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Risk factors for healthcare-associated infections: a single-centre study in a university hospital

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ABSTRACT

Purpose: Healthcare-associated infections (HAIs) are a constantly growing problem in contemporary health care. This research attempts to determine risk factors for HAIs in one ward of a university hospital.

Materials and methods: The study included 631 inpatients hospitalized between 2017 and 2018 who had been assigned an even number for their medical record when they were admitted, and who gave informed consent to participate in the study. The following were assessed for each patient included in the study: demographic, clinical and anthropometric data; parameters of body composition; biochemical parameters; functional status (e.g., activities of daily living [ADL] and Norton scale scores); nutritional risk score (NRS-2002); comorbidity scale scores (Charlson Comorbidity Index and Cumulative Illness Rating Scale); and ATLAS scale score. Remote follow-up was conducted by telephone interview after 14, 30, 90, and 365 days.

Results: The prevalence of HAIs was 17.9%. The occurrence of HAIs was shown to be more strongly related to iatrogenic factors (e.g., urine bladder catheterization [UBC] or central venous cannulation [CVC]) than to the 'patient-dependent' factors included in commonly used HAI risk scales. The 'Czerniak-score,' which extends the ATLAS score to include comorbidity analysis, the patient's functional status, and the need for CVC or UBC, allows the identification of a significant majority of patients at risk (≥ 3 points) and not at risk (< 3 points) of HAI, with 82.2% sensitivity, 94.02% specificity, a positive predictive value of 74.17%, and a negative predictive value of 95.68%.

Conclusions: Holistic HAI risk stratification included in the Czerniak-score can identify the majority of patients at risk (≥ 3 points) of HAI.

Keywords: healthcare-associated infections; risk factors; prognostic scales; single-center study

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Introduction

Healthcare-associated infections (HAIs), also known as hospital-acquired infections, are defined as infections acquired by patients in relation to hospitalization or during a stay in other healthcare settings [1–4]. An HAI diagnosis is made when local or systemic symptoms of infection appear 48 hours after admission to a ward or after a period related to infection incubation (e.g., in hepatitis C virus infection). Moreover, with regard to hospitalization associated with the implantation of a device or prosthesis, the symptoms of HAI can even be identified up to one year after the operation [1–4]. HAI can be recognized as endogenous when it is caused by the patient's own microorganisms (e.g., *Clostridioides difficile* in patients undergoing broad-spectral therapy with antibiotics or aggressive immunosuppression), and as exogenous when caused by microorganisms living in the hospital environment [1–5]. HAIs are a constantly growing problem in contemporary health care, and in Poland, they affect 5.6–6.4% of inpatients on average, which means that approximately 400,000 patients are affected by HAIs in the country annually [6]. Although HAIs can often be treated easily, in other cases they may prolong the patient's in-hospital stay, add a significant financial burden to both the patient and healthcare

system, and increase morbidity and mortality (for example, risk of mortality increases by 0.7% for urinary tract infection, and 10.2% for hospital-acquired pneumonia) [1–4, 7]. The most frequent types of HAI are those of the respiratory system (pneumonia), urinary tract, gastrointestinal tract, surgical site, bloodstream, bones, skin and subcutaneous tissue, and central nervous system [1–4]. The occurrence of HAI is related to patient- and procedure-dependent factors. Of the 'patient-dependent' factors, which are the variables on the majority of predictive HAI risk scales, the most important are as follows: age; comorbidities; and mode of hospitalization: urgent (immediate, emergency) or scheduled (planned), previous hospitalization, and multi-centre hospitalizations [8]. The iatrogenic factors increasing the risk of HAI are the following: hospital ward architecture, distance between beds, performance of procedures carrying the risk of HAI (e.g., surgery, intubation, central venous cannulation, mechanical ventilation, bladder catheterization, and nasal tube insertion), admission to an intensive care unit, and immunosuppression and antibiotic therapy [9, 10]. The majority of these factors are ward-specific.

Methods of HAI prevention rely on the following: (a) identification of patients with risk factors for HAI and the stratification of HAI risk occurrence risk; (b) prevention of HAI occurrence, for example through isolating the patient or a change from empiric to targeted antibiotic therapy; and (c) monitoring the effect of an applied strategy with the possibility of modification if the intended purpose is not achieved [1–4, 11]. The identification of patients at risk of HAI includes, among other methods, such tools as anal smears (for bacteria producing extended-spectrum beta-lactamases), throat or nasal smears (for COVID-19 detection), immunocompetency tests (e.g., neutropenia), and, most important of all, HAI risk scales, which are scoring systems involving clinical variables [12, 13]. Such scales include (a) patient's nutritional risk (e.g., determined by Nutritional Risk Screening 2002 [NRS-2002] score) [14, 15]; (b) nutritional status (e.g., determined using anthropometric and biochemical indices or body composition parameters) [15, 16]; (c) functional status (e.g., determined by using such simple indices as activities of daily living [ADL], instrumental activities of daily living [IADL], or the Barthel, Norton or frailty scale) [17–20]; (d) comorbidities (e.g. the age-adjusted Charlson Comorbidity Index) [12, 21, 22]; and (e) factors linked to hospital ward specificity (e.g. endovascular procedures, leg amputation, surgery, immunosuppression). However, in the majority of cases, these HAI-risk scales were validated in small populations; they are not always adequate for the specific conditions of different hospital wards, nor do they take into account all the factors that have been demonstrated to affect an increase in susceptibility to infection. Therefore, on the basis that HAI risk is determined multi-factorially, this observational study was performed to identify which of the analysed variables, both 'patient-dependent' and iatrogenic (i.e., hospital procedure-dependent), have predictive value for the occurrence of HAI specifically on the hospital ward. An additional objective of the study was to create a new, local scale for the assessment of HAI risk that would take into account the specificity of patients hospitalized in the ward and compare it with other, widely used scales.

Material and methods

Patients

Of the 5,322 patients hospitalized in one ward of a university hospital between January 2017 and December 2018, 631 (11.86%) were included in the study. The inclusion criteria were as follows: hospitalization in the hospital ward, a medical record that had been assigned an even number of medical history and informed consent to participate in the study. The study group was composed of 262 women and 369 men of Polish nationality, Caucasian, and aged 18–98 years (average age: 67.10 ± 14.20 years) (see Fig. 1 for the flow of patients).

Methods

All patients included in the study completed a survey questionnaire compiled by the authors, provided a medical history, and underwent a physical examination. Clinically driven biochemical determinations were collected for all patients as were anthropometric parameters of nutritional status assessment, which included: weight, height, and body mass index (BMI), abdomen, scapular, triceps, biceps, and skinfold thickness, and waist, arm, and calf circumference, and handgrip strength (HGS). Body composition was ascertained using bioelectrical impedance analysis (BIA) (using a TANITA BC-420 device in line with the European Union Medical Device Directive, MDD 93/42/EEC). The following assessment was also undertaken for each patient: functional status (ADL and Norton scales), malnutrition risk (NRS-2002 scale) [14–16], HAI risk assessment using the hospital's current survey form, score on a comorbidity scale (age-adjusted Charlson Comorbidity Index modified by the Deyo) [11, 23, 24], score on the Cumulative Illness Rating Scale (CIRS) [25], and on the ATLAS (age,

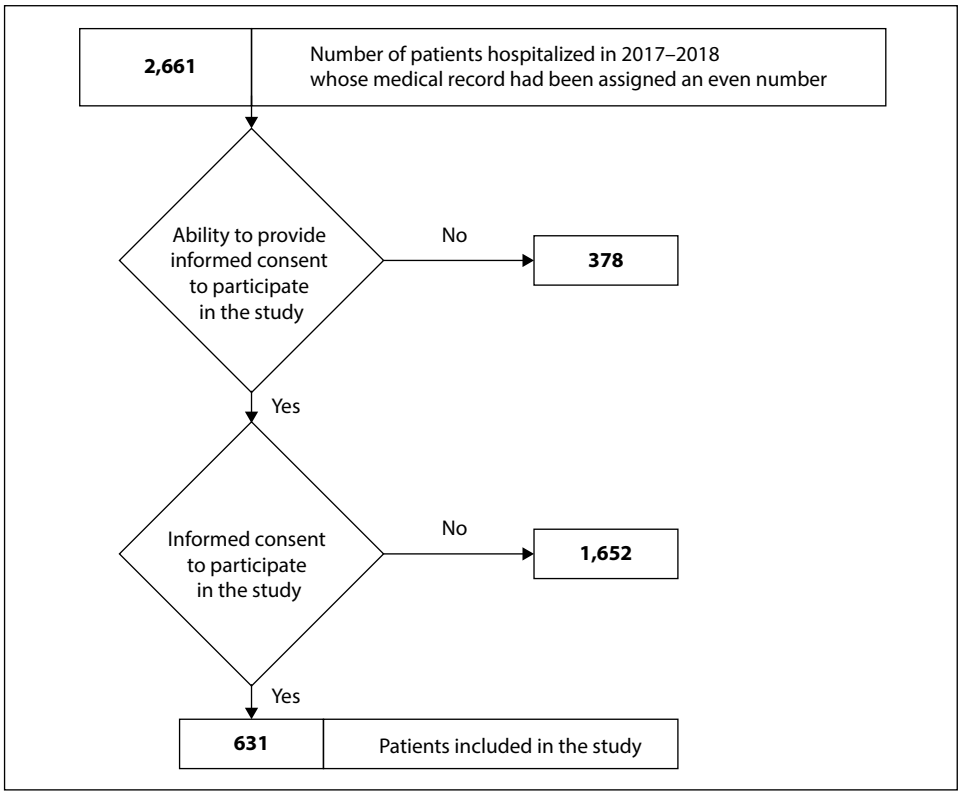

Figure 1. The flow of patients during qualification for participation in the study

temperature, leukocytes, albumin, systemic antibiotics given for longer than 1 day) scale [12, 13].

Bioethics

The study was carried out based on consent no. KB 705/2016 of the local Bioethics Committee and the written consent of each study participant.

Statistical analysis

The results were presented as the mean ± standard deviation or as a frequency (n, %) of the categorical variables. The statistical significance level was set at a p-value of < 0.05. The normal distribution of the study variables was analyzed using the Kolmogorov-Smirnov test. The statistical significance of differences between groups was verified using the Student's t-test and the Chi-square test for the categorical variables. Logistic regression was used for the calculation of odds ratios (ORs) and 95% confidence intervals (CIs), both in unifactorial and multifactorial analyses. Receiver operating characteristic (ROC) curve analysis was used to determine the cut-off values for continuous variables predictive of HAI occurrence. Kaplan-Meier curves were used to determine factors influencing HAI occurrence with duration of hospitalization stay. Statistical analysis was conducted using the licensed version of the statistical analysis software STATISTICA version 13.1 (TIBCO Software, Inc., 2017).

Results

Clinical characteristics of patients with and without HAI

HAI occurred in 113/631 (17.9%) of the patients included in the study (Table 1). The average number of types of HAI in the analyzed cohort amounted to 1.27 ± 0.55. The most prevalent forms of HAI were: pneumonia (PN, n = 46/113, 40.71%), bloodstream infection (BSI, n = 37, 32.74%), urinary tract infection (UTI, n = 30, 26.55%), infection of skin and soft tissues (SST, n = 9, 7.96%), and gastrointestinal tract infection by *C. difficile* (GI-CDI, n = 7, 6.19%).

Individuals with HAI were more likely to be older, to have been admitted urgently, and to have a longer length of stay than patients without HAI (Table 1). Moreover, individuals with HAI had, on admission,

Table 1. Clinical characteristics of patients with and without HAI

Parameter	With HAI (n = 113)	Without HAI (n = 518)	p
Age [years]	73.68 ± 15.78	65.68 ± 13.44	< 0.001
Male gender [n, %]	65 (57.52)	304 (58.69)	0.820
Length of in-hospital stay (days)	20.07 ± 26.57	4.24 ± 4.06	< 0.001
Urgent admission [n, %]	103 (91.15)	297 (57.34)	< 0.001
History of hospitalizations during the 12 months before current hospitalization [n, %]	66 (58.41)	263 (50.77)	0.141
NRS-2002 (score)	2.01 ± 1.38	0.85 ± 1.04	< 0.001
Height [cm]	166.17 ± 8.73	168.26 ± 9.21	0.116
Body weight [kg]	76.53 ± 21.92	78.12 ± 18.61	0.561
BMI [kg/m$^{2]}$	27.59 ± 6.44	27.50 ± 5.47	0.915
Waist-to-hip ratio	0.93 ± 0.09	0.96 ± 0.09	0.546
Fat mass (%)	18.00 ± 15.97	28.88 ± 10.32	0.038
Fat-free mass [kg]	54.65 ± 7.42	54.43 ± 11.58	0.969
Visceral fat level (score)	10.50 ± 9.47	12.31 ± 5.54	0.520
Handgrip strength [kg]	35.90 ± 13.27	28.85 ± 11.43	0.173
Arm circumference [cm]	26.90 ± 4.80	29.45 ± 4.28	0.188
Calf circumference [cm]	36.10 ± 4.13	36.77 ± 4.24	0.726
Norton score	12.74 ± 4.86	18.74 ± 2.75	< 0.001
Bedsores on admission [n, %]	20 (17.70)	4 (0.77)	< 0.001
ADL score on admission	2.21 ± 2.45	5.48 ± 1.41	< 0.001
Bedridden functional status [n, %]	93 (82.30)	133 (25.68)	< 0.001
Foley catheter [n, %]	82 (72.57)	49 (9.46)	< 0.001
Gastric tube [n, %]	36 (31.86)	6 (1.16)	< 0.001
Central venous cannulation [n, %]	36 (31.86)	3 (0.58)	< 0.001
Intubation and mechanical ventilation [n, %]	24 (21.24)	2 (0.39)	< 0.001
Steroid therapy [n, %]	27 (23.89)	24 (4.63)	< 0.001
Blood transfusion [n, %]	54 (47.79)	59 (11.39)	< 0.001
Leg amputation [n, %]	12 (10.62)	4 (0.77)	< 0.001
Creatinine [mg/dl]	1.62 ± 1.12	1.53 ± 6.44	0.886
White blood cell count [G/l]	17.55 ± 48.84	9.22 ± 9.82	< 0.001
Hemoglobin [g/l]	11.44 ± 2.34	13.20 ± 4.69	< 0.001
Red blood cells [T/l]	3.89 ± 0.77	4.36 ± 0.84	< 0.001
Hematocrit (%)	34.90 ± 6.52	38.84 ± 6.93	< 0.001
Red cell distribution width (RDW)	16.38 ± 2.49	14.93 ± 2.42	< 0.001
Procalcitonin [ng/ml]	3.96 ± 14.10	5.46 ± 15.96	0.556
C-reactive protein [mg/dl]	103.06 ± 123.77	53.25 ± 90.17	< 0.001

ADL — activities of daily living; BMI — body mass index; HAI — healthcare-associated infection; NRS-2002 — Nutritional Risk Screening 2002

Table 2. Scoring on HAI risk scales in patients with and without HAI

HAI risk scale	With HAI (n = 113)	Without HAI (n = 518)	p	OR; 95% CI; p
ATLAS score (without albumin)	2.48 ± 1.30	1.31 ± 1.11	< 0.001	2.14; 1.57–2.92; < 0.001
ATLAS score total	5.22 ± 1.44	2.65 ± 1.67	< 0.001	2.69; 2.02–3.60; < 0.001
The current hospital HAI risk scale (score)	6.58 ± 2.91	4.86 ± 2.69	< 0.001	1.24; 1.15–1.34; < 0.001
Current hospital HAI risk scale: risk groups [n, %]			< 0.001	2.46. 1.70–3.54; < 0.001
Low risk (score: 1–5)	40 (35.40)	290 (57.72)		
Moderate risk (score: 6–10)	64 (56.64)	210 (40.54)		
High risk (score: 11–20)	9 (7.96)	9 (1.74)		
CIRS (score)	16.60 ± 5.44	11.39 ± 5.48	< 0.001	1.17; 1.12–1.21; < 0.001
Charlson Comorbidity Index (score)	5.70 ± 3.20	3.87 ± 2.66	< 0.001	1.23; 1.14–1.31; < 0.001

ATLAS — age, temperature, leukocytes, albumin, systemic antibiotics given for longer than 1 day; CI — confidence interval; CIRS — Cumulative Illness Rating Scale; HAI — healthcare-associated infection; OR — odds ratio

greater nutritional risk (a higher NRS-2002 score), lower energy reserves and worse functional status, lower percentage of fat mass as measured in body composition analysis using BIA, lower scoring on the Norton and ADL scales, and had bedsores both on admission and more prevalently (Table 1) than patients without HAI. Patients with HAI more frequently required central venous cannulation, intubation and mechanical ventilation, and insertion of a medical device through bodily orifices (e.g., a Foley catheter or gastric tube) than patients without HAI. Patients with and without HAI did not differ in terms of values of anthropometric parameters of nutritional status assessment. The average length of in-hospital stay for patients with one type of HAI was 7.67 ± 8.06 days; for those with two types of HAI, this was 21.29 ± 13.06 days; and with three types of HAI, this was 48.00 ± 12.73 days.

Patients with HAI had higher scores on the current hospital HAI risk scale than patients without HAI (Table 2).

Risk factors for HAI

In one-factorial analysis, the occurrence of HAI was shown to be more strongly related (higher OR) to iatrogenic factors (e.g., Foley catheter, central venous cannulation, intubation and mechanical ventilation) than to the individual ('patient-dependent') factors included in commonly used HAI risk scales, except for the presence of bedsores on admission (Table 3). The OR for HAI was the highest in patients with the following: central venous cannulation; intubation and mechanical ventilation; after insertion of a medical device through bodily orifices (Foley catheter, gastric tube, or airway intubation); impaired functional status (bedsores on admission, lower ADL scores, and higher scores on the Norton scale); requiring surgery (mainly leg amputation due to the specificity of the ward); longer in-hospital stay; blood transfusion, steroid therapy, and combination antibiotic therapy; a higher score on the Charlson, CIRS, and ATLAS scales and a higher NRS-2002 score; and a lower percentage of fat mass (the 'obesity paradox'). What was surprising was the lack of significant associations between risk of HAI and values of anthropometric indices of nutritional status assessment, patient's age, and biomarkers of inflammatory response, such as blood C-reactive protein and procalcitonin concentrations (Table 3).

Czerniak-score

To achieve a ward-specific HAI risk scale, combined were established variables to allow generating a 'Czerniak-score,' assigning one point for each of the following variables: ATLAS score ≥ 4, ADL score < 6, CIRS score ≥ 12, bladder catheterization, central venous cannulation, bedsores on admission to hospital, and patients categorized as bedridden. Of the 113 patients with HAI, 89 (78.76%) had a score of at least 3 points on the Czerniak score. Using ROC analysis, the authors determined a cut-off value of a Czerniak-score of 3 (AUC; 95% CI: 0.922; 0.889–0.955; p < 0.001). In relation to

Table 3. Risk of HAI in relation to clinical characteristics

Clinical characteristic	OR; 95% CI; p
Age [years]	1.05; 1.03–1.07; < 0.001
Male gender [n, %]	0.95; 0.62–1.44; 0.82
Length of in-hospital stay [days]	7.66; 3.91–15.03; < 0.001
Urgent admission [n, %]	1.36; 0.90–2.06; 0.14
NRS-2002 [score]	2.08; 1.74–2.49; < 0.001
Body weight [kg]	0.99; 0.98–1.01; 0.56
BMI [kg/m^2]	1.00; 0.95–1.05; 0.91
Fat mass (%)	0.90; 0.81–0.99; 0.047
Fat-free mass [kg]	1.00; 0.92–1.10; 0.97
Visceral fat level (score)	0.94; 0.77–1.14; 0.52
Handgrip strength [kg]	1.05; 0.97–1.12; 0.18
Arm circumference [cm]	0.86; 0.69–1.08; 0.19
Calf circumference [cm]	0.96; 0.77–1.19; 0.72
Norton score	0.72; 0.68–0.76; < 0.001
Bedsores on admission [n, %]	27.63; 9.22–82.86; < 0.001
ADL score on admission	0.52; 0.47–0.58; < 0.001
Foley catheter [n, %]	25.31; 15.22–42.09; < 0.01
Gastric tube [n, %]	39.90; 16.24–99.97; < 0.001
Central venous cannulation [n, %]	80.26; 24.07–267.63; < 0.01
Intubation and mechanical ventilation [n, %]	69.57; 16.11–300.45; < 0.001
Steroid therapy [n, %]	6.46; 3.55–11.74; < 0.01
Blood transfusion [n, %]	7.12; 4.50–11.26; < 0.001
Leg amputation [n, %]	15.27; 4.82–48.40; < 0.001
Creatinine [mg/dl]	1.00; 0.97–1.03; 0.56
Hemoglobin [g/l]	0.80; 0.73–0.86; < 0.001
Red blood cells [T/l]	0.52; 0.41–0.66; < 0.001
Hematocrit (%)	0.93; 0.90–0.96; < 0.001
Red cell distribution width (RDW)	1.22; 1.13–1.31; < 0.001
Procalcitonin [ng/ml]	0.99; 0.97–1.01; 0.56

Data obtained using logistic regression. ADL — activities of daily living; BMI — body mass index; CI — confidence interval; HAI — healthcare-associated infection; NRS-2002 — Nutritional Risk Screening 2002; OR — odds ratio

Table 4. Risk factors for HAI in multifactorial analysis using logistic regression, Chi2 = 260.75, p < 0.001

Parameter	Constant	Bedsores on admission	CVC	Foley catheter	ADL score on admission
Estimation	–1.06	1.62	3.06	1.73	–0.33
Standard error	0.42	0.67	0.71	0.34	0.073
t(626)	–2.52	2.41	4.31	5.02	–4.54
p	0.012	0.02	< 0.001	< 0.001	< 0.001
OR; 95% CI	0.35; 0.15–0.79	5.07; 1.35–19.08	21.37; 5.30–86.20	5.63; 2.86–11.08	0.72; 0.62–0.83

ADL — activities of daily living; CI — confidence interval; CVC — central venous cannulation; HAI — healthcare-associated infection; OR — odds ratio

Table 5. Risk factors for HAI in multifactorial analysis using the Cox regression model, $Chi^2 = 103.35$; $p < 0.001$

Variable	Beta	Hazard risk; 95% CI	p
Age [years]	0.002; –0.01–0.016	1.002; 0.988–1.016	0.780
Urgent admission [yes/no]	0.482; –0.23–1.192	1.619; 0.796–3.292	0.183
Previous hospitalization during the 12 months before admission [yes/no]	0.665; 0.21–1.120	1.945; 1.234–3.292	0.004
Male gender [yes/no]	0.053; –0.40–0.503	1.054; 0.672–1.654	0.819
BMI [kg/m$^{2]}$	0.011; –0.05–0.70	1.011; 0.953–1.072	0.716
Fat mass (%)	–0.015; –0.05–0.070	0.985; 0.940–1.033	0.537
Norton scale (score)	–0.016; –0.9–0.060	0.984; 0.912–1.061	0.672
Bedsores on admission [yes/no]	–0.512; –1.18–0.161	0.600; 0.306–1.175	0.136
NRS-2002 (score)	–0.084; –0.27–0.106	0.919; 0.760–1.112	0.386
ADL score on admission	0.018; –0.13–0.168	1.018; 0.877–1.183	0.812
Foley catheter [yes/no]	–0.312; –1.12–0.495	0.732; 0.326–1.641	0.448
Gastric tube [yes/no]	–0.487; –1.12–0.143	0.615; 0.327–1.153	0.130
Central venous cannulation [yes/no]	0.182; –0.49–0.850	1.199; 0.615–2.339	0.594
Type of therapy (medical, surgery)	0.066; –0.44–0.572	1.068; 0.644–1.771	0.799
Blood transfusion [yes/no]	0.055; –0.41–0.525	1.056; 0.660–1.690	0.819
ATLAS (score)	0.129; –0.05–0.304	1.137; 0.954–1.356	0.152
Current hospital HAI risk scale (score)	0.080; 0.00–0.160	1.083; 1.00–1.173	0.049
CIRS (score)	0.001; –0.06–0.058	1.001; 0.945–1.060	0.974
Charlson Comorbidity Index (score)	–0.056; –0.16–0.051	0.946; 0.850–1.053	0.309
Hemoglobin concentration [g/l]	0.001; –0.09–0.089	1.001; 0.916–1.093	0.989
Czerniak-score (score)	0.594; 0.26–0.927	1.812; 1.298–2.528	< 0.0001

ADL — activities of daily living; ATLAS — age, temperature, leukocytes, albumin, systemic antibiotics given for longer than 1 day; BMI — body mass index; CIRS — Cumulative Illness Rating Scale; CI — confidence interval; HAI — hospital-associated infection; NRS-2002 — Nutritional Risk Survey 2002

HAI prediction, a Czerniak score ≥ 3 had: 82.20% sensitivity (95% CI: 71.54–87.14%), 94.02% specificity (95% CI: 91.61–95.90%), a positive predictive value (PPV) of 74.17% (95% CI: 66.84–80.35%), a negative predictive value (NPV) of 95.68% (95% CI: 93.83–96.99%), a likelihood ratio for a positive result (LR+) of 13.40 (95% CI: 9.41–19.08), and a likelihood ratio for a negative result (LR-) of 0.21 (95% CI: 0.14–0.31). An increase in the Czerniak score of 1 point increased the HAI risk by 5.43 times (OR; 95% CI: 5.43; 4.09–7.20; $p < 0.001$) (Table 4).

It was found that ATLAS scores (≥ 4 and < 4), ADL scores (< 6 and ≥ 6), and CIRS scores (< 12 and ≥ 12) also had clinically useful sensitivity and specificity for the prediction of HAI occurrence, but an extension of these scores to include comorbidity analysis, patient's functional status, the need for venous cannulation, and insertion of medical devices through bodily orifices in compiling a Czerniak-score allowed to identify a significant majority of the patients at risk (≥ 3 points) and not at risk (< 3 points) of HAI.

HAI risk in multifactorial analysis

In the multifactorial analysis using logistic regression, the strongest independent risk factors for HAI occurrence with prolongation of in-hospital stay were as follows: central venous cannulation, urine bladder catheterization, and bedsores found on admission to the clinic. A higher ADL score was related to a decrease in HAI risk of 28% per 1-point increase (Table 4). Whereas, in multifactorial analysis using the Cox regression model (Table 5), the strongest independent risk factor for HAI was that a 1-point increase in the Czerniak score increased the risk of HAI by 80% (Table 5). The other independent variables related to HAI risk were central venous cannulation, bladder catheterization, and bedsores found on admission to the clinic.

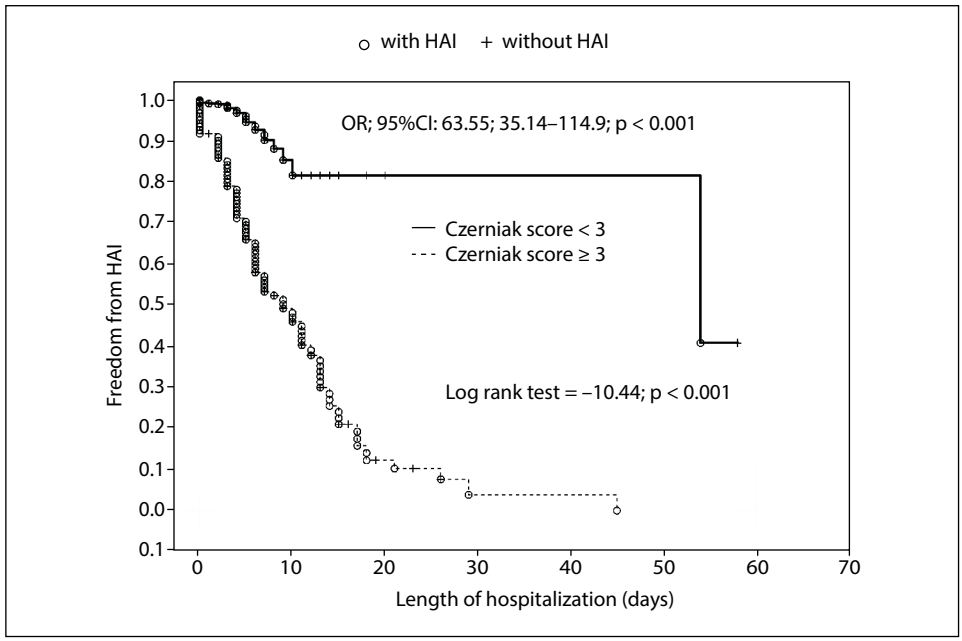

Figure 2. Risk of healthcare-associated infection (HAI) with the length of hospital stay in relation to the Czerniak score on admission, Kaplan-Meier plot

Period of freedom from HAI

As the length of a patient's stay is not only a complication of HAI but also seems to be an important factor in HAI risk, the Kaplan-Meier analysis was performed for the two groups to verify this hypothesis. The authors compared the probability of freedom from HAI periods in relation to the categorical variables or the cut-off values of the quantitative variables established as a median value or determined in ROC analysis. It was found that the following had a significant effect on HAI occurrence with prolongation of in-hospital stay: Norton scale score (< and ≥ 20, with log-rank test = –4.35; $p < 0.01$); ADL score (< 6 and ≥ 6, with log-rank test = –7.24; $p < 0.001$), CCI score (< 4 and ≥ 4, with log-rank test = 2.79; $p < 0.006$), and a Foley catheter (yes/no; with log-rank test = –7.04; $p < 0.01$). For these variables, the Kaplan-Meier curves separated after 10–12 days of hospitalization; however, when an analysis was performed in relation to the Czerniak-score (< and ≥ 3), the curves separated significantly after 5 days, and the risk of HAI in patients receiving at least 3 points as a Czerniak-score increased by 63.5 times (Fig. 2).

Discussion

This work tried to answer an unresolved question concerning the reliable identification of patients at risk from HAI, which would, in turn, help practitioners plan personalized prophylaxis and treatment. It was found that the most-used clinical scales (e.g., ATLAS and CIRS) and single clinical variables (e.g., bedsores on admission to the hospital, a bedridden patient's functional status, or an ADL score < 6) were good predictors of HAI occurrence; however, the allocation of a Czerniak-score was the basis of the best tool for the prediction of HAI occurrence on the clinical ward. The usefulness of the Czerniak score in predicting HAI was confirmed in one-factorial, multifactorial, and survival analyses. Moreover, it was confirmed that the risk of HAI increased with the length of in-hospital stay. However, in analyses concerning the most widely-used indicators of HAI risk, the Kaplan-Meier curves separated after 10–12 days of hospitalization, but the Czerniak-score was, by contrast, able to predict the occurrence of HAI after 5 days of hospitalization. This suggests that the Czerniak score is not only clinically useful for long hospitalizations but also for short hospital stays.

The prevalence of HAI in the study cohort was 17.9% (Table 1). Such a figure is comparable to HAI prevalence observed in other hospital wards where the treatment is conservative [1–4], although this is still lower than in intensive care units, in which HAI prevalence was found to amount to 35.8–39% of patients [6, 8, 26].

Also, it was found that a lower percentage of fat mass and a higher NRS-2002 score were related to a greater risk of HAI (Table 1, Table 3). This observation

corroborates data suggesting the existence of the 'obesity paradox' among patients requiring hospitalization, especially for those aged above 60 years, for whom new cut-off values for BMI have been proposed (< 23, 23–27, > 27 kg/m^2) [27]. With regard to the parameters of body composition, some authors suggest that low skeletal muscle mass, especially sarcopenia, correlates more strongly with the risk of HAI than low-fat mass [16]. Malnutrition was also recognized as a risk factor for hospital-acquired pneumonia [16, 17] and the risk of postoperative complications [14–16]. The potential pathomechanism linking HAI and malnutrition is immunodeficiency and lower production of antibodies, as well as a decrease in immunological cell activity (e.g. macrophages, lymphocytes, and neutrophils). For this reason, among other factors, according to Polish rules, all hospitalized individuals should have their nutritional risk (using the NRS-2002 score) determined and adequate actions introduced, including nutritional support [14–16]. The present study suggests that inpatients might benefit from such actions, not only concerning improvement in nutritional status but also in relation to decreasing HAI risk.

Compared to patients without HAI, patients with HAI had higher scores in comorbidity indices, both in the CIRS and Charlson scales (Table 2). Comorbidities are associated with organ insufficiency and reduced functional reserve, which increases the risk of HAI [12, 17–22]. This explanation was also confirmed in the present study through the lower risk of HAI among patients with an ADL score ≥ 6 and a Norton score ≥ 20 in a Kaplan-Meier plot (data not presented), which showed an average reduction in the risk of HAI by 28% with every 1 point increase on the ADL scale (Table 4). A reduction in HAI risk with improvement in the patient's functional status was confirmed by other authors [12, 17–22]. Unlike BMI, the NRS-2002 score was significantly associated with HAI risk, specifically a two-fold increase in risk for every 1 point on the NRS-2002 questionnaire. The high predictive role of the NRS-2002 in the prognosis of unfavourable hospital outcomes was observed in the other work [14]. It is also known that both malnutrition and bedridden functional status are risks for bedsore development [12, 14, 17–22], which, in turn, increases HAI risk by 27 (Table 3). Therefore, the hypothesis can be offered that a patient's rehabilitation, bedsore prevention, and nutritional support may not only improve the patient's functional status and decrease the risk of bedsores (pressure ulcers) but also lower HAI risk [17–22, 28]. Moreover, the identification of patients with bedsores on admission to the hospital, and/or with the risk of bedsore development after admission (according to, for example, the Norton scale) should also be part of HAI risk stratification.

In relation to procedure-dependent risk factors for HAI, the greatest OR for HAI concerned: central venous cannulation (HAI risk increases by 80 times), intubation and mechanical ventilation, urinary bladder catheterization, and gastric tube insertion (Table 3). Moreover, the risk of HAI increased by 5% with every year of the patient's age, and by 36% when hospitalization was urgent (Table 3). The present observations corroborate other data [1–4, 8, 26]. It was also found that the rationale for antibiotic therapy is an important factor in HAI prevention, as the HAI risk increased by seven times with each added antibiotic. However, it should be underlined that among 113 individuals, only seven patients were found with HAI caused by *C. difficile* [12, 13, 29], which suggests that antibiotic therapy is also a risk factor for HAI caused by other microorganisms. This statement can be confirmed by the observation that the ATLAS scale, which has, until now, been recommended for evaluating HAI risk among patients with combination antibiotic therapy, predicted HAI risk the most strongly, and that with every point of this scale, HAI risk increased by 169% (Table 2. Similar observations were reported by other authors [1–4, 8, 12, 13, 26]. In the present study, a one-unit increase in the current hospital HAI risk scale, CIRS, and CCI increased the risk of HAI by 24%, 17%, and 23%, respectively. Therefore, the Czerniak-score was constructed, which combines three HAI risk areas: HAI risk scoring systems (ATLAS), scoring of the patient's functional status (CIRS and bedridden functional status), and central venous cannulation (Table 5). Receiving at least 3 points as a Czerniak score increased the risk of HAI by 63.5 times, with the possibility of HAI prediction after the fifth day of hospitalization (Fig. 2). In this way, the use of the Czerniak score helps predict HAI occurrence earlier than the other HAI risk scales and can be useful both for short and long hospitalization durations. Moreover, the Czerniak score is characterized by high diagnostic test parameter values (sensitivity, specificity, PPV, and NPV). While it is clearly the case that other authors have not verified the usefulness of the Czerniak score, research on the use of a local, ward-specific and validated scale for identifying patients at high and low HAI risk has previously been published [1–4, 12, 13, 26, 30]. Moreover, the use of survival analysis in HAI prediction was used in sporadic publications, mainly concerning the evaluation of HAI-related outcomes or HAI therapy effectiveness [31–33].

Study limitations

Despite detailed planning in terms of study design, data collection, and data analysis, this study rom contains some limitations. First, the data was not collected from homogeneous patient groups with and without HAI with regard to clinical characteristics (e.g., age and mode of hospitalization), which could have affected the final measurements and outcomes of the study. Second, not all of the biochemical/ clinical determinations under study were made for the patients included in the research. For example, blood albumin concentration was not determined in all patients; therefore, the ATLAS score was calculated both with and without albumin (Table 2). Similarly, the bedridden functional status of patients made it impossible to perform body composition analysis using BIA because examination with the TANITA device requires the patient to be standing. Third, HAI occurrence after discharge was diagnosed during a telephone interview.

Conclusions

The occurrence of HAIs is more strongly related to iatrogenic factors (e.g., bladder catheter, central venous cannulation, intubation and mechanical ventilation) than to individual ('patient-dependent') factors on the most commonly used HAI risk scales. The extension of the assessment of HAI risk through the Czerniak-score, which includes the analysis of comorbidity, the patient's functional status, the need for central venous cannulation, and the insertion of a medical device through bodily orifices, enabled the identification of a significant majority of the patients at risk (≥ 3 points) and not at risk (< 3 points) of HAI. Further studies are needed to validate the Czerniak scale presented in this paper and to develop methods of HAI prevention in patients categorized as being at high risk of HAI.

Article information

Data availability statement: *None.*
Ethics statement: *The study was carried out based on consent no. KB 705/2016 (Appendix 1) of the Bioethics Committee at the Nicolas Copernicus University in Toruń, Ludwik Rydygier Collegium Medicum in Bydgoszcz with subsequent annexes (including Annex 2 issued on 02.26.2019) and the written consent of each study participant.*
Authors contribution: *Study Design: Beata Czerniak Jacek Budzyński; Data Collection: Beata Czerniak, Wioletta Banaś; Statistical Analysis: Jacek Budzyński, Beata Czerniak; Data Interpretation: Beata Czerniak, Wioletta Banaś, Jacek Budzyński; Manuscript Preparation: Beata Czerniak, Wioletta Banaś, Jacek Budzyński; Literature Search: Beata Czerniak, Wioletta Banaś, Jacek Budzyński; Funds Collection: N/A.*
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