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Incidence and Causes of Infusion Alarms in a Neonatal and Pediatric Intensive Care Unit: A Prospective Pilot Study

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OBJECTIVES To evaluate the incidence and causes of infusion alarms in a NICU/PICU setting.

METHODS We conducted a 90-day prospective analysis of event logs downloaded daily from infusion pumps (syringe and volumetric pumps). The details about conditions surrounding alarm events were described daily by bedside nurses on a standardized form. The occlusion pressure alarm was set at 300 mm Hg on each device.

RESULTS Forty-one pediatric patients including 12 neonates, mean weight 11.0 ± 11.3 kg (minimum–maximum, 0.48–50), were included for a total infusion time of 2164 hours. Eight hundred forty-three infusion alarms were documented (220 [26.1%] occlusion; 273 [32.4%] infusion completed; 324 [38.4%] door open/syringe disengagement; 26 [3.1%] air-in-line) resulting in an incidence of 4.7 infusion (1.2 occlusion) alarms per patient per day.

Detailed conditions surrounding occlusion alarm events were documented in only 22.7% (50/220) of the cases. Of these, 36% (18/50) were related to closed or clamped lines, 4% (2/50) to syringe change, 16% (8/50) to drug injection, and 8% (4/50) to patient-related factors. The remaining 36% (18/50) occurred without any apparent external cause during ongoing infusion, among these drug incompatibilities were a potential cause for 12 events.

CONCLUSION Alarms from infusion pumps were frequent in the NICU/PICU setting, a quarter of them resulting from line occlusion. Other than well-known triggers (mechanical and patient factors), drug incompatibilities were identified as a potential cause for occlusion alarms in this pilot study.

ABBREVIATIONS ICU, intensive care unit; IV, intravenous; NICU, neonatal intensive care unit; PICC, peripherally inserted central catheter; PICU, pediatric intensive care unit; PIVC, peripheral intravenous catheter; TPN, total parenteral nutrient; UVC, umbilical venous catheter

KEYWORDS drug incompatibility; infusion alarm; infusion pumps; neonatal intensive care unit; occlusion; pediatric intensive care unit

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Introduction

Medical device alarms have been a major issue in hospital settings for 20 years. Multiple alarms from various equipment and monitoring devices can be noisy and a source of stress for both patients and staff.[1,2] Noise resulting from alarms may induce nurse fatigue and alarm desensitization with the risk that significant alarms are missed or ignored.[3–5] The Joint Commission listed alarm management as a National Patient Safety Goal in 2019 to reduce the harm associated with clinical alarm systems.[6]

Infusion pumps are one of the sources of device alarms and monitoring alarms counting for approximately 10% of ICU alarms.[3] The use of high-performance infusion devices is recommended in NICUs and PICUs to increase the safety of drug administration.[7] Infusion alarms may occur from both clinical alerts from dose error reduction software implemented in smart pumps, and from the device itself.[7,8] In order to prevent any clinical consequences for the patient when the flow is interrupted, the devices are designed to alert health care staff using a visual and an auditory alarm.[7,9] There is a large variety of infusion alarms that may set off for technical reasons (e.g., door open, infusion completed) or infusion problems (e.g., occlusion, air- in-line detection).[10] An incidence of 2.2 infusion alarms per patient per day has been observed in 5 ICUs.[3] In another study in a 500-bed adult acute care setting, occlusion had the highest prevalence (38% of events) of infusion alarms, followed by infusion completed (21%), air in line (8%), and door open (4%) alarms.[11] NICUs and PICUs had

the highest number of alarms per drug delivery in 2 studies evaluating the frequencies of infusion alarms by care areas.[12,13]

Occlusion alarms on syringe drivers and air-in-line alarms on volumetric pumps are categorized as high-priority alarms and are intended to avoid the clinical consequences of non-delivery at low flow rates of critical medications and embolism.[14]

Approximately 42% of catheter occlusions in pediatric patients are non-thrombotic, due to mechanical causes (e.g., a clamped line or closed stopcock), drug or mineral precipitates, or lipid residue.[15] Parenteral infusion for neonates and children is particularly challenging due to the limited number of venous access sites, the small bore of catheters, and small drug volumes.[16] Highly concentrated solutions of high-risk drugs are commonly delivered at low infusion rates, in order to avoid volume overload but through the same line, thus increasing the risk of drug incompatibilities.[17] It has been estimated that 13.7% of drug coinfusions in PICUs and 74% in NICUs are incompatible or have not been tested.[18,19] Occlusions as a result of drug incompatibilities can have potentially harmful consequences such as pulmonary embolisms and/or granulomas or systemic inflammatory response syndrome.[20–23] To the best of our knowledge, there have been no studies evaluating if drug incompatibilities might be involved in the occurrence of occlusion alarms.

Materials and Methods

The aim of this pilot study was to quantify and identify the various causes of infusion and occlusion alarms occurring in our NICU/PICU, and to investigate drug incompatibilities as possible triggers of occlusion alarms. We conducted a prospective 90-day analysis of the event logs downloaded daily from syringe pumps and volumetric smart pumps.

Patients. Patients hospitalized in the NICU/PICU of the Geneva University Hospitals in Switzerland were included in the study. This unit is a tertiary care structure with 10 mixed tertiary care medical and surgical NICU/PICU beds admitting 500 to 600 patients a year, including slightly more than 200 patients after cardiac surgery, and 150 neonates who required intensive care from birth because of prematurity or other conditions (malformations, metabolic diseases). The patients included in this study ranged from birth to 16 years of age and were hospitalized between June and August 2008. Cardiac patients were hospitalized after surgery with 1, 2, or 3 lumen central venous catheters (Cook 3FR single lumen, or 4FR and 5FR double lumen; Cook Medical, LLC, Bloomington, IN) and 2 peripheral intravenous catheters (PIVCs). The remaining pediatric intensive care patients had PIVCs. The PIVCs used in our unit are the BD Neoflon (Becton Dickinson Infusion Therapy Systems, Inc, Helsingborg, Sweden), BD Insyte-N and BD Insyte-W (Becton Dickinson Infusion Therapy, Sandy, UT) and Vasofix Safety PUR (B Braun, Melsungen, Germany). The sizes ranged from 14G to 26G. Preterm patients requiring parenteral nutrition or antibiotics are given an umbilical venous catheter (UVC) (Vygon PUR umbilical catheter 2.5 or 3.5 FR single lumen; Vygon SA, Ecouen, France) for the first days of life; this is changed to a single lumen peripherally inserted central catheter (PICC) (Premicath 28G, Vygon SA) if the treatment needs to be continued. Only a few of the preterm patients have a PIVC inserted, and this depends on the number of drugs that need to be infused. Neonates with conditions such as hypoglycemia or an infection risk have a PIVC with a continuous running infusion.

Data Collection and Materials. Due to time and technical constraints (manual extraction via a portable personal computer), data downloads were not possible in parallel for the 10 beds and were limited to 2 beds (i.e., 2 patients) per day. Data were collected from 3 types of infusion devices: syringe pumps (Module DPS; Fresenius Vial, Brézins, France); Module MVP volumetric pumps (Fresenius Vial); and Volumed µVP7000 volumetric pumps (Arcomed, Kloten, Switzerland). Module DPS and Module MVP were driven by an Orchestra Base Intensive workstation (Fresenius Vial) with an integrated drug library of 95 drugs. The Volumed µVP7000 had an integrated drug library of 20 drugs. The occlusion pressure alarm was set at 300 mm Hg on all 3 devices and could not be changed by the clinical team. This is standard practice in the pediatric units of our institution.

Extraction of Alarm and Nursing Data. Event logs were downloaded to a portable personal computer twice daily using Base Dump (Fresenius Vial) and Druglib 224-1 software (Eeprom configuration v2.18; Arcomed). Extracted data were as follows: demographic data (age, weight); drug names and infusion rate (mL/hr); infusion time; all pump events (connection, disconnection, syringe change, rate change); and alarms (i.e., occlusion, infusion completed, syringe disengagement [for syringe pumps only], door open, and air-in line [for volumetric pumps only])-

Bedside nurses completed a standardized form giving detailed data on the occurrences of occlusion alarms, including the following: pathology of the patient (cardiac, newborn, transplantation, trauma); conditions of occlusion occurrence (clamped line or closed stopcock, slow or rapid manual bolus injection, patient agitation or care, without apparent external cause); technical data (types of syringes, pumps, IV catheters); coinfused drugs (concentration, solvent, infusion rate); and clinical consequences and management (catheter flushing, line change).

Evaluation of Drug Compatibility. We evaluated drug compatibility using Trissel's *Handbook on Injectable Drugs*[24], *King Guide to Parenteral Admixtures*[25] in their online versions, and the Swiss summary of product

Table 1. Demographic Parameters

	All Patients (N = 41)	Patients With Occlusion Alarm (n = 31)	Patients With No Occlusion Alarm (n = 10)
Age, yr			
Mean ± SD	2.9 ± 4.3	3.0 ± 4.4	0.002
Median (range)	0.9 (0.002–13)	0.9 (0.002–13)	24 h
Missing data*	22	13	9
Weight, kg			
Mean ± SD	11.0 ± 11.3	10.5 ± 10.7	12.3 ± 13.6
Median (range)	7.2 (0.48–50)	7.2 (0.66–50)	8.25 (0.48–39)
Patient type, n (%)			
Premature-neonate	12 (29.3)	7 (22.6)	5 (50)
Cardiac	19 (46.3)	18 (58.1)	1 (10)
Others	10 (24.4)	6 (19.3)	4 (40)
Trauma	1 (2.4)	1	0
Transplantation (hepatic)	1 (2.4)	1	0
Diabetes (onset)	1 (2.4)	1	0
Malaria	1 (2.4)	0	1
Orthopedic surgery	1 (2.4)	1	0
Missing data	5 (12.2)	2	3

* Approximately 50% of the data about age were missing.

characteristics (Swiss Agency for Therapeutic Products, Bern, Switzerland, website https://www.swissmedicinfo.ch/). Evaluation of coinfused drugs was performed based on reported drug concentrations and solvents by bedside nurses.

Data Analysis. Log files extracted from the pumps were downloaded to an Excel file (Excel 1997–2003, Microsoft Corp, Redmond, WA) and a descriptive analysis was performed. Demographic data and the number of alarms were expressed as mean ± standard deviation, median value, and the minimal and maximal range values.

Results

Overall, 41 patients with a mean weight of 11.0 ± 11.3 kg (7.2; 0.48–50) were included in the 90-day study (total infusion time, 2164 hours). One patient was included twice—before and after cardiac surgery. He was considered as 2 different patients for the purposes of the analysis. The proportions of patients included were representative of the unit's usual activities with 19 (46.3%) cardiac patients, 12 (29.3%) neonates, and 10 (25%) others (Table 1). Approximately 50% of the age data were missing (this information was not required input for smart-pump programming and was not documented by the nurses).

Eight hundred forty-three infusion alarms (220 [26%] occlusion, 273 [32%] infusion completed, 324 [39%] door open/syringe disengagement, 26 [3%] air-in-line) were recorded (Table 2). An incidence of 4.7 infusion alarms and 1.2 occlusion alarms per patient per day was determined. The mean number of infusion alarms per patient was 20.6 ± 16.2 (18; 0–75) recorded over a mean infusion time in hours of 52.8 ± 40.2 (49.1; 0.7–217). During the study, no infusion alarms and no occlusion alarms were recorded in 3 patients (7%) and 10 patients (24%), respectively (Table 2).

Conditions surrounding occlusion alarms events were documented in only 22.7% (50/220) of the cases by bedside nurses, representing 18 of 31 patients (Table 3). Of these, 36% (18/50) were related to a closed or clamped line, and 16% (8/50) to either slow or rapid manual direct injection. Patient care, agitation, and infusion changes were 3 rarer causes of occlusion alarms (4% [2/50] each). The remaining 36% (18/50) occurred without any apparent external cause during ongoing infusion.

The majority of occlusion alarms occurred on syringe pumps alone (76%, 38/50). In 36% (18/50) of the cases, they occurred simultaneously on the syringe and the volumetric pumps connected to the same catheter (Table 3).

Occlusion alarms caused therapy delays for the patients due to line checking, arm positioning, or stopcock opening if necessary. No severe consequences were reported and only 1 minor consequence was observed (removal of a peripheral line due to pain on site). Lumen flushing was performed in 22% (11/50) of the cases,

Table 2. Pump Alarm Data

	All Patients (N = 41)	Patients With Occlusion Alarm (n = 31)	Patients With No Occlusion Alarm (n= 10)
Infusion time, hr			
Number	2164	1853	311
Mean ± SD	52.8 ± 40.2	59.8 ± 41.5	31.1 ± 27.6
Median (range)	49.1 (0.7–217.0)	51.6 (7.3–217.0)	26.8 (0.7–71.9)
Infusion alarms			
Number	843	777	66
Mean ± SD	20.6 ± 16.2	25.1 ± 15.5	6.6 ± 8.8
Median (range)	18 (0–75)	21 (4–75)	2.5 (0–23)
Type of alarm, n (%)			
Occlusion	20/843 (26)	220/777 (28)	0
Air-in-line	26/843 (3)	21/777 (3)	5/66 (8)
Infusion completed	273/843 (32)	247/777 (32)	26/66 (39)
Door open/syringe disengagement	324/843 (39)	289/777 (37)	35/66 (53)
Occlusion alarms			
Number	220	220	
Mean ± SD	5.4 ± 5.3	7.1 ± 5.0	
Median (range)	4 (0–21)	8 (1–21)	

using normal saline or 0.45% sodium chloride with or without 0.5 UI/mL of heparin. No data were available on the success of this procedure.

Occlusion alarms that occurred spontaneously without any apparent external causes (36%, 18/50) in 9 patients (2 premature, 6 cardiac, 1 other) were analyzed in more detail (Table 4). In 1/18 cases, a total flow rate exceeding catheter tolerance was suspected as the cause of the occlusion alarm. Drug incompatibilities were a possible cause of occlusion alarms in 12/18 cases and occurred on Cook catheters (n = 8), PICC lines (n = 2), PIVC (n = 1), and UVC (n = 1). In 9/12 cases, a total parenteral nutrient (TPN) admixture and fat emulsion were administered with other drugs. Coadministration of midazolam and TPN, rifampin and TPN, albumin and TPN, flucloxacillin and fat emulsion, frozen plasma and glucose 40%, ketamine and heparin, and milrinone and furosemide were all evaluated as incompatible according to the literature[24,25].

Discussion

We recorded 843 infusion alarms during the 90 days (2164 infusion hours) on 2 NICU/PICU beds, giving an incidence of 4.7 infusion alarms per patient per day. This result is approximately 2 times higher than that observed in adult ICUs.[3] This difference may be explained by the different populations or study methodologies. Approximately 70% of infusion alarms were due to technical causes like a completed infusion, an open door, or syringe disengagement. Occlusion alarms were observed in 26% of the alarm events, with an incidence of 1.2 alarms per patient per day. Occlusion pressure alarm were set at 300 mm Hg, which is very high. This setting is a way of managing occlusion alarm levels (fixed or variable levels) and may explain the smaller percentage of occlusion alarms recorded when compared with other studies.[11] Air-in-line alarms were in the range of other studies.[11–13]

As expected, occlusion alarms mainly occurred due to mechanical causes, such as a clamped line, closed stopcock, or slow or rapid bolus injection; and to a lesser extent to patient factors such as agitation or care. However, in 36% of the cases, no clear causes could be identified by nurses. After evaluation of coadministered drugs, we found that drug incompatibilities were a possible cause in a number of these cases. TPN was possibly involved in the majority of the cases, with other drugs such as heparin and antibiotics. This seems to be in agreement with another study[12] showing that the majority of infusion alarms were due to IV fluids, heparin, and antibiotics, and that TPN had the highest rate of alarms per drug delivery.

Evaluating drug compatibility is not easy. There is a great heterogeneity in the methodologies of physical compatibility studies, which contributes to conflicting data.[26] Compatibility data are lacking for most of the drugs coinfused for NICU/PICU patients, and may contribute to unsafe medication practice.[18,19] Appropriately and consistently applied alarm settings might be clinically crucial for preventing underinfusion or overinfusion consecutive to postocclusion bolus and embolism.[27] The present study's results might suggest that occlusion alarms could be useful in the detection of drug incompatibilities. However, the time between the onset of an occlusion and the alarm can be influenced by different factors, such as flow rates, syringe size, line compliance and length.[28–31] Drug precipitates will probably have formed long before an occlusion alarm activates. Prevention of drug incompatibilities in high-risk units such as NICU/PICU should therefore rely

Table 3. Conditions of Occlusion Occurrence in 18 Patients

	Occlusion Alarms* Documented by Nurses (n = 50/220)
Pump type, n (%)	
Module DPS syringe pump	38 (76)†
Volumetric pump	30 (60)†
Module MVP	18 (36)
Volumed µVP7000	12 (24)
Catheter type, n (%)	
Cook	20 (40)
PICC	10 (20)
PIVC	10 (20)
UVC	3 (6)
Missing data	7 (14)
Mechanical cause, n (%)	
Total	20 (40)
Closed stopcock/clamped line	18 (36)
Infusion change	2 (4)
Patient cause, n (%)	
Total	4 (8)
Agitation	2 (4)
Care	2 (4)
Slow or rapid direct injection cause, n (%)	8 (16)
Without apparent external causes, n (%)	
Total	18 (36)
Possible drug incompatibility	12 (24)
Flow rate >> catheter tolerance	1 (2)
Undetermined	5 (10)

PICC, peripherally inserted central catheter; PIVC, peripheral intravenous catheter; UVC, umbilical venous catheter

* Pressure set at 300 mm Hg.

† Simultaneous occlusion alarm on syringe and volumetric pumps in 18 cases.

on other solutions such as infusion line design, in-line filters, or recommendations from unit-based clinical pharmacists.[32,33]

The present study was small and its results may have been biased. Although data on the incidence of infusion alarms relying on more than 800 events probably do provide a good picture of their occurrence in our institution's NICU/PICU setting, the analysis of occlusion alarms was incomplete because only a quarter of occlusion events were noted in detail by nurses. Drug compatibility was evaluated based on a literature search and no objective data such as precipitates in the line were available. Moreover, the occurrence of drug incompatibilities may have been influenced by infusion devices or rates, or drug concentrations.[34,35] All these factors varied significantly in our small patient group. The identified causes of occlusion alarms should therefore be considered with caution and be confirmed in a larger study.

Conclusion

An incidence of 4.7 infusion alarms per patient per day was determined in this pilot study, a quarter of these being occlusion alarms. Most of them were due to well-known triggers such as mechanical and patient factors. Drug incompatibilities were suspected as a potential cause of occlusion alarms in a few cases. Because the clinical consequences of drug incompatibilities can be severe, every effort should be made to prevent the infusion of incompatible drugs that might result in line occlusions. Consequently, drug incompatibilities should be considered when searching for the causes of occlusion alarms in daily NICU/PICU practice.

ARTICLE INFORMATION

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Table 4. Details on Occlusion Without Apparent External Causes (n = 18)

Case	Possible Cause of Occlusion Alarm	Patient	Type of Patient	Age	Weight, kg	Type of Catheter	Coadministered Drugs on Same Lumen
1	Drug incompatibility	1	Premature	7 days	2.6	PICC	flucloxacillin (52.5 mg/mL), TPN, fat emulsion 20%
2	Drug incompatibility	1	Premature	8 days	2.6	PICC	rifampin (1.2 mg/mL), TPN, fat emulsion 20%
3	Drug incompatibility	2	Cardiac	13 mo	4.5	Cook	midazolam (0.9 mg/mL), TPN, fat emulsion 20%
4	Drug incompatibility	2	Cardiac	13 mo	4.5	Cook	midazolam (0.9 mg/mL), TPN, fat emulsion 20%
5	Drug incompatibility	2	Cardiac	13 mo	4.5	Cook	midazolam (0.9 mg/mL), TPN, fat emulsion 20%
6	Drug incompatibility	2	Cardiac	13 mo	4.5	Cook	midazolam (0.9 mg/mL), TPN, fat emulsion 20%
7	Drug incompatibility	2	Cardiac	13 mo	4.5	Cook	midazolam (0.9 mg/mL), TPN, fat emulsion 20%
8	Drug incompatibility	2	Cardiac	13 mo	4.5	Cook	midazolam (0.9 mg/mL), TPN, fat emulsion 20%
9	Drug incompatibility	2	Cardiac	13 mo	4.5	Cook	furosemide (0.45 mg/mL), milrinone (0.13 mg/mL)
10	Drug incompatibility	3	Cardiac	7 yr	21	Cook	frozen plasma, glucose 40%
11	Drug incompatibility	3	Cardiac	7 yr	21	PIVC	midazolam (4.2 mg/mL), ketamine (6.3 mg/mL), heparin (2500 UI/mL)
12	Drug incompatibility	4	Cardiac	1 day	0.9	UVC	albumin 20%, TPN
13	Flow rate >> catheter tolerance	8	Other (spinal surgery)	12 yr	17	PIVC	paracetamol (10 mg/mL) at 100 mL/hr
14	Undetermined	3	Cardiac	7 yr	21	PIVC	midazolam 4.2 mg/mL, ketamine 6.3 mg/mL
15	Undetermined	4	Cardiac	11 mo	4.3	Cook	glucose 10% with KCl, calcium gluconate, NaCl (additives)
16	Undetermined	6	Cardiac	25 mo	7.6	Cook	heparin 0.5 UI/mL in NaCl 0.45%
17	Undetermined	7	Premature	1 day	2.2	Missing data	inositol (50 mg/mL), glucose 10%
18	Undetermined	9	Cardiac	24 mo	3.5	PIVC	morphine (0.14 mg/mL), midazolam (0.35 mg/mL)

PICC, peripherally inserted central catheter; PIVC, peripheral intravenous catheter; TPN, total parenteral nutrition (2-in-1); UVC, umbilical venous catheter

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