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Bloodstream Infections in the Intensive Care Unit: a Single-Center Retrospective Bacteriological Analysis Between 2007 and 2019

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Abstract

Hospital-acquired bloodstream infections are a severe worldwide problem associated with significant morbidity and mortality. This retrospective, single-center study aimed to analyze bloodstream infections in patients hospitalized in the intensive care unit of the Military Institute of Medicine, Poland. Data from the years 2007–2019 were analyzed. When the infection was suspected, blood samples were drawn and analyzed microbiologically. When bacterial growth was observed, an antimicrobial susceptibility/resistance analysis was performed. Among 12,619 analyzed samples, 1,509 were positive, and 1,557 pathogens were isolated. In 278/1,509 of the positive cases, a central line catheter infection was confirmed. Gram-negative bacteria were the most frequently (770/1,557) isolated, including *Acinetobacter baumannii* (312/770), *Klebsiella pneumoniae* (165/770; 67/165 were the isolates that expressed extended spectrum beta-lactamases (ESBL), 5/165 isolates produced the New Delhi metallo-β-lactamases (NDM), 4/165 isolates expressed *Klebsiella pneumoniae* carbapenemase (KPC), and 1/165 isolate produced OXA48 carbapenemase), *Pseudomonas aeruginosa* (111/770; 2/111 isolates produced metallo-β-lactamase (MBL), and *Escherichia coli* (69/770; 11/69 – ESBL). Most Gram-positive pathogens were staphylococci (545/733), mainly coagulase-negative (368/545). Among 545 isolates of the staphylococci, 58 represented methicillin-resistant *Staphylococcus aureus* (MRSA). Fungi were isolated from 3.5% of samples. All isolated MRSA and methicillin-resistant coagulase-negative *Staphylococcus* (MRCNS) strains were susceptible to vancomycin, methicillin-sensitive *Staphylococcus aureus* (MSSA) isolates – to isoxazolyl penicillins, and vancomycin-resistant *Enterococcus* (VRE) – to linezolid and tigecycline. However, colistin was the only therapeutic option in some infections caused by *A. baumannii* and KPC-producing *K. pneumoniae*. *P. aeruginosa* was still susceptible to cefepime and ceftazidime. Echinocandins were effective therapeutics in the treatment of fungal infections.

K e y w o r d s: central line-associated bloodstream infections, Gram-positive pathogens, Gram-negative pathogens, antimicrobial susceptibility, antimicrobial resistance, intensive care unit

Introduction

Hospital-acquired bloodstream infections (BSI) are a severe care problem worldwide, associated with significant mortality (Massart et al. 2021). According to Watson et al. (2019), hospital-acquired bloodstream infections result in a 1.3- to 4.3-fold increase in the hospitalization duration, 2.8- to 5.3-fold higher hospitalization costs and a 4.3- to 8-fold increase in the percentage of patients who died.

Observations from the last few years have shown an increased incidence of bloodstream infections (Salm et al. 2018; Tajima et al. 2021). Moreover, data from Denmark revealed a considerable increase in bacteremia between 2000 and 2014, although the all-cause 30-day mortality after first-time bacteremia decreased (Holm et al. 2021).

Over 50% of patients admitted to the intensive care unit (ICU) require central vein catheterization (CVC) (Blot et al. 2015). Central lines are necessary for multiple

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purposes, including drug infusion, blood sample collection, and hemodynamic monitoring. The presence of a catheter inside a central vein is associated with the risk of central line-associated bloodstream infections (CLABSI). In the USA, five million CVCs are inserted each year, leading to approximately 200,000 cases of CLABSI, and the number of deaths attributable to such infections may be as high as 25,000 (Blot et al. 2015). However, these estimates may be understated because some cases of BSI secondary to urinary, respiratory, and gastrointestinal infections may be assigned the International Classification of Disease (ICD) codes for those illnesses (Goto and Al-Hasan 2013).

The objective of this study was to analyze bloodstream infections in patients hospitalized in the intensive care unit of the Military Institute of Medicine between 2009 and 2017 and to determine the changes in the incidence of pathogens and their susceptibility/resistance to antimicrobial agents with particular attention paid to the incidence of CVC infections in the analyzed cohort.

Experimental

Materials and Methods

Study design. It was an observational cohort study. The study protocol was approved by the institutional Bioethical Committee (43/WIM/2020 of August 19, 2020).

Setting. Data were collected in the intensive care unit of the Military Institute of Medicine in Warsaw, Poland, between January 1, 2007, and December 31, 2019. The Military Institute of Medicine is a 1,000-bed university hospital and a regional trauma center. The number of beds in the ICU varied throughout the study period: from 8 (2007–2013), 14 (2014), to 18 beds (2015–2019).

Participants and the procedures when infection was suspected. We analyzed the data of all critically ill patients hospitalized in our ICU during the study period. No other eligibility criteria were applied.

In our center, the physicians always insert central venous catheters, either specialists or residents. Regardless of who performed the CVC insertion, the procedure was the same and was performed aseptically. Trained nurses provided routine care of inserted catheters and venous line connectors. When the infection was suspected, two blood samples were drawn: one sample of peripheral blood and a second one drawn through the CVC; both were submitted to microbiological testing. When a catheter-related bloodstream infection was suspected, the procedure was like that described above. The blood samples were taken from both the catheter and a peripheral vein. The catheter was removed according to clinical guidelines (O'Grady et al. 2011), and the tip of the catheter was microbiologically analyzed. Blood samples were collected by trained nurses under aseptic conditions, according to standard procedures in all cases. Its tip was cut off and microbiologically analyzed whenever the catheter was removed. Catheters were released by physicians, under aseptic conditions, according to standard procedures.

Microbiological analysis. Blood samples (10 ml) were collected into two BactAlert Bottles (bioMérieux, France): a BactAlert FA Plus Bottle to detect the presence of aerobes and fungi and a BactAlert FN Plus Bottle to check for anaerobes. Both blood samples were placed in a BactAlert 3D automatic analyzer (bioMérieux, France) and incubated at 37°C either until the growth of the pathogens was observed or until the end of the fifth day of incubation.

When pathogen growth was noted, the samples were inoculated on specific growth media: Columbia agar, McConkey agar, chocolate agar, and Sabouraud agar. When the growth of anaerobic pathogens was observed, the samples were inoculated in a Schaedler agar. The pathogens were incubated in the growth media for 24–48 hours at 37°C under aerobic or anaerobic conditions. After the incubation period, the Gram-stained bacteria morphology was analyzed.

When the growth of a mixed bacterial culture was observed, separating procedures were performed to obtain pure colonies, which were further identified, and antibiotic susceptibility of isolates was assayed. The microorganisms were identified by an automatic VITEK® 2 testing system (bioMérieux, France) using VITEK® ID Cards (VITEK® 2 GN ID Card for the identification of fermenting and non-fermenting Gram-negative bacilli, VITEK® 2 GP ID Cards for Gram-positive bacteria, and VITEK® YST ID Cards of yeast and yeast-like organisms, respectively) following the manufacturer's instructions. The quality of bacterial identification was assessed with the VITEK® 2 Advanced Expert System. The results were defined as acceptable at a confidence level between 96–99% (excellent identification) or 93–95% (very good quality). Antimicrobial susceptibility testing was performed with the VITEK® 2 system according to the manufacturer's instructions, using the software 9.02 version and the AST-N 332, AST-P644, AST-643, AST-ST03 cards for Gram-negative bacteria, staphylococci, enterococci, and streptococci, respectively. Between 2007 and 2010, the antimicrobial susceptibility of isolated pathogens was classified according to the Clinical and Laboratory Standard Institute (CLSI 2009; 2010a; 2010b), and since 2011 following the regulations of the European Committee on Antimicrobial Susceptibility Testing (EUCAST 2013; 2017) and the National Reference Centre for Susceptibility Testing in Warsaw, Poland. Control susceptibility tests included reference strains of *Pseudomonas aeruginosa*

ATCC 27853, *Escherichia coli* ATCC 25922, *Staphylococcus aureus* ATCC 29213, *Enterococcus faecalis* ATCC 29212, *Klebsiella pneumoniae* ATCC 700603, *Klebsiella pneumoniae* ATCC BAA-2814, *Staphylococcus aureus* NCTC 124943, and *Enterococcus faecalis* ATCC 51299.

The microbiological investigation of the catheters was performed using both a semiquantitative Maki et al. (1977) and a quantitative Brun-Buisson et al. (1987) techniques. A central venous line may be a source of blood infection when the growth of the same pathogen identified in a catheter-drawn sample is observed two or more hours earlier in a blood sample drawn from a peripheral vein. In a catheter tip culture, more than 15 CFU colonies of the same pathogen were isolated via the semiquantitative analysis (Maki et al. 1977). More than thousand bacterial species were isolated via the quantitative analysis (Brun-Buisson et al. 1987).

Study size. Due to the retrospective nature of this study, its size was not determined before the start of the project.

Statistical methods. Collected data were archived and analyzed using the Microsoft Excel software. Descriptive statistics were used for analysis. All figures were prepared with the DataGraph software.

Results

The study analyzed data collected between 2007 and 2019. General information regarding the number of patients hospitalized in the ICU, the reasons for their hospitalization, the number of microbiological investigations of blood samples, and the results of these examinations are shown in Tables I and II.

Study population and blood samples. Between 2007 and 2019, 3,502 patients were hospitalized in our ICU. Among these, 2,581/3,502 were men (73.7%), and 921/3,502 (26.3%) were women. Among 46,253 microbiological specimens, 12,619 (27.3%) were obtained from blood samples. One thousand five hundred nine samples (12%) were positive, and 1,557 pathogens were isolated. Among these were 770/1,557 (49.5%) Gram-negative bacteria, 733/1,557 (47.1%) Gram-positive bacteria, and 54/1,557 (3.5%) fungal species. A CVC was inserted in 3,460 of the 3,502 (98.8%) patients. The CVC was inserted into a subclavian vein in 2,588/3,460 cases (74.8%), into the internal jugular in 685/3,460 cases (19.8%), and the femoral vein in 187/3,460 cases (5.4%). A CVC was implicated in 278/1,509 (18.4%) of positive blood cultures, and the number of infected central vein catheters was 278/632 (44.6%). The pathogens isolated from positive blood cultures are shown in Table II. Among all Gram-negative bacteria, *A. baumannii* was isolated quite often, in 312/770 (40.5%) of cases. It represented 312/1,557 (20%) of all isolated pathogens.

Isolated pathogens. Gram-negative bacilli were the most common isolated pathogens in our materials. The most frequently isolated pathogen was *A. baumannii*, followed by *K. pneumoniae,* and *P. aeruginosa*. Among Gram-positive cocci, the most frequent was *MRCNS*, followed by *E. faecalis*. *A. baumannii* was isolated from 312 samples (20% of all isolated pathogens and 40.5% (312/770) of all Gram-negative isolates). *P. aeruginosa* was obtained from 111 blood samples (7.4% (111/1,509)), representing 7.1% of all isolated bacterial species and 14.4% (111/770) of Gram-negative pathogens. Only in two *A. baumannii* isolates with the MBL mechanism of antibiotic resistance were found. *K. pneumoniae* was detected in 165 blood samples (11% (165/1,509)), and represented 10.6% (165/1,557) of all isolated pathogens and 21.4% (165/770) of Gram-negative bacterial isolates. Among all *K. pneumoniae* strains, the following antibiotic resistance mechanisms were identified: ESBL in 67 (40.6%) isolates, NDM in five, KPC – four, and OXA-48 in one isolate. *E. coli* was isolated from 69 samples and comprised 4.6% (69/1,509) of all and 9% (69/770) of Gram-negative isolates. Eleven of them (15.9%) exhibited an ESBL mechanism of resistance.

Staphylococci were the most frequent (74.4% (545/733)) isolates among the Gram-positive bacteria. The majority (368/545, 67.5%) of all isolated staphylococci were MRCNS. More than 78% (426/545) of staphylococci were resistant to methicillin (86.4% (368/426) of them were MRCNS). Enterococci were isolated from 184/1509 (12.2%) samples; 41/184 (22.3%) strains exhibited a high-level aminoglycoside resistance (HLAR), and 11 (6%) *E. faecium* species were resistant to vancomycin.

The resistances of isolated pathogens to antimicrobial agents are shown in Tables III and IV. The graphical presentation of these data is shown in Fig. 1, 2, and 3. The above data include the number of Gram-positive (Table III, Fig. 2) and Gram-negative (Table III, Fig. 3) alert pathogens with their resistance mechanisms. All MRSA and MRCNS strains were susceptible to vancomycin during the analyzed period. From 2010, all MRSA strains were susceptible to gentamycin and trimethoprim/sulfamethoxazole. However, MRCNS strains were rather (mean 57%, median 61%) susceptible to sulphonamide and exhibited high resistance (up to 90% in 2019) to gentamycin. MRSA was more susceptible to the other than mentioned above antimicrobials than MRCNS. All MSSA strains were susceptible to isoxazolyl penicillins.

Amongst the enterococci, all *E. faecalis* isolates (21% of isolates with the HLAR mechanism of resistance) were susceptible to ampicillin, *E. faecium* to vancomycin and teicoplanin, and VRE to linezolid and tigecycline.

The most problematic Gram-negative alert pathogen was *A. baumannii* due to its high prevalence and

Table I
Descriptive statistics of the study population and their primary diagnoses according to ICD10.

		Year												
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Patients	n	197	182	216	173	224	178	172	186	350	422	422	450	348
Age	median	53	54	60	59	49	43	45	49	43	43	52	57	53
	minimum	18	18	18	21	19	18	18	15	19	18	19	21	24
	maximum	84	86	87	87	82	87	82	91	87	85	87	85	88
	Q1-Q3	42–69	29–74	42–71	44–75	37–65	28–59	28–67	37–62	27–63	29–57	40–67	38–69	37–63
Hospitalization time in ICU (days)	median	22	26	16	30	17	20	23	14	16	15	14	14	8
	minimum	1	1	1	1	1	1	1	1	1	1	1	1	1
	maximum	136	147	124	137	48	107	106	273	126	275	205	159	238
	Q1-Q3	11–47	9–48	7–27	11–58	5–27	11–31	10–36	8–39	8–31	7–35	5–36	5–32	24
Deaths	n (%)	71 (36%)	62 (34%)	68 (31%)	57 (33%)	83 (37%)	60 (34%)	56 (33%)	64 (34%)	135 (39%)	117 (28%)	166 (39%)	160 (36%)	149 (43%)
Main diagnosis according to ICD10														
		Year												
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Other bacterial diseases [A30–A49][1]		4	4	6	3	6	3	4	4	8	11	13	12	10
Malignant neoplasms of lip, oral cavity, and pharynx [C00–C14][2]		3	5	3	4	4	3	4	3	4	4	3	5	4
Malignant neoplasms of digestive organs [C15–C26][3]		0	1	2	0	0	0	0	0	0	1	0	0	0
Malignant neoplasms of respiratory and intrathoracic organs [C30–C39][4]		0	0	1	0	0	0	0	0	1	1	0	0	0
Malignant neoplasms of lymphoid, hematopoietic, and related tissue [C81–C96][5]		4	3	4	4	4	4	3	4	7	8	6	6	5
Diabetes mellitus [E10–E14][6]		4	7	5	4	5	3	2	4	6	5	7	6	5
Obesity and other hyperalimentation [E65–E68]		0	0	1	0	1	0	0	0	2	2	3	3	1
Metabolic disorders[7]		4	2	3	0	1	0	1	1	3	0	3	4	2

Diagnoses were presented in blocks, as on the World Health Organization webpage (https://icd.who.int/browse10/2019/en)
[1] including sepsis due to other specified staphylococci (A41.1); sepsis due to anaerobes (A41.4); sepsis due to other Gram-negative organisms (A41.5); sepsis, unspecified (A41.9)
[2] including malignant neoplasm of other and unspecified parts of the tongue (C02); malignant neoplasm of other and ill-defined sites of the lip, oral cavity, and pharynx (C14)
[3] including malignant neoplasm of the stomach (C16); malignant neoplasm of the colon (C18)
[4] including malignant neoplasm of bronchus and lung (C34)
[5] including acute myeloblastic leukemia (C92.0)
[6] including diabetes mellitus with coma (E.10.0), ketoacidosis (E10.1), and multiple complications (E10.7)
[7] including acidosis (E87.2)

Table I. Continued.

	Year												
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Inflammatory diseases of the central nervous system [G00–G09][8]	3	1	2	0	4	0	0	0	2	2	3	4	2
Systemic atrophies primarily affecting the central nervous system [G10–G14][9]	0	0	1	0	0	0	0	0	0	0	0	0	0
Episodic and paroxysmal disorders [G40–G47][10]	2	3	2	0	1	0	0	1	1	2	1	2	2
Diseases of myoneural junction and muscle [G70–G73][11]	0	0	1	1	0	0	0	0	0	1	0	0	0
Cerebral palsy and other paralytic syndromes [G80–G83][12]	0	2	0	0	0	0	0	0	0	0	0	0	0
Other disorders of the nervous system [G90–G99][13]	0	0	0	0	0	0	0	0	2	1	0	0	0
Ischemic heart diseases [I20–I25][14]	3	3	4	0	3	2	2	2	4	6	6	5	4
Pulmonary heart disease and diseases of pulmonary circulation [I26–I28][15]	2	1	2	0	2	2	2	3	6	7	8	8	6
Other forms of heart disease [I30–I52][16]	36	27	25	13	27	17	16	17	24	31	27	34	28
Cerebrovascular diseases [I60–I69][17]	6	8	10	0	10	8	8	8	14	13	14	22	16
Diseases of arteries, arterioles, and capillaries [I70–I79][18]	4	2	2	0	0	0	0	0	2	1	1	0	0
Diseases of veins, lymphatic vessels, and lymph nodes [I80–I89][19]	1	0	0	0	0	0	0	0	0	0	1	0	0
Influenza and pneumonia [J09–J18][20]	1	0	3	5	5	3	2	2	5	6	6	6	4
Chronic lower respiratory diseases [J40–J47][21]	7	7	9	10	9	8	8	9	16	19	18	21	18

Diagnoses were presented in blocks, as on the World Health Organization webpage (https://icd.who.int/browse10/2019/en)

[8] including bacterial meningitis, not elsewhere classified (G00); bacterial meningoencephalitis and meningomyelitis, not elsewhere classified (G04.2); encephalitis, myelitis, and encephalomyelitis in diseases classified elsewhere

[9] including motor neuron disease (G12.2)

[10] including epilepsy (G40); status epilepticus (G41); brain stem stroke syndrome (G46.3); cerebellar stroke syndrome (G46.4)

[11] including myasthenia gravis and other myoneural disorders (G70)

[12] including cerebral palsy (G80); flaccid tetraplegia (G82.3)

[13] including encephalopathy, unspecified (G93.4)

[14] including acute myocardial infarction (I21)

[15] including pulmonary embolism (I26)

[16] including cardiac arrest with successful resuscitation (I46.0); other cardiac arrhythmias (I49); heart failure (I50)

[17] including subarachnoid hemorrhage (I60); intracerebral hemorrhage (I61); cerebral infarction (I63); stroke (I64)

[18] including abdominal aortic aneurysm, ruptured (I71.3)

[19] including embolism and thrombosis of vena cava (I82.2)

[20] including influenza with pneumonia, seasonal influenza virus identified (J10.0); bacterial pneumonia (J15); pneumonia due to other infectious organisms (J16); pneumonia, organism unspecified (J18)

[21] including other chronic obstructive pulmonary disease (J44); status asthmaticus (J46)

Table I. Continued.

	Year												
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Lung diseases due to external agents [J60–J70][22]	5	4	5	0	2	2	1	1	1	3	3	4	2
Other respiratory diseases principally affecting the interstitium [J80–J84)[23]	5	1	5	6	6	4	3	3	3	5	5	4	3
Suppurative and necrotic conditions of the lower respiratory tract [J85–J86][24]	0	1	0	0	0	0	0	0	0	2	0	1	0
Other diseases of the respiratory system [J95–J99][25]	21	10	19	44	38	28	22	19	25	30	28	37	27
Diseases of esophagus, stomach, and duodenum [K20–K31][26]	5	4	4	2	2	2	1	0	2	4	5	6	0
Hernia [K40–K46][27]	0	0	1	1	2	0	0	0	1	1	0	0	2
Other diseases of the intestines [K55–K64][28]	0	0	1	2	1	1	0	0	2	3	4	3	1
Diseases of peritoneum [K65–K67][29]	5	8	10	11	13	9	11	9	16	16	14	16	10
Diseases of the liver [K70–K77][30]	0	0	1	0	0	1	0	1	2	2	3	3	0
Disorders of gallbladder, biliary tract, and pancreas [K80–K87][31]	13	10	10	13	14	9	8	9	11	9	7	10	6
Other diseases of the digestive system [K90–K93][32]	0	0	0	0	0	0	1	1	0	0	3	2	0
Infections of the skin and subcutaneous tissue [L00–L08][33]	0	0	0	0	0	1	0	0	0	0	0	0	0
Systemic connective tissue disorders [M30 –M32][34]	0	0	0	0	0	0	0	0	0	1	0	0	0
Osteopathies and chondropathies [M80–M94][35]	0	0	0	0	0	0	0	0	0	0	0	1	0

Diagnoses were presented in blocks, as on the World Health Organization webpage (https://icd.who.int/browse10/2019/en)

[22] including pneumonitis due to food and vomit (J69.0)

[23] including adult respiratory distress syndrome (J80); other interstitial pulmonary diseases (J84)

[24] including abscess of the mediastinum (J85.3)

[25] including postprocedural respiratory disorders (J95); respiratory failure (J96)

[26] including perforation of the esophagus (K22.3); duodenal ulcer, acute with hemorrhage (K26.0), acute with hemorrhage and perforation (K26.2); gastrojejunal ulcer with hemorrhage (K28.0), hemorrhage and perforation (K28.2); acute hemorrhagic gastritis (K29)

[27] including ventral hernia (K43)

[28] including paralytic ileus and intestinal obstruction without hernia (K56)

[29] including peritonitis (K65)

[30] including toxic liver disease (K71); hepatic failure (K72)

[31] including cholelithiasis (K80); cholecystitis (K81); obstruction of the bile duct (K83.1); acute pancreatitis (K85)

[32] including gastrointestinal hemorrhage, unspecified (K92.2)

[33] including other local infections of the skin and subcutaneous tissue (L08)

[34] including systemic lupus erythematosus (M32)

[35] including osteomyelitis (M86)

Table I. Continued.

	Year												
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Injuries to the head [S00–S09][36]	5	5	7	9	9	8	11	9	27	23	23	24	16
Injuries to the neck [S10–S19][37]	0	0	0	4	0	2	3	0	2	0	0	2	0
Injuries to the thorax [S20–S29][38]	4	3	3	2	0	2	0	4	7	3	8	4	2
Injuries to the abdomen, lower back, lumbar spine, and pelvis [S30–S39][39]	2	3	3	4	4	2	0	2	10	17	23	17	9
Injuries to the shoulder and upper arm [S40–S49][40]	0	0	0	0	0	1	0	0	0	1	0	0	0
Injuries to the hip and thigh [S70–S79][41]	0	0	0	0	0	0	0	0	2	2	0	0	2
Injuries to the knee and lower leg [S80–S89][42]	0	0	1	0	0	0	0	0	0	2	0	1	0
Injuries involving multiple body regions [T00–T07][43]	44	45	53	21	32	41	48	57	101	142	145	141	134
Burns and corrosions [T20–T32][44]	4	9	6	9	16	10	11	11	19	31	29	35	26
Poisoning by drugs, medicaments, and biological substances [T36–T50][45]	0	2	1	1	2	2	0	2	1	3	2	1	0
Other and unspecified effects of external causes [T66–T78][46]	0	1	0	0	1	0	0	0	1	1	0	0	1

Diagnoses were presented in blocks, as on the World Health Organization webpage (https://icd.who.int/browse10/2019/en)

[36] including fracture of the skull and facial bones (S02); intracranial injury (S06); other and unspecified injuries of the head (S09)

[37] including open wound of the neck (S11); fracture of the neck (S12); injury of nerves and spinal cord at neck level (S14); injury of blood vessels at neck level (S15)

[38] including fracture of rib(s), sternum, and thoracic spine (S22); injury of blood vessels of the thorax (S25); injury of other and unspecified intrathoracic organs (S27); crushing injury of the thorax and traumatic amputation of part of thorax (S28)

[39] including fracture of lumbar spine and pelvis (S32); injury of blood vessels at abdomen, lower back, and pelvis level (S35); injury of intra-abdominal organs (S36)

[40] including traumatic amputation of shoulder and upper arm (S48)

[41] including fracture of the femur (S72); crushing injury of hip and thigh (S77)

[42] including crushing injury of the lower leg (S87); traumatic amputation of the lower leg (S88)

[43] including fractures involving multiple body regions (T02); crushing injuries involving multiple body regions (T04); other injuries involving multiple body regions (T06); multiple unspecified injuries (T07)

[44] including burn and corrosion of head and neck (T20); burn and corrosion of trunk (T21); burn and corrosion of respiratory tract (T27); burn and corrosion of other internal organs (T28); burns and corrosions of multiple body regions (T29); burns classified according to the extent of body surface involved (T31)

[45] including poisoning by narcotics and psychodysleptics [hallucinogens] (T40)

[46] including hypothermia (T68); drowning and nonfatal submersion (T75.1); effect of electric current (T75.8); anaphylactic shock (T78.2)

Table II
The number of microbiological analyses, with their results, performed between 2007 and 2019.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Beds in ICU (n)	8	8	8	8	8	8	8	14	18	18	18	18	18
Hospitalizations (n)	179	182	216	173	224	178	172	186	350	422	422	450	348
Microbiological analyses (n)	2,361	2,349	2,710	2,454	3,123	2,796	2,797	2,811	4,093	5,376	5,030	5,089	5,264
Microbiological analyses of blood samples (n)	670	613	785	641	1,245	1,016	944	831	1,219	1,326	988	1,161	1,180
Blood microbiological analyses, negative results (n)	548	473	632	534	1,130	889	809	690	1,064	1,140	858	1,023	994
Blood microbiological analyses, positive results (n)	107	120	135	97	104	99	106	112	120	154	104	106	145
Blood microbiological analyses, contaminated samples (n)	15	20	18	10	11	28	29	29	35	32	26	32	41
Microbiological analyses of the tip of the catheter (n)	30	23	28	18	39	29	45	53	70	70	76	77	65
Microbiological analyses of the tip of the catheter, positive results (n)	13	11	17	12	21	11	31	30	20	29	31	26	26

resistance to antimicrobial agents. In such cases, colistin was virtually the only therapeutic choice. In the last two years of the period analyzed, all *P. aeruginosa* isolates were susceptible to ceftazidime, cefepime, and gentamycin.

The most frequently isolated species of Enterobacterales were *K. pneumoniae* (165 isolates) and *E. coli* (69 isolates). More than 40% (67/165) of *K. pneumoniae* strains and more than 16% of *E. coli* (11/69) exhibited an ESBL mechanism of resistance. Fortunately, all these pathogens were susceptible to meropenem, and only six of these isolates produced carbapenemases.

We had a broad spectrum of therapeutic options for fungal infection treatment. *Candida albicans* isolates

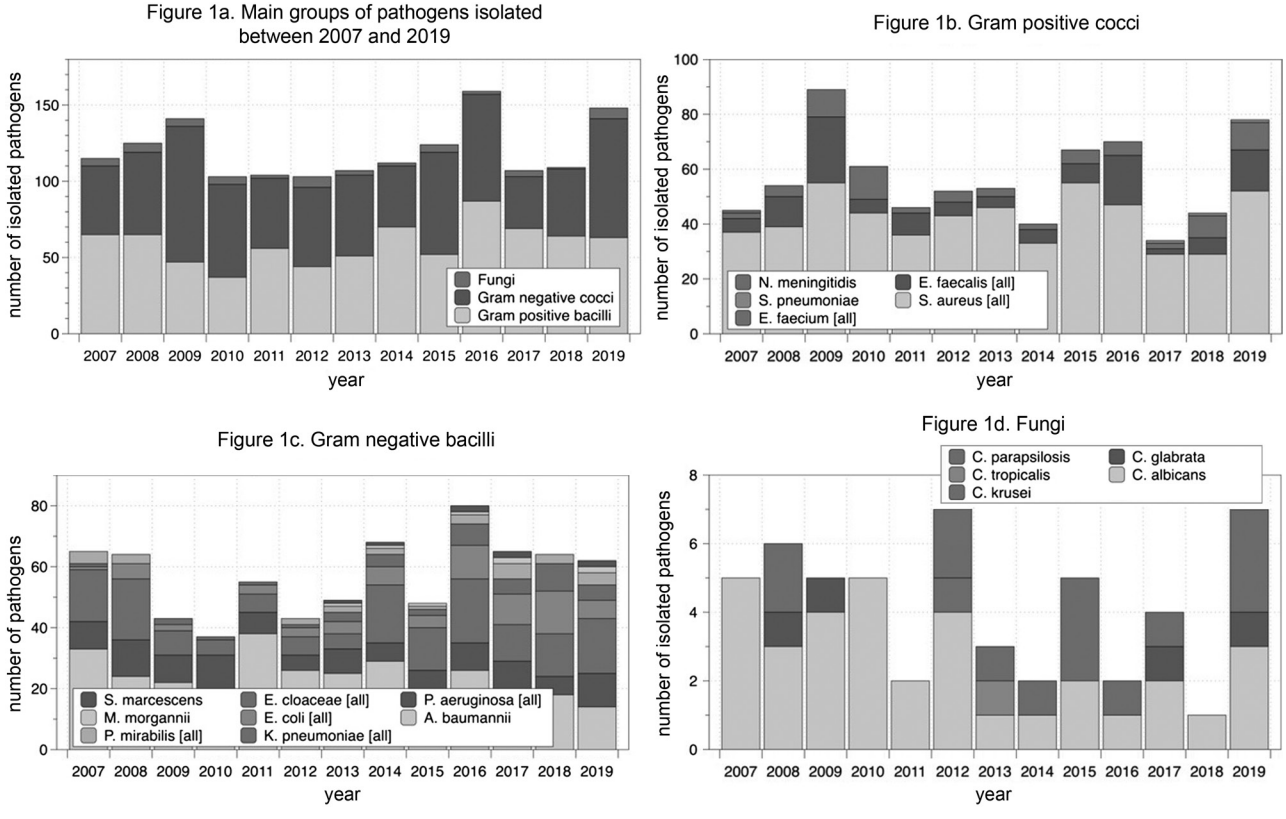

Fig. 1. Trends in pathogens isolated between 2007 and 2019.

Table III
The number of pathogens isolated from blood samples between 2007 and 2019.

Pathogen (mechanism of antibiotic resistance)		2007	2008	2009	2010	2011	2011	2012	2013	2014	2015	2016	2017	2018	Total
Gram-negative bacilli	*Acinetobacter baumannii*	33	24	22	19	38	26	25	29	18	26	20	18	14	312
	Pseudomonas aeruginosa	9	12	9	12	7	5	7	6	8	8	9	6	11	109
	Pseudomonas aeruginosa (MBL)	0	0	0	0	0	0	1	0	0	1	0	0	0	2
	Stenotrophomonas maltophila	0	0	4	0	1	1	2	2	4	7	4	0	1	26
	Klebsiella pneumoniae	6	8	5	2	4	2	4	9	7	14	6	8	13	88
	Klebsiella pneumoniae (ESBL)	11	8	3	3	2	4	1	10	7	7	4	5	2	67
	Klebsiella pneumoniae (NDM)	0	0	0	0	0	0	0	0	0	0	2	1	2	5
	Klebsiella pneumoniae (KPC)	0	4	0	0	0	0	0	0	0	0	0	0	0	4
	Klebsiella pneumoniae (OXA 48)	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	Escherichia coli	1	3	2	0	3	3	4	6	4	9	7	11	5	58
	Escherichia coli (ESBL)	0	2	0	0	0	0	0	0	0	2	3	3	1	11
	Enterobacter cloacae	1	0	1	0	1	1	3	3	2	5	5	7	5	34
	Enterobacter cloacae (ESBL)	0	0	1	1	0	0	0	1	0	2	0	2	0	7
	Proteus mirabilis	0	1	0	0	0	2	2	2	1	3	3	3	4	21
	Proteus mirabilis (ESBL)	4	3	0	0	0	0	0	0	0	0	2	0	0	9
	Morganella morgani	0	0	0	0	0	0	1	1	1	1	2	0	2	8
	Serratia marcescens	0	0	0	0	0	0	1	1	0	2	2	0	2	8
Gram-positive cocci	*Staphylococcus aureus*	1	5	1	3	7	3	3	3	4	4	4	9	18	65
	Staphylococcus aureus (MRSA)	3	7	15	3	5	4	2	3	7	3	2	4	0	58
	Coagulase-negative Staphylococcus (CNS)	2	2	5	3	2	2	6	4	6	12	5	1	4	54
	Coagulase-negative Staphylococcus (MRCNS)	31	25	34	35	22	34	35	23	38	28	18	15	30	368
	Enterococcus faecalis	5	8	15	5	5	5	4	5	6	16	2	6	13	95
	Enterococcus faecalis (HLAR)	0	3	9	0	3	0	0	0	1	2	0	0	2	20
	Enterococcus faecium	1	2	9	5	1	2	1	0	4	3	0	2	7	37
	Enterococcus faecium (VRE)	0	1	0	1	0	0	1	1	0	1	2	3	1	11
	Enterococcus faecium (HLAR)	1	1	1	6	1	2	1	1	1	1	0	3	2	21
	Streptococcus pneumoniae	0	0	0	0	0	0	0	0	0	0	1	1	1	3
	Neisseria meningitidis	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Fungi	*Candida albicans*	5	3	4	5	2	4	1	1	2	1	2	1	3	34
	Candida glabrata	0	1	1	0	0	0	0	0	0	0	1	0	1	4
	Candida krusei	0	0	0	0	0	1	0	0	0	0	0	0	0	1
	Candida tropicalis	0	0	0	0	0	0	1	0	0	0	0	0	0	1
	Candida parapsilosis	0	2	0	0	0	2	1	1	3	1	1	0	3	14
	Total	115	125	141	103	104	103	107	112	124	159	107	109	148	1,557

were completely susceptible to fluconazole and *non-albicans Candida* species were susceptible to echinocandins and amphotericin.

Discussion

Bloodstream infections may lead to metastatic infections, severe sepsis, and multiorgan failure. The prevalence of bloodstream infections is estimated at 174–204/100,000 in North America and 166–189/100,000 in Europe, corresponding to 73,349–84,823 cases in the USA and 157,750–276,318 in Europe (Goto and Al-Hasan 2013). CVCs may be related to BSIs in 90% of cases (Polderman and Girbes 2002).

Possible reasons for this strong correlation include lack of asepsis upon catheter insertion and use, skin changes (e.g., burn-related), the biofilm formation on the catheter's inner and outer surfaces, and the development of central vein thrombosis at the site of the catheter insertion. The only way to decrease the number of CLABSI cases is to ensure rigorous asepsis when the

Table IV
Resistance of Gram-negative pathogens to antimicrobial agents.

Antimicrobial agent	*Pseudomonas aeruginosa*												
	2007 n = 9	2008 n = 12	2009 n = 9	2010 n = 12	2011 n = 7	2012 n = 5	2013 n = 7	2014 n = 6	2015 n = 8	2016 n = 8	2017 n = 9	2018 n = 6	2019 n = 11
Ceftazidime	2	4	3	0	0	0	1	0	0	2	1	0	0
Cefepime	0	3	0	0	1	1	2	0	0	3	1	0	0
Piperacillin/tazobactam	1	1	5	0	0	1	1	0	1	4	1	0	0
Gentamycin	5	4	5	1	3	2	3	0	0	4	0	0	0
Ciprofloxacin	6	3	5	0	2	2	2	2	2	5	3	2	0
Imipenem	3	2	4	4	2	1	2	0	2	5	4	3	7
Meropenem	3	0	4	3	2	1	2	0	1	4	4	3	7
	Acinetobacter baumannii												
	2007 n = 33	2008 n = 24	2009 n = 22	2010 n = 19	2011 n = 38	2012 n = 26	2013 n = 25	2014 n = 29	2015 n = 18	2016 n = 26	2017 n = 20	2018 n = 18	2019 n = 14
Gentamycin	30	22	7	11	29	24	22	25	16	18	13	15	8
Ciprofloxacin	32	24	21	19	34	25	23	29	18	25	20	18	14
Imipenem	11	6	10	11	31	23	21	28	17	25	19	17	10
Meropenem	6	6	8	11	31	23	21	28	17	25	19	17	10
Trimethoprim-sulfamethoxazole	20	18	16	19	36	24	15	27	16	25	20	17	10
Ampicillin/sulbactam	12	12	8	12	19	3	9	20	16	nd	nd	nd	nd
Colistin	–	–	–	–	–	–	–	–	0	0	0	0	0
	Stenotrophomonas maltophila												
	2007 n = 0	2008 n = 0	2009 n = 4	2010 n = 0	2011 n = 1	2012 n = 1	2013 n = 2	2014 n = 2	2015 n = 4	2016 n = 7	2017 n = 4	2018 n = 0	2019 n = 1
Trimethoprim-sulfamethoxazole	–	–	0	–	0	0	0	0	0	0	0	–	0
	ESBL-negative Enterobacterales												
	2007 n = 8	2008 n = 12	2009 n = 8	2010 n = 2	2011 n = 8	2012 n = 9	2013 n = 15	2014 n = 22	2015 n = 15	2016 n = 34	2017 n = 25	2018 n = 29	2019 n = 31
Ceftazidime	0	0	0	0	0	0	0	0	0	0	0	0	0
Cefepime	0	0	0	0	0	0	0	0	0	0	0	0	0
Ciprofloxacin	0	3	3	0	1	0	5	1	2	10	6	4	5
Gentamycin	0	2	0	0	0	0	0	0	0	2	0	2	5
Piperacillin/tazobactam	0	0	1	0	0	0	1	1	0	0	1	4	8
Trimethoprim-sulfamethoxazole	3	2	3	1	1	1	6	1	0	3	4	2	4
	ESBL-positive Enterobacterales												
	2007 n = 15	2008 n = 13	2009 n = 4	2010 n = 4	2011 n = 2	2012 n = 4	2013 n = 1	2014 n = 11	2015 n = 7	2016 n = 11	2017 n = 9	2018 n = 10	2019 n = 3
Amoxicillin/clavulanate	12	9	3	4	2	4	1	11	6	8	9	10	3
Gentamycin	10	9	3	4	2	4	1	8	7	7	6	8	2
Ciprofloxacin	13	11	4	4	2	4	1	11	7	11	9	10	3
Imipenem	4	3	0	0	0	0	0	0	0	0	2	0	0
Meropenem	0	0	0	0	0	0	0	0	0	0	0	0	0
Trimethoprim-sulfamethoxazole	13	9	2	3	1	3	1	9	5	11	9	8	3
	KPC-producing *Klebsiella pneumoniae*												
	2007 n = 0	2008 n = 4	2009 n = 0	2010 n = 0	2011 n = 0	2012 n = 0	2013 n = 0	2014 n = 0	2015 n = 0	2016 n = 0	2017 n = 0	2018 n = 0	2019 n = 0
Amikacin	–	0	–	–	–	–	–	–	–	–	–	–	–
Gentamicin	–	0	–	–	–	–	–	–	–	–	–	–	–
Tigecycline	–	2	–	–	–	–	–	–	–	–	–	–	–
Trimethoprim-sulfamethoxazole	–	4	–	–	–	–	–	–	–	–	–	–	–
Colistin	–	0	–	–	–	–	–	–	–	–	–	–	–

Table IV. Continued.

Antimicrobial agent	NDM-producing *Klebsiella pneumoniae*												
	2007 n = 0	2008 n = 0	2009 n = 0	2010 n = 0	2011 n = 0	2012 n = 0	2013 n = 0	2014 n = 0	2015 n = 0	2016 n = 0	2017 n = 2	2018 n = 1	2019 n = 2
Amikacin	–	–	–	–	–	–	–	–	–	–	2	1	2
Gentamicin	–	–	–	–	–	–	–	–	–	–	1	1	1
Tigecycline	–	–	–	–	–	–	–	–	–	–	2	1	0
Trimethoprim-sulfamethoxazole	–	–	–	–	–	–	–	–	–	–	1	1	1
Colistin	–	–	–	–	–	–	–	–	–	–	0	0	0
	OXA48-producing *Klebsiella pneumoniae*												
	2007 n = 0	2008 n = 0	2009 n = 0	2010 n = 0	2011 n = 0	2012 n = 0	2013 n = 0	2014 n = 0	2015 n = 0	2016 n = 0	2017 n = 0	2018 n = 0	2019 n = 1
Amikacin	–	–	–	–	–	–	–	–	–	–	–	–	0
Gentamicin	–	–	–	–	–	–	–	–	–	–	–	–	1
Tigecycline	–	–	–	–	–	–	–	–	–	–	–	–	1
Trimethoprim-sulfamethoxazole	–	–	–	–	–	–	–	–	–	–	–	–	1
Colistin	–	–	–	–	–	–	–	–	–	–	–	–	0

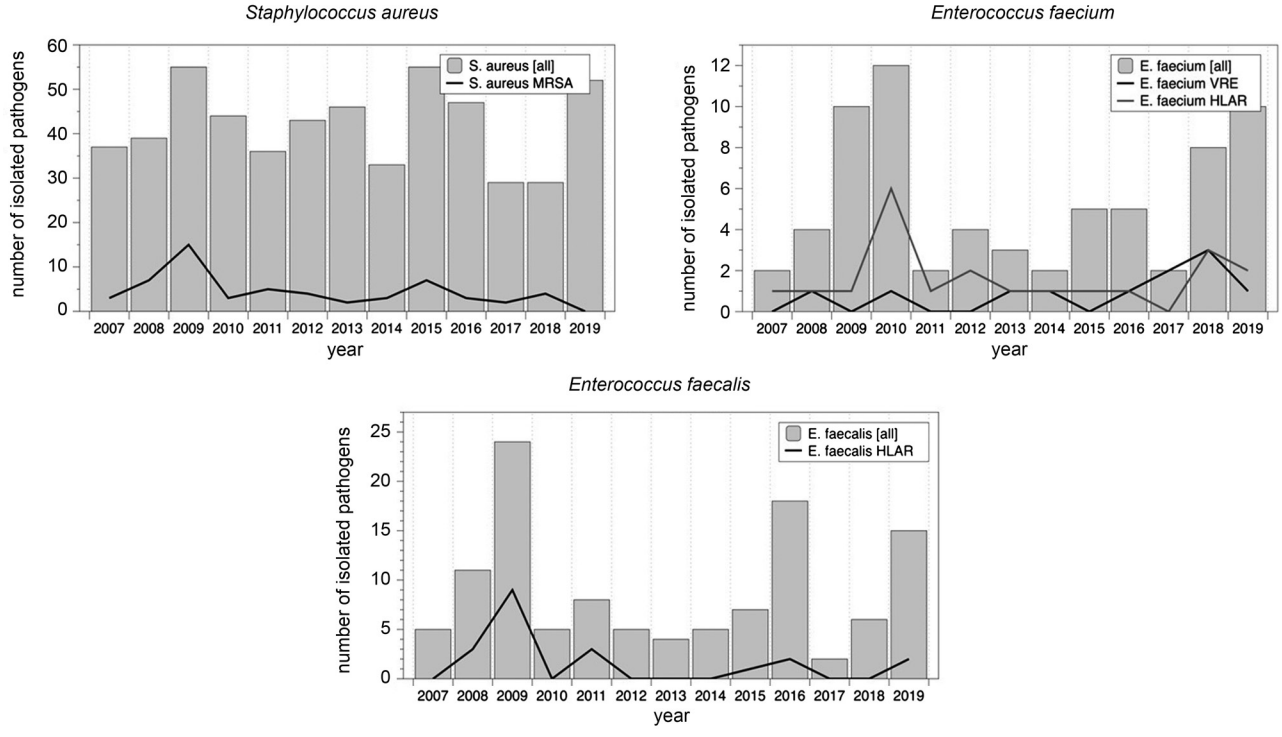

Fig. 2. Gram-positive alert pathogens with mechanisms of resistance, isolated between 2009 and 2019.

catheter is placed and used (Ling et al. 2016; Bell and O'Grady 2017; Ielapi et al. 2020).

Our work has been one of the most extensive single-center analyses performed in Poland in recent years. The study was conducted over a long period in a multibed tertiary hospital, a regional trauma center that gives credibility to the results and allows their generalization. The authors of this study believe that analyzing the microbiological situation in single centers may help make up a complete picture of both microbiological hazards and therapeutic possibilities on the national and regional levels. Our analysis was performed at a multidisciplinary ICU, with most of the cases being surgical and trauma patients. Some of them may be immunocompromised; in such patients, the transfer of pathogens from the site of infection to the lumen of the catheter via different connectors may be reasonably easy, resulting in more facile development and progression of a disease.

The data suggest that one in 20 ICU patients develop bloodstream infections. The longer the period of central vein catheterization, the higher the incidence of

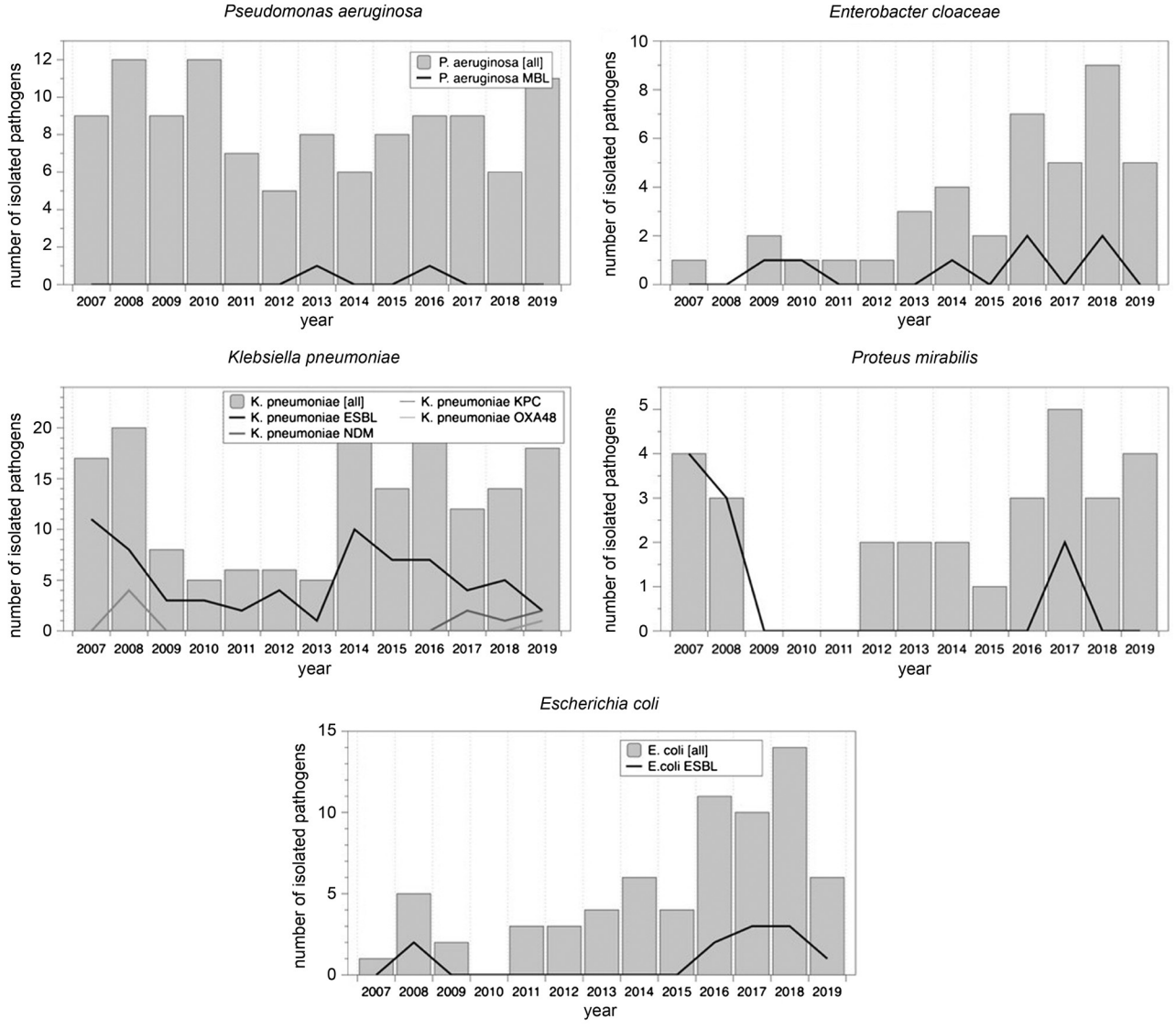

Fig. 3. Gram-negative alert pathogens with mechanisms of resistance, isolated between 2009 and 2019.

catheter infection (Gunst et al. 2011). We found that the incidence of positive microbiological results in blood samples was 12.8%. Those values are relatively low compared to the results of other studies which report positive results in 18.9% to 31.3% of cases (Rani et al. 2012; Musicha et al. 2017; Rani et al. 2017). This discrepancy may be due to the procedures at our center, where patient blood samples are analyzed microbiologically every time the patient's body temperature exceeds 38°C. Some studies from ICUs in southern Poland report a lower incidence of BSI (Wałaszek et al. 2018). However, the spectrum of pathogens isolated from blood samples was similar to our results, including *A. baumannii*, coagulase-negative staphylococci, *E. coli*, *P. aeruginosa*, *K. pneumoniae*, and *C. albicans* (Kołpa et al. 2018; Wałaszek et al. 2018).

The etiology of bloodstream infection depends on the geographical localization of the hospital. For example, in Malawi (Africa), the most common BSI pathogens are *Salmonella* Typhi and *Streptococcus pneumoniae* (Musicha et al. 2017). The Surveillance Network data from Korea collected from 2006 to 2017 showed that the most common pathogens were *E. coli* and *S. aureus*. In Japan, *E. coli*, *S. aureus*, and *K. pneumoniae* are the most common isolates (Rani et al. 2017; Lee et al. 2018).

Data from the European Antimicrobial Resistance Surveillance Network study performed in 22 countries between 2000 and 2009 indicated that *E. coli* and *S. aureus* were the most common BSI pathogens (Gagliotti et al. 2011). The results of a EUROBACT study spanning 162 ICUs in 24 European countries and Turkey, Brazil, and China showed that in 53%, 32%, 7.8%, and 1.2% of cases, bacteremia was caused by Gram-negative bacteria, Gram-positive pathogens, fungi, and anaerobic bacteria, respectively. Multidrug-resistant pathogens were isolated in 47.8% of cases (Tabah et al. 2012). Our results were similar, although there were some differences in the exact numbers of

isolated pathogens (49.5% Gram-negative strains, 47.1% Gram-positive strains, and 3.5% fungi).

Gram-positive pathogens were responsible for half of all bloodstream infections. Most of them were staphylococci. Their resistance to methicillin ranges from 40 to 60%. of importance is that MRCNS are a more likely etiological factor in infection than MRSA (Gunst et al. 2011; Louzi et al. 2016; Tian et al. 2019; Tomaszewski et al. 2019). Our results supported this observation. Moreover, MRCNS exhibit greater resistance to antimicrobials, except against vancomycin. We also noted the difference in resistance to gentamycin and trimethoprim/sulfamethoxazole. Such differences may result from the different proportions of branched-chain and straight-chain fatty acids in the membrane lipids of bacteria (Tiwari et al. 2020). However, susceptibility to sulphonamide is significant clinically because the drug can be administered orally, which may be necessary in patients who suffer from staphylococcal bone infections and require proper therapy for an extended time.

In many studies, Gram-negative pathogens responsible for more than half of bloodstream infections pose a greater therapeutic challenge than Gram-positive bacteria, partially due to their increasing antibiotic resistance. Enterobacterales produce ESBL and CPE mechanisms of resistance. Both *Acinetobacter* spp. and *Pseudomonas* spp. exhibit mechanisms of resistance that are multidirectional and difficult to treat.

In our study, Gram-negative bacteria were isolated in 49.5% of cases. The most frequently isolated was *A. baumannii* (40.5%), followed by *K. pneumoniae* (21.4%), *P. aeruginosa* (14.1%), and *E. coli* (9%). These results differ significantly from those found in an analysis of 9,334 strains of *A. baumannii* performed between 1994 and 2011 (Munoz-Price et al. 2013), during which time this pathogen was responsible for 11% of blood infections. This situation is alarming because the only effective antimicrobial against this pathogen is colistin.

Among the Gram-negative bacteria, 30.4% were *K. pneumoniae* or *E. coli*. The ESBL mechanism of resistance was found in 40.6% of *K. pneumoniae* and 16% of *E. coli*. These results are similar to those found by other researchers. According to the literature, the ESBL mechanism of resistance is present in 34–75% of *K. pneumoniae* and is increasingly common (Gunst et al. 2011; Louzi et al. 2016; Tian et al. 2019). Fortunately, we found this pathogen to be entirely susceptible to meropenem. Moreover, only a small number of the isolated *K. pneumoniae* exhibited a KPC resistance mechanism.

There are a few significant limitations to our study. The first group of constraints is related to other observational studies with routinely collected electronic data. They include missing data, potential bias, and possible misclassification or inconsistencies in medical coding. The second one is related to the indication for blood sample collection. In our center, blood samples were collected when the infection was suspected clinically. It cannot be ruled out that some patients' pathogens were present in their bloodstream with no clinical and bacteriological signs and symptoms of infection. The third one is related to the setting of this study: our analysis is connected to only one hospital, although a large one. Finally, assessing the results with some differences in patient-level factors, such as the severity of illness, may have influenced the conclusions.

Despite the limitations mentioned earlier, we believe that our results may be informative and exciting for those interesting in the epidemiology of BSI. Our study estimated bloodstream infections in a large tertiary university hospital and trauma center for 13 years, as incidence rates and pathogens' distribution, and their susceptibility/resistance to antimicrobial agents. The presented data may constitute material for further analyses assessing the microbiological situation in Poland and the region to improve the quality of care and outcome in critically ill patients.

Conclusions

Our 13-year study shows that among 12,619 microbiologically analyzed blood samples, 12% (1,509/12,619) were positive. In 278/1,509 (18.4%) of cases, a central line catheter infection was confirmed, and 1,557 pathogens were isolated.

The most frequently (770/1,557; 49.5%) isolated species were Gram-negative bacteria. Among the Gram-negative bacteria, the most frequently isolated were *A. baumannii* (312/770; 40.5%), *K. pneumoniae* (165/770 (24.1%); 67/165 (40.6%) of them produced ESBL, 5/165 (3%) – produced NDM, 4/165 (3.4%) – expressed KPC, 1/165 (0.6%) – produced OXA48), *P. aeruginosa* (111/770 (14.4%); 2/111 (1.8%) strains produced MBL), and *E. coli* (69/770 (9%); 11/69 (15.9%) strains expressed ESBL).

Gram-positive pathogens were isolated in 733/1,557 (47.1%) cases. The majority were staphylococci (545/733; 74.4%), mainly coagulase-negative (368/545; 67.5%). MRSA species represented 58/545 (10.6%) of all staphylococci. Fungi were isolated from 3.5% of samples.

Using these data to improve clinical practice, one can say that the MRSA and MRCNS species are susceptible to vancomycin, MSSA is susceptible to isoxazolyl penicillins, and VRE is susceptible to linezolid and tigecycline. However, colistin remains the only therapeutic option in some infections caused by *A. baumannii* and KPC-producing *K. pneumoniae*. *P. aeruginosa* is still susceptible to cefepime and ceftazidime. Echinocandins are effective therapeutics in treating fungal infections caused by *C. albicans* and *non-albicans Candida* species.

The bacteriological situation in our department, assessed by the incidence of infections, is similar to other ICUs in Poland and Eastern Europe. However, the number of *A. baumannii* and *P. aeruginosa* among the isolated pathogens is disturbing. We implemented and followed the infection control procedures. They include the decontamination of the patient environment, prevention of secondary contamination, personnel training, compliance control, hand hygiene, and clothing policy. We also follow the central catheter procedures. They emphasize full aseptic, and the additional connections are reduced to a minimum. A separate catheter lumen is reserved for parenteral nutrition, and the administration of drugs takes place after the disinfection of the connectors.

The applied infection reduction procedures follow the existing recommendations (Hryniewicz et al. 2013). In addition to the guidelines, it is essential to be aware of the infections, severity of the problem, prevention methods, and the real benefits of compliance with the recommendations that translate into a reduction in the frequency of infections in intensive care units.

List of abbreviations

BSI – bloodstream Infection
CLABSI – central line-associated bloodstream infections
CVC – central venous catheter
ESBL – extended-spectrum beta-lactamases
HLAR – high-level aminoglycoside resistance
ICD – International Classification of the Diseases
ICU – intensive care unit
KPC – *Klebsiella pneumoniae* carbapenemase
MBL – metallo-β-lactamases
MRSA – methicillin-resistant *Staphylococcus aureus*
MRCNS – methicillin-resistant coagulase-negative *Staphylococcus*
MSSA – methicillin-susceptible *Staphylococcus aureus*
NDM – New Delhi metallo-β-lactamase
VRE – vancomycin-resistant enterococci

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Ethical statement

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the Military Institute of Medicine, Warsaw, Poland (43/WIM/2020 of August 19, 2020).

Author contributions

Conceptualization, AG, ZR, and DT; methodology, AG; formal analysis, AG and DT; investigation, AG; data curation, A.W-K.; writing-original draft preparation, AG, ZR, and DT; writing-review and editing, AG, ZR, A.W-K, and DT; visualization, DT; project administration, AG, ZR, DT, and A.W-K. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors do not report any financial or personal connections with other persons or organizations, which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

Literature

Bell T, O'Grady NP. Prevention of central line-associated bloodstream infections. Infect Dis Clin North Am. 2017 Sep;31(3):551–559. https://doi.org/10.1016/j.idc.2017.05.007

Blot K, Vogelaers D, Blot S. Central line-associated bloodstream infections: A critical look at the role and research of quality improvement interventions and strategies. In: Vincent JL, editor. Annual update in intensive care and emergency medicine. Cham (Switzerland): Springer Cham; 2015. p. 15–24. https://doi.org/10.1007/978-3-319-13761-2_2

Brun-Buisson C, Abrouk F, Legrand P, Huet Y, Larabi S, Rapin M. Diagnosis of central venous catheter-related sepsis. Critical level of quantitative tip cultures. Arch Intern Med. 1987 May 01;147(5): 873–877. https://doi.org/10.1001/archinte.1987.00370050069012

CLSI. Performance standards for antimicrobial susceptibility testing. 19th ed. CLSI supplement M100-S19. Wayne (USA): Clinical and Laboratory Standards Institute; 2009.

CLSI. Performance standards for antimicrobial susceptibility testing. 20th ed. CLSI supplement M100-S20. Wayne (USA): Clinical and Laboratory Standards Institute; 2010a.

CLSI. Performance standards for antimicrobial susceptibility testing. 20th ed. (June 2010, Update). CLSI supplement M100-S20-U. Wayne (USA): Clinical and Laboratory Standards Institute; 2010b.

EUCAST. EUCAST guideline for the detection of resistance mechanisms and specific resistances of clinical and/or epidemiological importance. Version 1.0. Basel (Switzerland): The European Committee on Antimicrobial Susceptibility Testing; 2013 [cited 2022 Jan 26]. Available from https://www.eucast.org/resistance_mechanisms/

EUCAST. EUCAST guideline for the detection of resistance mechanisms and specific resistances of clinical and/or epidemiological importance. Version 2.0. Basel (Switzerland): The European Committee on Antimicrobial Susceptibility Testing; 2017 [cited 2022 Jan 26]. Available from https://www.eucast.org/resistance_mechanisms/

Gagliotti C, Balode A, Baquero F, Degener J, Grundmann H, Gür D, Jarlier V, Kahlmeter G, Monen J, Monnet DL, et al.; EARS-Net Participants (Disease Specific Contact Points for AMR). *Escherichia coli* and *Staphylococcus aureus*: bad news and good news from the European Antimicrobial Resistance Surveillance Network (EARS-Net, formerly EARSS), 2002 to 2009. Euro Surveill. 2011 Mar 17;16(11):19819. https://doi.org/10.2807/ese.16.11.19819-en

Goto M, Al-Hasan MN. Overall burden of bloodstream infection and nosocomial bloodstream infection in North America and Europe. Clin Microbiol Infect. 2013 Jun;19(6):501–509. https://doi.org/10.1111/1469-0691.12195

Gunst M, Matsushima K, Vanek S, Gunst R, Shafi S, Frankel H. Peripherally inserted central catheters may lower the incidence of catheter-related blood stream infections in patients in surgical intensive care units. Surg Infect (Larchmt). 2011 Aug;12(4):279–282. https://doi.org/10.1089/sur.2008.058

Holm MKA, Jansåker F, Gradel KO, Nielsen RT, Østergaard Andersen C, Jarløv JO, Schønheyder HC, Dahl Knudsen J. Decrease in all-cause 30-day mortality after bacteraemia over a 15-year period: a population-based cohort study in Denmark in 2000–2014. Int J Environ Res Public Health. 2021 Jun 2;18(11):5982. https://doi.org/10.3390/ijerph18115982

Hryniewicz W, Kusza K, Ozorowski T, Misiewska-Kaczur A, Fleischer M, Trejnowska E, Deptuła A. [Strategia zapobiegania lekooporności w oddziałach intensywnej terapii. Rekomendacje profilaktyki zakażeńw oddziałach intensywnej terapii] (in Polish). Warsaw (Poland): National Medicines Institute; 2013.

Ielapi N, Nicoletti E, Lorè C, Guasticchi G, Avenoso T, Barbetta A, de Franciscis S, Andreucci M, Sapienza P, Serra R. The Role of biofilm in central venous catheter related bloodstream infections:

Evidence-based nursing and review of the literature. Rev Recent Clin Trials. 2020;15(1):22–27. https://doi.org/10.2174/1574887114666191018144739

Kołpa M, Wałaszek M, Gniadek A, Wolak Z, Dobroś W. Incidence, microbiological profile and risk factors of healthcare-associated infections in intensive care units: A 10 year observation in a provincial hospital in southern Poland. Int J Environ Res Public Health. 2018 Jan 11;15(1):112. https://doi.org/10.3390/ijerph15010112

Lee H, Yoon EJ, Kim D, Jeong SH, Won EJ, Shin JH, Kim SH, Shin JH, Shin KS, Kim YA, et al. 2018. Antimicrobial resistance of major clinical pathogens in South Korea, May 2016 to April 2017: first one-year report from Kor-GLASS. Euro Surveill. 2018 Oct; 23(42):1800047. https://doi.org/10.2807/1560-7917.ES.2018.23.42.1800047

Ling ML, Apisarnthanarak A, Jaggi N, Harrington G, Morikane K, Thu LTA, Ching P, Villanueva V, Zong Z, Jeong JS, et al. APSIC guide for prevention of Central Line Associated Bloodstream Infections (CLABSI). Antimicrob Resist Infect Control. 2016 Dec;5(1):16. https://doi.org/10.1186/s13756-016-0116-5

Louzi L, Doblali T, Sbiti M, L'Kassmi H. Microbiological and resistance patterns of blood cultures clinical isolates at Moulay Ismail Military Hospital of Meknes, Morocco. A four-year period retrospective study: 2011–2014. JSM Microbiol. 2016;4(1):1030.

Maki DG, Weise CE, Sarafin HW. A semiquantitative culture method for identifying intravenous-catheter-related infection. N Engl J Med. 1977 Jun 09;296(23):1305–1309. https://doi.org/10.1056/NEJM197706092962301

Massart N, Wattecamps G, Moriconi M, Fillatre P. Attributable mortality of ICU acquired bloodstream infections: a propensity-score matched analysis. Eur J Clin Microbiol Infect Dis. 2021 Aug; 40(8):1673–1680. https://doi.org/10.1007/s10096-021-04215-4

Munoz-Price LS, Arheart K, Nordmann P, Boulanger AE, Cleary T, Alvarez R, Pizano L, Namias N, Kett DH, Poirel L. Eighteen years of experience with Acinetobacter baumannii in a tertiary care hospital. Crit Care Med. 2013 Dec;41(12):2733-42. https://doi.org/10.1097/CCM.0b013e318298a541

Musicha P, Cornick JE, Bar-Zeev N, French N, Masesa C, Denis B, Kennedy N, Mallewa J, Gordon MA, Msefula CL, et al. Trends in antimicrobial resistance in bloodstream infection isolates at a large urban hospital in Malawi (1998–2016): a surveillance study. Lancet Infect Dis. 2017 Oct;17(10):1042–1052. https://doi.org/10.1016/S1473-3099(17)30394-8

O'Grady NP, Alexander M, Burns LA, Dellinger EP, Garland J, Heard SO, Lipsett PA, Masur H, Mermel LA, Pearson ML, et al.; Healthcare Infection Control Practices Advisory Committee (HICPAC). Guidelines for the prevention of intravascular catheter-related infections. Clin Infect Dis. 2011 May 01;52(9):e162–e193. https://doi.org/10.1093/cid/cir257

Polderman K, Girbes A. Central venous catheter use. Intensive Care Med. 2002 Jan;28(1):18–28. https://doi.org/10.1007/s00134-001-1156-7

Rani RD, Chaitanya SB, Rajappa SJ, Kumar BR, Prabhakar KK, Mohan KM, Nayak VK, Kumar P, Santa A, Rao S. Retrospective analysis of blood stream infections and antibiotic susceptibility pattern of gram negative bacteria in a Tertiary Care Cancer Hospital. Int J Med Res Health Sci. 2017;6(12):19–26.

Rani VN, Gopal K, Narendra VM, Vishwakanth D, Nagesh V, Yogitha M, Sunil VM, Palani T. A retospective study on blood stream infections and antibiotic susceptibility patterns in a tertiary care teaching hospital. Int J Pharm Pharm Sci. 2012;4(1):543–548.

Salm F, Schwab F, Behnke M, Brunkhorst FM, Scherag A, Geffers C, Gastmeier P. Nudge to better care – blood cultures and catheter-related bloodstream infections in Germany at two points in time (2006, 2015). Antimicrob Resist Infect Control. 2018 Dec; 7(1):141. https://doi.org/10.1186/s13756-018-0432-z

Tabah A, Koulenti D, Laupland K, Misset B, Valles J, Bruzzi de Carvalho F, Paiva JA, Çakar N, Ma X, Eggimann P, et al. Characteristics and determinants of outcome of hospital-acquired bloodstream infections in intensive care units: the EUROBACT International Cohort Study. Intensive Care Med. 2012 Dec;38(12): 1930–1945. https://doi.org/10.1007/s00134-012-2695-9

Tajima T, Asai Y, Endo M, Suzuki T, Matsunaga N, Tsuzuki S, Hayakawa K, Ohmagari N. Rate of blood culture submissions in Japan as an indicator of bloodstream infections. J Infect Chemother. 2021 Aug;27(8):1270–1272. https://doi.org/10.1016/j.jiac.2021.04.019

Tian L, Zhang Z, Sun Z. Antimicrobial resistance trends in bloodstream infections at a large teaching hospital in China: A 20-year surveillance study (1998–2017). Antimicrob Resist Infect Control. 2019 Dec;8(1):86. https://doi.org/10.1186/s13756-019-0545-z

Tiwari KB, Gatto C, Wilkinson BJ. Plasticity of coagulase-negative staphylococcal membrane fatty acid composition and implications for responses to antimicrobial agents. Antibiotics (Basel). 2020 Apr 28;9(5):214. https://doi.org/10.3390/antibiotics9050214

Tomaszewski D, Rybicki Z, Duszyńska W. The Polish Prevalence of Infection in Intensive Care (PPIC): A one-day point prevalence multicenter study. Adv Clin Exp Med. 2019 Apr 13;28(7):907–912. https://doi.org/10.17219/acem/94147

Wałaszek M, Różańska A, Bulanda M, Wojkowska-Mach J; Polish Society of Hospital Infections Team. Alarming results of nosocomial bloodstream infections surveillance in Polish intensive care units. Przegl Epidemiol. 2018;72(1):33–44.

Watson D, Spaulding AB, Dreyfus J. Risk-set matching to assess the impact of hospital-acquired bloodstream infections. Am J Epidemiol. 2019 Feb 01;188(2):461–466. https://doi.org/10.1093/aje/kwy252