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Comprehensive critical incident monitoring in a neonatal-pediatric intensive care unit: experience with the system approach

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Abstract *Objective*: To examine the occurrence of critical incidents (CIs) in order to improve quality of care.
Design: Prospective survey.
Setting: Multidisciplinary, neonatal-pediatric intensive care unit (ICU) of a non-university, teaching children's hospital.
Patients: Four hundred and sixty-seven admissions over a 1-year period.
Methods: A CI is any event which could have reduced, or did reduce, the safety margin for the patient. Comprehensive, anonymous, non-punitive CI monitoring was undertaken. CI severity with respect to actual patient harm was graded: major (score 3), moderate (2) or minor (1). The system approach incorporates the philosophy that errors are evidence of deficiencies in systems, not in people. We undertook 2-monthly analyses of CIs.
Results: There were 211 CI reports: 30 % major, 25 % moderate, 45 % minor. The CI categories were management/environment 29 %, drugs 29 %, procedures 18 %, respiration 14 %, equipment dysfunction 7 %, nosocomial infections 3 %. The respiratory CIs were the most severe, the drug-related CIs the least severe (score mean, SD: 2.9, 0.26 vs 1.4, 0.76; $p < 0.001$). However, 20 out of 62 drug-related CIs were potentially life-threatening. Thirteen percent of drug CIs were decimal point errors. Eleven of the 29 respiratory CIs were accidental extubations (2.6/100 ventilator days). CIs were most often precipitated by consultants (32 %), followed by residents (23 %, over-represented in drug CIs, 22/62) and specialized nurses (21 %). Doctors had a greater proportion of major CIs than nurses ($p < 0.01$). Fifty percent of the CIs were detected by routine checks. The most important method of detection was patient inspection (44 %), alarms accounted for only 10 %. Contributing factors were human errors (63 %), communication failure (14 %), organizational problems (10 %), equipment dysfunction (7 %) and milieu (3 %).
Conclusion: CIs are very common in pediatric intensive care. Knowledge of them is a precious source for quality improvement through changes in the system.

Key words Neonatal-pediatric · Intensive care · Critical incidents · System approach

Introduction

A critical incident (CI) is any event which could have reduced, or did reduce, the safety margin for the patient [1]. The intensive care unit (ICU) is a complex environment and CIs might be frequent. The system approach in quality management regards errors and deviations not as human failures, but as opportunities to improve the system [2]. In order to make as many CIs as possible known to the whole ICU team, we implemented a voluntary, anonymous, non-punitive CI reporting system.

In aviation, confidential reporting systems are well established [2]. In medicine, anesthesia was the first specialty to introduce this approach. Recently, there have been reports on CI monitoring in adult intensive care [1, 3, 4, 5, 6]. In pediatric intensive care there are reports on medication errors [7, 8, 9], two of them based on anonymous, non-punitive incident reporting [8, 9]. In two further studies, complications of care in pediatric intensive care were prospectively investigated [10, 11]. However, there are no studies dealing with overall CI monitoring in a pediatric ICU.

Methods

The study was performed in a 12-bed multidisciplinary, neonatal-pediatric ICU of a non-university, teaching children's hospital in the eastern part of Switzerland. The unit does not admit patients requiring heart surgery, organ transplantation, extracorporeal membrane oxygenation or hemodialysis. The ICU staff consists of three consultants, three residents and 29 nurses (15 registered nurses trained in intensive care, 8 registered nurses in training for specialization, 1 registered nurse and 5 nurse trainees). There is 24 h dedicated physician coverage. The unit is also responsible for the neonatal transport service of the region (about 10,000 births a year).

Before starting the monitoring, several tutorial sessions and group discussions were held in order to familiarize nursing and medical ICU staff with the system approach philosophy. The incident reporting system had to be non-threatening to ICU staff, encourage team involvement and focus on deficits in the system rather than the individual. As our CI monitoring is used solely for quality management, complications of care with actual patient harm have additionally to be recorded on the patient chart for medicolegal reasons. We used a shortened and modified version of the incident reporting form of the Australian incident monitoring study/ intensive care [1]. The form consists of six sections: (1) narrative section about the incident, details about any factors which might have contributed to or limited the impact of the CI, actual harm to the patient and proposals of measures to prevent any such CI in the future; (2) information about the patient involved (age, gender, involvement of more than one patient, mechanical ventilation, intraarterial line, central venous line, catecholamines, ICU day, restlessness); (3) severity of CI: major (score 3, death or need for therapeutic interventions specific to the ICU), moderate (score 2, requiring routine therapy available outside the ICU), minor (score 1, no interventions required); (4) function of staff member precipitating/detecting CI; (5) when and where CI happened (date, hour of day, CI occurring during admission interventions, time lag between CI and its detection, CI occurring in ICU or during transport, detection of CI by routine check or incidentally, method of detection); (6) factors contributing to CI (human error, equipment dysfunction, milieu, organization/communication, no cause).

The staff were encouraged to fill out this form immediately on awareness of an event that did, or could potentially, affect patient safety. Completed forms were deposited in a box. Every 2 months the reports were analyzed by the CI group (two nurses and one consultant). The CIs were categorized into the following sections: management/ environment, drugs, procedures, respiration, equipment dysfunction, nosocomial infections. The CI group worked out organizational measures for each CI in order to prevent its recurrence. Afterwards a review session was held for the whole ICU team. These sessions were combined with the mortality conference. CIs which were judged to be of concern for other departments of the hospital were discussed at the general staff meetings of the hospital.

For the present study the CI reports of the first year (1.3.98–28.2.99) were analyzed with respect to frequency distributions and proportions of incident types, predisposing factors, staff and patient factors and CI severity. Differences between groups were analyzed using the unpaired Student t-test, chi-squared test or Mann-Whitney U-test as appropriate. A p less than 0.05 was considered significant.

Results

During the study period 467 children were admitted to the ICU with 3140 patient days. The average patient stay was 6.7 days. Fifty-six percent of all admissions were neonates (≤ 28 days of age). One hundred and sixteen children were mechanically ventilated (419 ventilator days) and 68 patients were on nasal CPAP (210 days). There were 17 deaths (3.6%), 14 neonates and 3 children. The number of CIs reported was 211, 30% major, 25% moderate and 45% minor. There were no deaths directly attributable to CIs. Ten reports did not refer to an individual patient. Twelve CIs occurred during 206 transports. Thirty CIs concerned more than one patient. There were 0.45 CIs/neonatal admission and 0.40 CIs/pediatric admission ($n = 201$ patient-related CIs). The frequency of reporting did not change over the 1-year period (number of reports for the six 2-month intervals: 36, 24, 38, 37, 33 and 43).

The distribution of the CI categories and their mean actual severity are given in Table 1. The respiratory CIs were the most severe and the CIs involving drugs were the least severe ones ($p < 0.001$, paired t-test). Another means of describing the impact or risk of the individual categories is to multiply the CI frequency with the mean severity score. This leads to a different ranking with drug-related CIs being much more important (Table 1). Furthermore, 20 out of the 62 drug-related CIs were potentially life-threatening. In 15% of the drug CIs a wrong prescription was detected prior to drug administration. In 48% a wrong medication order was actually carried out. In 19% a correctly ordered drug was wrongly prepared and wrongly administered and in 16% a correctly prescribed drug was correctly prepared but wrongly administered. Thirteen percent of the drug CIs were due to punctuation mistakes (e.g. 3 instead of 0.3 or g instead of mg). There were the following error types (as to prescription and/or preparation and/or administration): wrong route (3 events), dose too high (31), dose too low (6), wrong drug (11), drug omitted (7). There was a series of eight episodes of toxic methemoglobinemia in premature infants after the combined

Table 1 Distribution, mean actual severity and impact (frequency × severity score) of CI categories. Severity scores: 3 = major, 2 = moderate, 1 = minor

CI category	Number of reports	Mean severity score (SD)	CI impact
Management/environment	62 (29 %)	1.6 (0.76)	99
Drugs	62 (29 %)	1.4 (0.76)	87
Procedures	37 (18 %)	2.0 (0.59)	75
Respiration	29 (14 %)	2.9 (0.26)	84
Equipment dysfunction	15 (7 %)	1.8 (0.94)	27
Nosocomial infections	6 (3 %)	2.5 (0.83)	15

Table 2 Indicators of patient acuity in children with CIs and in all admissions during the study period (*p* chi-squared test)

	Children with CIs ($n = 201$)	All children admitted to ICU ($n = 467$)	*p* value
Mechanical ventilation	97 (48 %)	116 (25 %)	< 0.0001
Central venous catheter	90 (45 %)	80 (17 %)	< 0.0001
Intraarterial catheter	60 (30 %)	58 (12 %)	< 0.0001
Catecholamines	32 (16 %)	34 (7 %)	< 0.0001

Table 3 Staff members precipitating and detecting CIs

	Precipitating ($n = 182$)	Detecting ($n = 208$)
Consultants	60	65
Residents	43	22
Registered nurses trained in intensive care	38	87
Others	16	4
Registered nurses in training for intensive care	14	17
Registered nurses	5	5
Nurse trainees	5	4
Parents	1	4

exposure to prilocaine through EMLA cream and caudal anesthesia for herniotomy [12]. Table 2 shows that the patients with CIs received more intensive and invasive care.

The 29 respiratory CIs consisted of 11 accidental extubations (2.6/100 ventilator days), 7 postextubation stridors, 5 tube obstructions (one of them by kinking of a 2.5 mm Portex endotracheal tube), 3 main bronchus intubations and 3 others (disconnection of respirator circuit tubing; upper airway obstruction due to a blood clot after nasopharyngeal CPAP; inappropriately large endotracheal tube diameter, not recognized in time, without patient harm). In the management/environment category, there were two CIs involving mechanical trauma (patient fell from the bed, an infusion pump fell just near the head of a neonate), five CIs involving the skin and four patients with marked hypothermia after surgery. In the procedure category five CIs could be identified in association with umbilical artery catheter complications (2 episodes of transient ischemia of the legs; 3 patients with arterial hypertension requiring antihypertensive therapy). In the latter three patients, the tip of the umbilical arterial lines were at the vertebral body level of T7, T9 and T11, respectively. In one patient, Doppler sonography showed diminished regional renal perfusion. In the other two patients, no sonographic correlates were found, so the associations remain speculative. In the nosocomial infection group, a septic (*Staphylococcus aureus*) thrombus in the right atrium associated with an umbilical venous catheter was reported.

The distributions of the precipitating and detecting staff members are given in Table 3. In 29 out of 211 instances no precipitating person could be identified. One CI was caused by parents. Residents were over-represented in drug-related CIs (22 out of 62 events). When comparing precipitating nurses and doctors, three relevant differences become evident: a greater proportion of the doctors' CIs concerned respiratory CIs (17/103 vs 5/62, $p > 0.05$, chi-squared test), doctors had a greater proportion of major CIs than nurses (37/103 vs 10/62, $p < 0.01$, chi-squared test) and the milieu (noise, high unit activity, sparse space) was never judged a contributing factor in CIs precipitated by doctors, whereas in nurses it accounted as a contributing factor in 10 % of their CIs.

Most of the CIs were detected by specialized nurses (41 %) and consultants (31 %). Parents detected CIs in four instances (Table 3). Fifty percent of the CIs were detected by routine checks, 41 % incidentally. These proportions did not differ significantly among the categories. In 9 % the mode of detection could not be determined. The most important method of detection was inspection of a patient, his/her X-ray and/or laboratory results (44 %). Chart or ordering form inspection accounted for 31 %, alarms 10 % and equipment inspection 9 %. In 6 % no item could be identified. The following factors were judged as contributing to the CIs by the staff members filling out the forms: human error 63 %, communication 14 %, organizational problems 10 %, equipment dysfunction 7 %, milieu 3 %, no contributing factor identified 3 %.

The 24-h distribution revealed CI clusterings at 8 a.m., lunchtime, 4 p.m. and 12 p.m. (Fig. 1). The nursing handovers take place at 7–7.30 a.m., 3.30–4 p.m. and 11.30–12 p.m. Of the 11 accidental extubations, six occurred between 11 p.m. and 6 a.m. and five occurred between 12 a.m. and 2 p.m. The median time lag be-

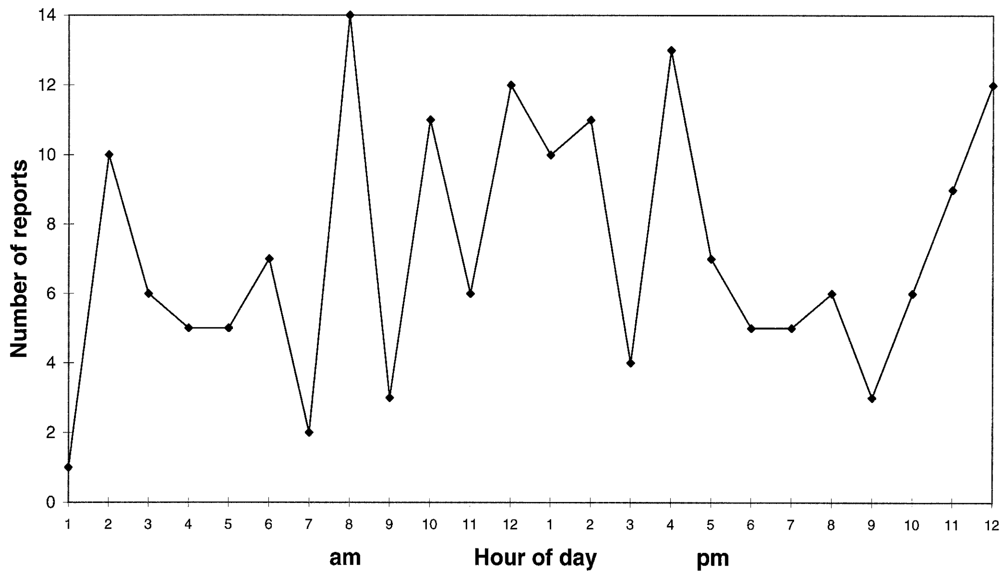

Fig. 1 Diurnal distribution of critical incidents

Table 4 Time lags between CIs and their detection for the different categories

CI category	Median	Range
Respiration	0[a,b]	0–84 hours
Procedures	2 hours	0–90 days
Equipment dysfunction	2 hours	0–10 hours
Management/environment	3 hours	0–30 days
Drugs	8.5 hours[b]	0–41 days

[a] "0" means "immediate detection"
[b] Respiration vs drugs: $p = 0.002$ (Mann-Whitney *U*-test)

tween the CIs and their detection was 2.8 h ($n = 190$, nosocomial infection group not included because of difficulty in assessing the exact lag times). Twenty-two percent of CIs were detected within 1 min, 27% within 10 min, 38% within 1 h and 52% within 3 h. Separate analysis of the different categories reveals different lag times, as shown in Table 4. The median ICU day when CIs occurred was the third day (range 1–217 days). Twelve percent of CIs occurred during the admission procedures. Twenty-nine percent of CIs occurred on the first ICU day.

Discussion

Compared to the studies of CI monitoring in adult intensive care, our rate of 211 CIs/year is quite high. Abramson et al. [4] reported on 145 incidents during a 5-year period, Wright et al. [5] found 137 events over 1 year and Buckley et al. [6] reported on 281 CIs over a 3-year period. However, Donchin et al. [3] showed, in a similar reporting setting to ours, that human errors in intensive care are actually very frequent. During their 4-month study in an adult unit, nurses and doctors recorded 554 human errors. There might be several reasons for our high reporting rate. We focused on incidents rather than complications. Major complications are rare and usually they are made known to all staff whereas unspectacular incidents might go unrecognized by the team. However, it is these incidents which allow us to find system failures and improve quality of care. We speculate that the high and sustained reporting rate is primarily a result of the unit's mode of system approach. In the traditional mode of apportioning blame to incident precipitators, the reporting rate would have been much lower. It is our aim to develop this culture so far that we will be able to abandon the anonymity of the reports in future.

The CI rates identified in this study may not be complete as we conducted an anonymous reporting system and not an observational study. However, in our small unit, the investigators had a good view of what was going on and kept encouraging the staff to report CIs. At least for major complications, such as accidental extubations, the rates are complete. On the other hand, the nosocomial infection rate may be an underestimation because only unequivocal incidents such as hospital-acquired RSV bronchiolitis or central venous catheter-related sepsis have been reported.

The present 1-year survey reveals some tendencies of CIs in our unit which will lead to organizational changes. The respiratory CIs were the most severe ones. The accidental extubations occurred at lunchtime (possible contributing factor: insufficient nurse presence) and during the night shifts (reduced efficiency, consultants on call at home). These findings underline the need for a continuous patient/nurse ratio for intubated children of 1:1 which has not been the case in our unit.

However, exact ratios of nursing staff to patients at the time of the CIs have not been studied prospectively. The rate of accidental extubations (2.6/100 ventilator days) is in the range of other pediatric ICUs (1.4/100 ventilator days [10], 1.26/100 intubation days [13]).

The rate of drug-related CIs was quite high, but their mean severity was low, a finding also made by Wilson et al. [8]. Stambouly et al. [10] reported only 12% drug-related complications in their study of complications in pediatric intensive care, which is also in accordance with our result. The low mean severity of drug CIs can be partly explained by the fact that a wrong prescription was detected prior to drug administration in 15% of these incidents and that many of the wrongly administered drugs obviously had a wide therapeutic range. Nevertheless, the impact (frequency x severity) of drug-related CIs was high. Drug ordering and administration are particularly prone to human error because they rely on short-term memory and vigilance [2]. However, in drug therapy slips like improper placement of the decimal point might have serious consequences. Computer-aided prescription systems may reduce the error rate in drug therapy [9, 14].

As to the precipitating staff members we could not confirm the findings in adult intensive care of nurses precipitating incidents more often than doctors [1, 3]. However, Donchin et al. [3] reported on much higher error rates in physicians than in nurses when errors were related to the number of activities carried out on patients. Obviously, in our pediatric ICU, doctors are more involved in direct patient care than in the latter two studies. Furthermore, doctors might be performing more risky procedures than nurses, as shown by the higher mean severity score of the doctors' CIs. The frequencies of CIs precipitating by specific staff groups may be biased by different levels of preparedness to participate in the study.

Half of the CIs were detected by means of routine checks. This rate fits well with the findings in adult intensive care [1, 5, 6]. A high rate of routine detection might indicate a high efficiency of the checks carried out. Like pilots who go through a checklist before each take-off, ICU staff should go through checklists at each handover and probably at regular intervals in between. We found several errors in transcribing medical orders onto the nurses' care plan. By introducing an additional check at handovers we could almost eliminate this error source. Another indicator of the performance of patient monitoring is the median delay between the occurrence of CIs and their detection, which was 2.8 h in our study. In the study by Beckmann et al. [1] 51% of CIs were detected within 1 h. In our study this proportion was lower (38%). However, the overall median time lag may not be very useful for comparisons. Median time lags related to specific incident types (Table 4) are more appropriate. The median time lag when detecting a CI was shortest in the respiratory group. The most important method of CI detection was patient inspection, a finding also made by studies in adult intensive care [1, 6]. The rate of alarms drawing staff's attention to a CI was astonishingly low in view of the high numbers of monitors in use (percentage of CIs detected by alarms: 10% in our study, 8% in [1] and 24% in [6]). This reinforces the importance of the presence of appropriately trained nursing and medical staff who frequently and thoroughly examine patients and their charts in neonatal-pediatric intensive care.

As in adult studies [1, 6], human errors were most often judged to be contributing to the CIs. In 14% of the reports there were overt communication problems. Absence of communication was a major contributor to CIs in the study by Donchin et al. [3].

The 24-h distribution of CIs revealed possible vulnerable periods at 8 a.m., lunchtime, 4 p.m. and 12 p.m. These are tendencies, they are not supported by formal statistics. The reasons for these peaks might be high unit activity, limited staff presence (lunchtime) and insufficient information transfer at physicians' and nurses' handovers as described in adult intensive care [3]. The results of our study indicate that patients receiving the most intensive and invasive care are especially prone to CIs and that the majority of CIs occurred during the first few days, that is during the most acute stage of the patients' illness. Twelve percent of CIs occurred during the admission procedures.

Our CI monitoring was able to identify the repeated occurrence of adverse events of unknown etiology, thus facilitating their clarification and preventing their recurrence. This was the case with the repeated observation of infants having symptoms such as cyanosis and mottled skin after herniotomy. The causative relationship between prilocaine and the infants' deterioration was brought to our attention by the CI monitoring [12]. The five serious complications with umbilical arterial lines in premature infants led to a change in our policy, namely to use the radial artery as the first choice of intraarterial blood pressure monitoring.

In conclusion, CIs occur more frequently than commonly thought in intensive care and their impact on patient morbidity is considerable. Knowledge of their occurrence is a precious source of information for quality improvement through system changes. These changes are implemented at regular team discussions and yearly after analyzing trends which are only recognizable over longer periods of time. The introduction of the system approach method has made a further impact of our CI monitoring system on quality improvement. Finally, the filling out of the questionnaires causes staff members to think about CIs and their prevention.

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