

Abbreviation: PAE, preanalytical errors.

4 | DISCUSSION

This pediatric study identified that the risk of PAE was significantly higher with CBS than with VBS. PAE was also associated with blood analysis requiring multiple sample tubes and low body weight. Furthermore, the use of body weight as a continuous variable, indicated that increases in the child's body weight reduced the risk of PAE in the VBS group but not in the CBS group. This study indicates that denser introduction of VBS may prevent clotting. The community of pediatric healthcare needs to improve the blood sampling procedure to achieve best clinical practice and secure patient safety.

In this study, clotting was the most frequent cause of PAE, consistent with other reports (Hjelmgren et al., 2019; Rooper et al., 2017; Salvagno et al., 2008). However, to the best of our knowledge, PAE have never been analyzed between CBS and VBS.

FIGURE 2 Odds ratios and 95% confidence intervals for preanalytical errors for increasing weight and number of blood tubes, for venous- and capillary blood sampling, respectively

FIGURE 3 Association between weight (kg) and preanalytical errors probability of total samples (a), and stratified by capillary- (b), and venous blood sampling (c)
in a pediatric hospital context. Possible reasons reducing the apparent association between clotting and CBS is deletion of the first drop of blood, mixing of the sample during and after sampling, and gentle pressing of surrounding tissue are prerequisites for a capillary sample without clots and hemolysis. Healthcare professionals have previously been reported to have difficulties in complying with the guidelines in blood sampling procedures (Simundic et al., 2015). To improve the outcome of CBS in pediatric healthcare, the establishment of detailed guidelines, repeated clinical training programs supporting staff, and avoiding the risk factor of clotting will be important.

Low body weight in children has not previously been associated with PAE. Interestingly, the stratified analysis indicated that increasing weight was only protective in the VBS group. This finding highlights implementation of more VBS could reduce the events of PAE. The existing worldwide guidelines on blood sampling procedures have not noticed an increased risk of PAE in small children (CLSI, 2017; Simundic et al., 2018; World Health Organization, 2010). From a child’s perspective, VBS appears to be less painful than CBS for neonates and well babies (Jewell et al., 2007; Shah & Ohlsson, 2011).

This study generated some novel findings by showing that PAE risk increases when the number of tubes in a blood sample increases from one to two or more. When stratified for both CBS and VBS, a tube number greater than one still remains a high risk; this has not been described before, to our knowledge. Healthcare professionals working in a pediatric context report that needle procedures are challenging (Kennedy et al., 2008) therefore, while sampling blood from children, extra arms are needed to change tubes and maintain a good procedure all the way through. A study from Canada demonstrated that nurses viewed the VBS process less time consuming, less painful for the infant, and an easier method for blood collection than CBS (Jewell et al., 2007). Even though VBS is considered a more advanced procedure than CBS, it is the gold standard. We, therefore, recommend that CBS be used sparingly in children visiting the hospital as this will allow obtaining of a good blood sample while considering sample quality, patient safety, and the wellbeing of the pediatric patient.

Our results also indicate the need of improving the CBS method in children. CBS in children, whether administered as a finger prick or a heel prick, requires that nurses have sufficient clinical skills. (World Health Organization, 2010). CBS should be approached with caution in pediatric hospital care; only small blood volumes can be recommended and CBS should not be used as first choice when the analyses require added anticoagulant. Immediately mixing of the blood with anticoagulant can prevent clotting (Krleza et al., 2015). A reason to ensure CBS is present is when repeated sampling is needed and to preserve iv-sight in sick neonates and infants (Coffin et al., 2002).

5 | LIMITATIONS

This study used a relatively large number of observations and was based on information from a laboratory register from two study sites. The results can be generalized in relation to other hospital-based pediatric contexts where both VBS and CBS are utilized. Based on our results, we plan to revise and implement local hospital guidelines focusing on staff education for avoiding clotting. Future research needs to assess the effect and feasibility of such intervention, and stratify the blood collection data for CBS and VBS, as well as stratify pediatric health care separately, as this may have a major influence on different rejection errors. The limitation of this study is that the size of the sample tube was not recorded, we cannot distinguish if Microtainers or venous sample tubes were used. The size of the sample tubes may influence the PAE.

6 | CONCLUSION

In this study, the risk of PAE was significantly higher with CBS compared with VBS. Associated risk factors were blood collection using multiple sample tubes and low body weight in children. This study indicates that PAE, such as clot can be avoided in pediatric healthcare by introducing more VBS.

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CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

HOW MIGHT THIS INFORMATION AFFECT NURSING PRACTICE?

This study indicates that implementing more venous blood sampling instead of capillary sampling could reduce the number of pre-analytical errors in pediatric hospitals.

DATA AVAILABILITY STATEMENT

Data sharing including nonpersonal data will be possible if Ethical Authority approves the sharing prior do delivery.

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