Active surveillance of hospital-acquired infections in Pediatric Intensive Care Unit: a single center study

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ABSTRACT

Objective: The aim of our study was to describe and analyze HAI incidence, etiology and risk factors in pediatric intensive care unit (ICU).
Background: Intensive care patients are at high risk of hospital-acquired infections (HAI) due to their underlying diseases and exposure to invasive devices.
Methods: The study group consisted of patients admitted to children's hospital ICU for more than 2 days during a six-month period (267 patients, 1570 patient-days). We used the European Centre for Disease Prevention and Control standard protocol HAI-Net ICU v2.2 for data collection.
Results: HAI occurred in 17 (6.4%) included patients (10.8 infections per 1000 patient-days). The most frequent were catheter-related bloodstream infections (33%, 7.6 per 1000 catheter-days) and intubation-associated pneumonia (25%, 10.9 per 1000 intubation-days). Gram-negative bacteria (*Pseudomonas aeruginosa, Klebsiella spp.*) were identified as the most common etiological agents. Significantly higher risk of HAI had patients with central venous catheter (OR: 14.5, 95% CI 3.2–65.1), intubated (OR: 14.4, 95% CI 4.4–46.2), with Pediatric Index of Mortality score higher than 10 (OR: 17, 95% CI 2.7–111.5) and with previous bacterial or/and fungal colonization (OR: 30.6, 95% CI 9.2–101.3).
Conclusions: Active surveillance identified unreported HAI cases and proved to be an effective tool of infection control.

KEYWORDS
hospital-acquired infections – active surveillance – pediatric intensive care unit

SÚHRN

Fulová M., Kotrbancová M., Perželová J., Bražinová A.: Aktívna surveillance nemocničných infekcií na pediatrickej jednotke intenzívnej starostlivosti

Cieľ: Cieľom práce bolo opísať a analyzovať výskyt, etiológiu a rizikové faktory nemocničných nákaz na pediatrickej jednotke intenzívnej starostlivosti (JIS).
Úvod: Pacienti hospitalizovaní na JIS patria medzi vysokorizikových z hľadiska vzniku nemocničných nákaz (NN) kvôli závažnému až kritickému zdravotnému stavu a potreby invazívnych diagnostických a terapeutických zásahov.
Metódy: Do štúdie sme zaradili pacientov hospitalizovaných na detskej JIS na dlhšie ako 2 dni v priebehu šiestich mesiacov (spolu 267 pacientov, 1570 pacientskych dní). Pre zber údajov o výskyte NN sme použili štandardný protokol Európskeho centra pre prevenciu a kontrolu chorôb HAI-Net ICU v2.2.
Výsledky: Infekcie v súvislosti s hospitalizáciou na JIS sme zistili u 17 (6,4 %) pacientov (10,8 infekcií/1000 pacientskych dní). Najčastejšie išlo o infekcie krvného riečiska v súvislosti so zavedeným katétrom (33 %, 7,6/1000 katétrových dní) a pneumóniu v súvislosti s intubáciou (25 %, 10,9/1000 dní intubácie). V etiológii dominovali gramnegatívne baktérie (*Pseudomonas aeruginosa*, *Klebsiella spp.*). Vyššie riziko vzniku NN mali pacienti s centrálnym venóznym katétrom (OR: 14,5; 95% CI 3,2–65,1), intubovaní (OR: 14,4; 95% CI 4,4–46,2), s Pediatrickým indexom mortality vyšším ako 10 (OR: 17; 95% CI 2,7–111,5) a s predchádzajúcou bakteriálnou a/alebo mykotickou kolonizáciou (OR: 30,6; 95% CI 9,2–101,3).
Záver: Aktívne sledovanie výskytu nemocničných nákaz poskytuje presný obraz o situácii na úrovni vybraných oddelení nemocnice a patrí medzi prvé kroky k cielenej prevencii.

KĽÚČOVÉ SLOVÁ
nemocničné nákazy – aktívna surveillance – pediatrická JIS

Epidemiol Mikrobiol Imunol, 2024; 73(4): 192–197
https://doi.org/10.61568/emi/11-6390/20241024/138874

INTRODUCTION

In acute care hospitals, Intensive Care Units (ICU) represent the high-risk setting for hospital-acquired infections (HAI) due to patients´ severe underlying diseases and exposure to invasive devices [1]. A point prevalence study implemented in 2022–2023 in 33 European countries revealed the highest HAI prevalence in ICU, where 20.5% of patients had at least one HAI compared with the average 7.1% for all other specialties [2]. In pe-

diatric ICU, in a similar study from 29 European countries in 2012, the HAI prevalence was 15.5%, compared with the average of 4.2% in all words [3]. The impact of HAI is significant on the patient´s health status and outcome as well as on costs due to increased length of stay, additional diagnostics and treatment. There is evidence that HAI is largely preventable. Active HAI surveillance at the hospital level is a first step to targeted prevention and improved safety in routine patient care.

The aim of the study was to describe how active surveillance, description and risk factors analysis of HAI can help to determine priority infection control targets. The study was implemented in the pediatric ICU of a children hospital in the Slovak Republic.

MATERIALS AND METHODS

Our retrospective study took place in a ten-bed ICU of a tertiary referral children's hospital in the Slovak Republic where healthcare from birth to 18 years of age is provided. All patients admitted to the ICU for more than two days in a six-month period (January–June 2018) were included in the study. In the hospital passive surveillance (reporting by healthcare staff) of healthcare associated infections is implemented based on the legislation of the Slovak Republic. The hospital epidemiologist coordinates infection prevention. We obtained data on reported HAI from the hospital epidemiologist.

For active data collection, we used the European Centre for Disease Prevention and Control (ECDC) HAI-Net ICU v2.2 patient-based (standard option) protocol for active surveillance of ICU-acquired infections [4]. Data on hospitalized patients was obtained from the patient´s medical records. Following data were collected: age, gender, length of hospitalization, type of ICU admission, immunity status, invasive device exposure (central venous catheter – CVC, urinary catheter, intubation), results of microbiological testing, presence or absence of HAI, their sites and etiology and antimicrobial use indications. The microbiological testing consisted of routine microbiological monitoring (culture of samples: nasal swab, tonsil swab, urine, rectal swab) and additional testing according to the patient´s health conditions (e.g. blood culture). For evaluation of antimicrobial resistance, we used minimal and recommended antimicrobial resistance markers in the ICU according to the HAI-Net ICU protocol. The Pediatric Mortality Index 2 (PIM 2) score was calculated for each patient using the online calculator [5].

The presence of HAI was determined using the EU standard definitions [6]. For description we used the following indicators: incidence rate (number of HAI per 100 hospitalized patients), incidence density (number of infections per 1000 patient-days) and device-associated infection rates (number of infections per 1000 device-days).

We used the following definition to determine colonization: the presence of microorganisms on the skin, mucous membranes, in wounds, or in secretions/excreta without clinical symptoms, whereas it is not a normal microflora or contamination of the sample [1].

For the analysis of patient risk factors, we used the chi-square test with Yates correction and logistic regression in the STATA 16.0 software. P-values less than 0.05 were considered statistically significant.

RESULTS

Patients characteristics

In the monitored period, 287 patients were admitted to the ICU. In 267 patients, the hospitalization lasted longer than 2 days and they were included in the study. The average length of hospitalization was 7 days (from 3 to 77 days, 1570 patient-days together). The median age was 4 years (from 1 month to 18 years) and the male-to-female ratio was 1.2:1.

Patients were admitted to the ICU mostly (214/80%) from other wards of the same hospital or from another hospital, predominantly after scheduled surgery. Less often, patients were admitted from the community (53/20%), and these were mostly patients with trauma or polytrauma (e.g. fall from a height, car accident), intoxication, burns, severe infections or after drowning. The improvement of the health condition in 259 patients led to discharge to another ward in the hospital, 8 (3%) patients died in the ICU, of whom 6 were younger than one year.

In 233 (87%) patients, at least one of the invasive devices (CVC, intubation or urinary catheter) was introduced. The median exposure was 4 days for CVC (min 1 – max 51 days, 1059 CVC-days), 2 days for intubation (min 1 – max 42 days, 551 intubation-days) and 3 days for urinary catheter (min 1 – max 68 days, 1412 catheter-days).

Hospital-acquired infections

Six HAI were reported to the hospital epidemiologist during the study period. Active surveillance revealed 24 HAIs in 17 (6.4%) out of 267 patients (1.4 HAI per 1 patient). The incidence density was 10.8 HAI per 1000 patient-days. The most common HAI types were bloodstream infections (37.5%) and pneumonia (37.5%) (table 1). Association with device use was found in 89% (8 out of 9) of bloodstream infections and 67% (6 out of 9) of pneumonias. This represents incidence rates of 7.6 bloodstream infections per 1000 CVC-days and 10.9. pneumonia per 1000 intubation-days. Bacteria (75.0%), viruses (20.8%) and fungi (4.1%) were identified as etiological agents. One pneumonia had no positive microbiology and in one gastroenteritis there was a combined etiology (rotavirus and adenovirus).

Table 1. Types and etiology of hospital-acquired infections

	All n (%)	Pneumonia n (%)	Bloodstream infection n (%)	Gastroenteritis n (%)	Eye infection n (%)	Local inf. CVC-related n (%)
Hospital-acquired infections						
HAIs all	24 (100)	9 (37.5)	9 (37.5)	3 (12.5)	2 (8.3)	1 (4.1)
Microbiologically confirmed HAIs						
Number of identified microorganisms	24 (100)	8 (100)	9 (100)	4 (100)	2 (100)	1 (100)
Identified groups of microorganisms						
Gram-positive bacteria	7 (29.1)	–	6 (66.60)	–	1 (50.0)	–
Gram-negative bacteria	11 (45.8)	6 (75.0)	3 (33.3)	–	1 (50.0)	1 (100)
Viruses	5 (20.8)	1 (12.5)	–	4 (100)	–	–
Fungi	1 (4.1)	1 (12.5)	–	–	–	–
Most frequently identified microorganisms*						
Staphylococcus aureus	2 (8.3)	–	1 (11.1)	–	1 (50.0)	–
Coagulase-negative staphylococci	3 (12.5)	–	3 (33.3)	–	–	–
Pseudomonas aeruginosa	6 (25.0)	3 (37.5)	1 (11.1)	–	1 (50.0)	1 (100)
Klebsiella pneumoniae	2 (8.3)	1 (12.5)	1 (11.1)	–	–	–
rotavirus	3 (12.5)	–	–	3 (75.0)	–	–

*Other microorganisms identified: *Enterococcus faecalis, Klebsiella oxytoca, Enterobacter cloacae, E. coli,* adenovirus, *Aspergillus fumigatus*

Table 2. Colonization – tested samples and etiology

Sample type and day of testing after admission	All n (%)	Nasal/ tonsils swab n (%)	BAL* n (%)	Rectal swab n (%)	Urine n (%)	Wound swab n (%)	Days after admission n (%)	
							0–2	3 and more
Colonized patients	37 (100)	35 (94.5)	17 (45.9)	10 (27.0)	9 (24.3)	2 (5.4)	24 (64.8)	21 (56.7)
Number of identified microorganisms	128 (100)	76 (100)	27 (100)	13 (100)	9 (100)	3 (100)	53 (100)	69 (100)
Identified groups of microorganisms								
Gram-positive bacteria	10 (7.8)	8 (10.5)	2 (7.4)	–	–	–	7 (13.2)	3 (4.3)
Gram-negative bacteria	96 (75.0)	57 (75.0)	25 (92.5)	5 (38.4)	6 (66.6)	3 (100)	35 (66.0)	56 (81.1)
Yeasts	22 (17.1)	11 (14.4)	–	8 (61.5)	3 (33.3)	–	11 (20.7)	10 (14.4)
Most frequently identified microorganisms**								
Staphylococcus aureus	9 (7.0)	7 (9.2)	2 (7.4)	–	–	–	6 (11.3)	3 (4.3)
Pseudomonas aeruginosa	26 (20.3)	11 (14.4)	9 (33.3)	3 (23.0)	2 (22.2)	1 (33.3)	5 (9.4)	19 (27.5)
Stenotrophomonas maltophilia	19 (14.8)	10 (13.1)	6 (22.2)	1 (7.6)	1 (11.1)	1 (33.3)	4 (7.5)	15 (21.7.)
Klebsiella pneumoniae	14 (10.9)	8 (10.5)	5 (18.5)	–	1 (11.1)	–	5 (9.4)	8 (11.5)
Klebsiella oxytoca	9 (7.0)	5 (6.5)	2 (7.4)	1 (7.6)	1 (11.1)	–	4 (7.5)	5 (7.2)
Enterobacter cloacae	10 (7.8)	8 (10.5)	–	–	1 (11.1)	1 (33.3)	5 (9.4)	3 (4.3)
E. coli	8 (6.2)	7 (9.2)	1 (3.7)	–	–	–	5 (9.4)	3 (4.3)
Acinetobacter spp.	6 (4.6)	5 (6.5)	1 (3.7)	–	–	–	4 (7.5)	2 (2.8)
Candida albicans	10 (7.8)	5 (6.5)	–	3 (23.0)	2 (22.2)	–	5 (9.4)	4 (5.7)
Candida parapsilosis	3 (2.3)	3 (3.9)	–	–	–	–	2 (3.7)	1 (1.4)

*Bronchoalveolar lavage

**Other microorganisms identified: *Enterococcus faecalis, Klebsiella variicola, Acinetobacter pittii, Burgholderia cepacia, Acinetobacter junii, Chryseobacterium indologenes, Candida lusitaniae, Candida glabrata, Candida tropicalis, Candida fabianii, Candida guilliermundii, Candida krusei*

Enterobacteriaceae isolates were resistant to third-generation cephalosporins in 40%, no isolate was resistant to carbapenems. Carbapenem resistance was found in 33% of *Pseudomonas aeruginosa* isolates. During the study period 11% of all antibiotics prescribed in the ICU were used to treat HAI. The case-fatality rate was 23.5% for patients with HAI compared with 1.6% for patients without HAI ($p < 0.001$).

Colonizations

Colonization was found in 37 (14%) vs. HAIs in 17 (6.4%) patients ($p < 0.01$). In colonized patients, there were usually multiple samples tested positive with multiple different agents (table 2). Colonization was detected in 24 (65% out of 37) patients during the first two days after ICU admission and in 21 (56%) patients hospitalized longer than 3 days ($p > 0.05$). Overall, gram-negative bacteria were the most common agents in the etiology of colonization. *Pseudomonas aeruginosa* was identified significantly more often ($p < 0.05$) in patients hospitalized for more than 3 days. For other agents there were not significant differences according to the patient´s length of stay. *Enterobacteriaceae* isolates were resistant to third-generation cephalosporins in 39%, no isolate was resistant to carbapenems. *Pseudomonas aeruginosa* isolates were in 23% carbapenem resistant. *Staphylococcus aureus* isolates were in 78% (7 out of 9) methicillin resistant (MRSA).

Patient risk factors

The higher risk of acquiring HAIs depended upon the patient´s health conditions and the presence of invasive devices. The statistically significant results of the analysis are shown in table 3. The factors that presented the highest chance of acquiring HAI were the following: colonization, PIM II score above 10, insertion of CVC and intubation. Age, gender, length of hospital stay and number of inserted invasive devices were not statistically significant.

Table 3. Patient risk factors

	All patients		Patients with HAI		OR	p-value	95% CI
	number	%	number	%			
All patients	267	100	17	6.4			
Pediatric Index of Mortality II score							
0.1–2	210	79	6	2.9	reference category		
2.1–4	16	6	2	12.5	4.8	0.067	0.8–26.3
4.1–10	35	13	7	20.0	5.8	< 0.001	2.6–27.1
10 and more	6	2	2	33.3	17	0.003	2.7–111.5
Presence of invasive devices							
CVC	100	37	15	15.0	14.5	< 0.001	3.2–65.1
Intubation	59	22	13	22.0	14.4	< 0.001	4.4–46.2
Urinary catheter	214	80	14	6.5	1.2	0.81	0.32–4.2
Colonization							
Yes	37	14	13	35.1	30.6	< 0.001	9.2–101.3
No	230	86	4	1.7	reference category		
Impaired immunity*							
Yes	19	7	4	21.1	4.8	0.013	1.4–16.5
No	248	93	13	5.2	reference category		
Antibiotic treatment in 48 hours before or after ICU admission**							
Yes	48	18	10	20.8	7.9	< 0.001	2.8–22.2
No	219	82	7	3.2	reference category		
Origin of the patient							
Community	53	20	2	3.8	reference category		
Ward in this/other hospital	214	80	15	7.0	1.9	0.395	0.42–8.67
Type of ICU admission							
Scheduled surgical	176	66	4	2.3	reference category		
Other***	91	34	13	14.3	7.1	0.001	2.2–22.6

*Impaired immunity due to treatment (chemotherapy, radiotherapy, immune suppression, corticosteroids long duration or high doses recently), due to disease (leukemia, lymphoma, AIDS), or white blood cells < $0{,}5 \times 10^9$/L (as defined in APACHE II score)

**antibiotic therapy for an infection around ICU admission has been given, not: antimicrobial prophylaxis, local treatment

***Other reason for ICU admission than recovery from a scheduled surgery e.g. patients with trauma or polytrauma, intoxication, burns, severe infections, respiratory failure

DISCUSSION

The active surveillance in the pediatric ICU revealed four times more HAIs than reported by healthcare staff (6 vs. 24). Passive surveillance is easy to implement, but prone to underreporting of the cases. Active surveillance detects every case, but it requires trained personnel and financial resources. Giving the real picture of the situation active surveillance is a better tool for infection control. Currently artificial intelligence applications in hospitals have the potential to improve data collection [7].

In a single-center incidence study, we found a HAI rate 10.8 per 1000 patient-days (6.4% out of included patients). Other single-center of multi-center incidence studies in pediatric ICUs describe rates between 18.3–3.6 HAIs per 1000 patient days [8, 9, 10] or 15–2.47% if the rate is expressed per 100 patients [11, 12, 13]. As in this study, the most frequent types of HAI in the other studies were bloodstream and respiratory infections related to invasive devices [8, 9, 10, 11, 13]. We did not reveal device-associated urinary tract infections; however, they were the third most frequent infection type in the other pediatric studies with published rates 4.1–10.7 urinary infections per 1000 urinary catheter days [8, 9, 10, 11, 13].

According to our results, significantly more ICU patients were colonized than got HAI. Colonization detected 0–2 days after admission was probably not related to the stay at the ICU. MRSA colonization was detected mostly in the first two days of ICU stay, in patients transferred from other wards of this/other hospital, suggesting the imported cases. Colonization detected 3 and more days after ICU admission along with detected HAI agents reflect the pathogens circulating in the ICU. In colonized patients these were mostly gram-negative bacteria, notably *Pseudomonas aeruginosa* and *Candida spp.*

In consistency with other studies [2, 3, 8, 9, 13] gram-negative bacteria were the most common isolated HAI agents, mainly *Enterobacteriaceae* and *Pseudomonas aeruginosa.* We did not detect carbapenem-resistant *Enterobacteriaceae*, although in the Point Prevalence Survey of HAI in 28 European countries among pediatric patients in average 9% of *Enterobacteriaceae* isolates were carbapenem resistant [3]. In the same survey, 44% of *Enterobacteriaceae* were resistant to third-generation cephalosporins, which is like the 40% in HAI/colonization isolates in our study. Out of *Pseudomonas aeruginosa* isolates, carbapenem resistant were 33% in HAI and 23% in colonization. *Staphylococcus aureus* and coagulase-negative-staphylococci were the most frequent gram-positive bacteria, in agreement with other studies [2, 3, 8, 9, 11, 13]. We detected no MRSA in HAI etiology, but 78% (7 out of 9) *of Staphylococcus aureus* isolates in colonized patients were resistant to methicillin. In the Point Prevalence Survey of HAI in 28 European countries among pediatric patients, 19% of *Staphylococcus aureus* isolates were resistant to methicillin [3].

According to the World Health Organization carbapenem-resistant *Pseudomonas aeruginosa*, and carbapenem-resistant and third-generation cephalosporin-resistant *Enterobacteriaceae* are listed as high-priority and critical-priority bacteria [14]. This is due to their ability to cause HAI associated with high morbidity and mortality, their potential to cause outbreaks and our lack of treatment. In our study, 2 out of four patients with HAI with fatal outcome had carbapenem-resistant *Pseudomonas aeruginosa* infection. Multimodal prevention strategies should be implemented to control infections/colonization and consist of at least transmission precautions (hand hygiene, isolation), environmental cleaning (including water safety), continuous monitoring and infection management [14].

Analysis of risk factors pointed to the highest risk for HAI in those patients who were colonized (OR 30.6, 95% CI 9.2–101.3). Similarly, in a study from Spain, previous bacterial colonization by multidrug-resistant bacteria was the most important extrinsic risk factor for HAI (OR 20.4, 95% CI 14.3–29.1) [10]. The severity of the underlying disease and the presence of invasive devices are well known risk factors for HAI [1, 3, 8–11, 15]. In our study there was a significantly increased chance of acquiring HAI in the ICU patients with a severe underlying disease described as a PIM II score (OR 5.8 for PIM II higher than 4, OR 17 for higher than 10), an infection presents at admission (OR 7.9), impaired immunity (OR 4.8) and admission for other reasons than recovery from scheduled surgery (OR 7.1). A significantly higher PIM II score for patients with HAI was confirmed in a study from Japan [15]. Other studies confirmed that there was a higher risk for HAI in patients with severe underlying disease using different scores: McCabe score [3], pediatric mortality risk score (PRISM) [8, 10]. The severity of the disease requires invasive therapeutic interventions, the presence of both factors results in a higher infection rate. We confirmed a significantly higher chance of HAI in patients with introduced invasive devices (CVC OR 14.5, intubation OR 14.4). There is evidence for care bundles implementation as an effective control measure for device-associated HAI [10, 16, 17]. Age under 12 months and prolonged hospital stay were identified as independent risk factors for HAI [3], but in our study, age and length of stay were insignificant.

The limitations of our research are the following: first, the study describes the situation only during a 6-month period. The epidemiological situation changes over time, and therefore repeated or continuous monitoring is necessary for effective targeted control. Second, we did not consider arterial catheters when monitoring invasive devices, because most of patients included in our study with vascular catheter had the venous cathe-

ter. A study of colonization of CVC and arterial catheters in a pediatric ICU revealed 4% colonized CVC but up to 10% colonized arterial catheters [18]. Since both types of catheters are often inserted simultaneously, the arterial catheter may be an undetected factor in bloodstream infections related to invasive devices and should be included in future surveillance.

CONCLUSION

The purpose of this study was to identify priority infection control points for daily practice in one pediatric ICU. Epidemiological situation in a hospital ward is a combination of patient´s and environmental factors, it changes over time and may vary in different departments of the hospital. Results of this study point to the prevention of device-associated infections and gram-negative bacteria infection/colonization.

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Conflict of interest
The authors declare no conflict of interest.

Funding: This research received no external funding. The APC was funded by project VEGA 1/0761/22 Scientific Grant Agency of the Ministry of Education, science, research and sport of the Slovak Republic and the Slovak Academy of Sciences.

Acknowledgments: We acknowledge the hospital epidemiologist Jana Boledovičová, MSc. for data access.

Do redakce došlo dne 2. 5. 2024.

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