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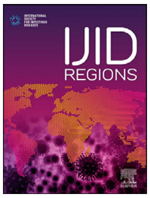

Bacterial contamination rates and drug susceptibility patterns of bacteria recovered from medical equipment, inanimate surfaces, and indoor air of a neonatal intensive care unit and pediatric ward at Hawassa University Comprehensive Specialized Hospital, Ethiopia

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ABSTRACT

Introduction: Bacterial contamination of medical equipment, inanimate surfaces, and indoor air of the hospital environment is the main source of hospital-acquired infection in developing countries.
Objective: The aim of this study was to determine the bacterial contamination rates for medical equipment, inanimate surfaces, and indoor air, and the drug susceptibility profiles of bacteria, in the neonatal intensive care unit and pediatric ward of Hawassa University Comprehensive Specialized Hospital (HUCSH).
Methods: A hospital-based cross-sectional study was carried out from October 20 to December 30, 2020. Samples were collected from medical equipment, inanimate surfaces, and indoor air of the neonatal intensive care unit and pediatric ward, and processed using standard microbiological methods. Data entry and analysis were carried out using SPSS software version 25.0.
Results: Of the total samples collected, 171 (74.7%; 95% CI 68.4–83.5) were culture positive. These comprised 33 (58.9%) of samples taken from medical equipment, 26 (42.6%) from inanimate surfaces, and 112 (100%) from indoor air . *Micrococcus* species (41.3%), *Acinetobacter* species (13.7%), and *Klebsiella pneumoniae* (10.2%) were the most commonly isolated bacteria.
Conclusions: High bacterial contamination rates of medical equipment, inanimate surfaces, and indoor air of the neonatal intensive care unit and pediatric ward were found. Most of the bacterial species isolated were known causative agents of hospital-acquired infection. Around one-quarter of the bacteria were multidrug resistant.

Introduction

Aside from providing curative services, healthcare settings can be potential sources of pathogenic bacteria which may lead to hospital-acquired infections (HAIs) (Alemayehu et al., 2019). Most bacteria that cause HAIs are resistant to antibiotics, and are major causes of mortality and morbidity in pediatric wards and neonatal intensive care units (NICUs) (Borghesi et al., 2008). HAIs directly affect the healthcare system because they increase the demand for medical supplies, duration of hospitalization, and costs of treatment (Zaidi et al., 2005). As a result of weakening or manipulation of the immune system, hospitalized patients in intensive care units (ICUs) present a higher susceptibility to pathogenic bacteria residing in the hospital environment (Mora et al., 2016).

The origin of HAIs could be the patient's own commensal bacteria, or the pathogen may originate from other patients, medical staff, or the hospital environment (Chinn et al., 2003). There are several sources of evidence showing the contribution of contaminated inanimate surfaces and medical equipment to HAIs in NICUs and pediatric wards (Ylipalosaari et al., 2006). Determining the levels of contamination and the sources of HAIs is necessary to effectively control HAIs, especially in ICUs and pediatric wards, where patients are more susceptible (Ylipalosaari et al., 2006).

A high prevalence of HAIs has been reported in different regions of Ethiopia, including 19.4% in Jimma (Ali et al., 2018) and 14% in Adama (Chernet et al., 2020), all of which were caused by bacteria. HAIs can be caused by different types of microorganism, but bacteria are responsible for most cases, with other microorganisms, such as protozoans, fungi, and viruses, encountered less frequently (Horan et al., 2008). According to an Ethiopian study in Hawassa and Addis Ababa, and personal communication, the most frequent bacteria isolated from early neonatal sepsis were *Klebsiella* species (Alemayehu et al., 2019; Shitaye et al., 2020), with a possible source of these bacteria being the hospital environment.

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Antimicrobial resistance is a global public health problem, particularly among bacteria causing HAIs, which contribute to morbidity, mortality, increased healthcare costs resulting from treatment failure, and longer hospital stays. Hospitals are reservoirs of microorganisms, many of which are multidrug resistant (MDR) (Davane et al., 2014; Muhammad et al., 2013).

Most studies from Ethiopia have focused on wards other than ICUs, while those that have included ICUs have considered a limited range of medical equipment and/or inanimate surfaces (Davane et al., 2014). The purpose of our study was to determine the bacterial contamination rates and drug susceptibility patterns of bacteria isolated from medical equipment, inanimate surfaces, and indoor air.

Materials and methods

A hospital-based cross-sectional study was conducted from October 20 to December 30, 2020 at HUCSH in Hawassa, the Sidama region capital, which is located 275 km from Addis Ababa, the capital city of Ethiopia. The NICU of HUCSH has four separate rooms, whereas the pediatric ward has three.

Sample collection

Samples were collected from 56 items of medical equipment and 61 inanimate surfaces. Indoor air samples were collected from the seven rooms serving the NICU and pediatric ward. Two indoor air samples were collected per day from each room — one between 10:00 am and 11:00 am, and the second between 3:00 pm and 4:00 pm. Indoor air sample collection was conducted for 8 weeks, giving 112 samples in total ($2 \times 7 \times 8 = 112$). Accordingly, the total number of samples collected for the study was 229.

Sample processing

All medical equipment and inanimate surfaces in the NICU and the pediatric ward were wiped with a sterile swab moistened with sterile physiological saline. All swab samples were inserted into a sterile test tube and labeled. Indoor air samples were collected from the NICU and pediatric ward using the settle plate sampling method (Pasquarella et al., 2000). Blood agar, MacConkey agar, and mannitol salt agar plates (Oxoid, UK) were left open in the NICU and pediatric ward for an hour. The plates were placed 1 meter above the floor and 1 meter away from the wall (Pasquarella et al., 2000).

Isolation of bacteria

After collection, all swab specimens were transported immediately to the microbiology laboratory, inoculated onto blood agar, MacConkey agar, and mannitol salt agar, and incubated aerobically at 37°C for 24 hours. Open-plate air exposure samples (for indoor air) were incubated aerobically for 24 hours at 37°C. Initially, bacteria were assessed for their colony characteristics and Gram-stained smears. Identification of Gram-positive bacteria was based on catalase test, coagulase test, novobiocin, and bacitracin susceptibility, following the standard bacteriological techniques. Identification of Gram-negative bacteria was based on their characteristics or reaction on KIA, indole, citrate agar, triple sugar iron agar, lysine decarboxylase agar, mannitol agar, urea agar, oxidase, and motility medium.

Antibiotic susceptibility testing

Antimicrobial susceptibility testing was performed for selected bacterial isolates, as recommended by the Clinical Laboratory Standard Institute (CLSI, 2019). Antibiotics were selected on the basis of local availability, literature reviews, and the CLSI guidelines (CLSI, 2019). In brief, three to five similar colonies of bacteria were inoculated into a test tube containing sterile normal saline to make a uniform suspension that matched the 0.5% McFarland standard. Next, a sterile cotton swab was dipped into the suspension and inoculated uniformly on Mueller Hinton agar. The inoculated agar was incubated overnight at 37°C, and the subsequent zone of inhibition was measured using a ruler.

Data quality control

Data consistency and completeness were checked throughout data collection, entry, and analysis. The sterility of culture media was checked by incubating 5% of the batch at 35–37°C overnight. To check the performance of culture media, reference strains, such as *E. coli* (ATCC-25922), *S. aureus* (ATCC-25923), and *P. aeruginosa* (ATCC-27853), were employed. During the collection of indoor air samples, sterile gloves, mouth masks, and protective gowns were worn to prevent contamination of the agar plates, and each agar plate was checked visually for any bacterial growth before it was used.

Data management and analysis

For data entry and analysis, SPSS version 25.0 computer software was used. Data were summarized and presented in text and table form.

Operational definitions

Inanimate surface: The surfaces of beds, tables, and sinks used to provide patient care in the NICU and pediatric ward of HUCSH.

Medical equipment: Equipment used for the management of patients admitted to the NICU and pediatric ward of HUCSH. This included incubators, oxygen hoods, radiant warmers, weighing scales, phototherapy units, stethoscopes, thermometers, and ultrasound and X-ray equipment.

Settle plate: A petri dish placed in the open air to check for the presence of bacteria.

Multidrug-resistant (MDR): When a bacterial isolate is resistant to three or more classes of antimicrobial agent (Magiorakos et al., 2012).

Indoor air: The air within the rooms of the HUCSH NICU and pediatric ward.

Results

Features of medical equipment, inanimate surfaces, and indoor air

Of the 229 samples collected, 56 were from medical equipment, 61 from inanimate surfaces, and 112 from indoor air. The predominant medical equipment tested was oxygen hoods, with ultrasound equipment accounting for the fewest samples. Most inanimate surface swabs collected came from beds (Table 1).

Bacterial contamination rates

Of 229 samples examined, 171 were culture positive, giving a total contamination rate of 74.7% (95% CI 68.4–83.5). Bacteria were isolated from 33 (58.9%), 26 (42.6%), and 112 (100%) of the samples from medical equipment, inanimate surfaces, and indoor air, respectively. The majority of samples (156; 68.1%) were collected from the NICU, of which 112 (71.8%) were found to be culture positive (Table 2).

Of the four incubators sampled, three (75%) were culture positive and one was culture negative. Of the 14 radiant warmers sampled, 12 (85.7%) were culture positive and two (14.3%) were culture negative. Of the 44 bed surfaces sampled, 17 (38.6%) were culture positive (Table 3).

Distribution of bacteria

In total, 284 bacteria were isolated — 212 (74.6%) from indoor air, 38 (13.4%) from medical equipment, and 34 (12%) from inanimate surfaces. Of these, Gram-positive bacteria accounted for 145 (51.1%), with

Table 1
Characteristics of medical equipment, inanimate surfaces, and indoor air of the NICU and pediatric wards at HUCSH, October 20 to December 30, 2020 ($N = 229$).

Category	Frequency (%)
Medical equipment, $n = 56$	
Incubators	4 (7.1)
Oxygen hoods	13 (23.2)
Radiant warmers	14 (25)
Weighing scales	2 (3.6)
Phototherapy units	5 (8.9)
Stethoscopes	11 (19.6)
Thermometers	5 (8.9)
Ultrasound	1 (1.9)
X-ray	1 (1.9)
Inanimate surfaces, $n = 61$	
Bed	44 (72.1)
Table	11 (18)
Sink	6 (9.8)
Indoor air, $n = 112$	
NICU	64 (57.1)
Pediatrics	48 (42.9)

HUCSH: Hawassa University Comprehensive Specialized Hospital, NICU: neonatal intensive care unit.

Table 3
Culture positivity across different medical equipment and inanimate surfaces in the NICU and pediatric wards, HUCSH, October 20 to December 30, 2020.

Category	Culture positive, n (%)
Medical equipment ($n = 56$)	
Incubators ($n = 4$)	3 (75)
Oxygen hoods ($n = 13$)	8 (61.5)
Radiant warmers ($n = 14$)	12 (85.7)
Weighing scales ($n = 2$)	1 (50)
Phototherapy units ($n = 5$)	2 (40)
Thermometers ($n = 5$)	1 (20)
Stethoscopes ($n = 11$)	4 (36.4)
Ultrasound ($n = 1$)	1 (100)
X-ray ($n = 1$)	1 (100)
Total ($n = 56$)	33 (58.9)
Types of inanimate surface ($n = 61$)	
Bed ($n = 44$)	17 (38.6)
Table ($n = 11$)	7 (63.6)
Sink ($n = 6$)	2 (33.3)
Total ($n = 61$)	26 (42.6)

HUCSH: Hawassa University Comprehensive Specialized Hospital, NICU: neonatal intensive care unit.

the predominant bacteria being *Micrococcus* species (41.3%), *S. epidermidis* (5.3%), and *S. saprophyticus* (4.2%). Gram-negative bacteria accounted for 139 (48.9%) of the isolates (Table 4).

Out of 72 bacterial isolates recovered from medical equipment and inanimate surfaces, 56 (77.8%) were from the NICU and 16 (22.2%) from the pediatric ward. The predominant bacteria isolated from the pediatric ward and NICU were *Acinetobacter* species (19; 26.4%) and *Micrococcus* species (16; 22.2%) (Table 5).

Regarding the types of bacteria on medical equipment and inanimate surfaces, *Acinetobacter* species ($n = 1$) and *Pseudomonas* species ($n = 2$) were isolated from oxygen hoods, while *K. pneumoniae* ($n = 2$), *K. rhinoscleromatis* ($n = 7$), *K. oxytoca* ($n = 2$), *Acinetobacter* ($n = 7$), and *Pseudomonas* ($n = 1$) species were isolated from beds (Table 6).

All samples collected from indoor air ($n = 112$) were culture positive. Of the 212 bacterial isolates recovered from indoor air samples, 117 (55.2%) were from the NICU and 95 (44.8%) were from the pediatric ward. The predominant bacteria isolated were *Micrococcus* species (102; 48.1%), followed by *K. pneumoniae* (23; 10.8%) and *Acinetobacter* species (20; 9.4%) (Table 7).

Antimicrobial susceptibility profile

Of the bacteria isolated, 39 (28.1%), 35 (25.9%), and 34 (25.8%) were resistant to ciprofloxacin, cefazolin, and ceftazidime, respectively (Table 8). Eight (53.3%), four (26.7%), four (26.7%), and two (13.3) isolates of *S. epidermidis* were resistant to cefoxitin, oxacillin, clindamycin, and penicillin, respectively (Table 9). Of the 154 bacteria tested, 33 (21.4%) were MDR (Table 10).

Discussion

The overall bacterial contamination rate for medical equipment, inanimate surfaces, and indoor air (74.7%) found in our study was higher than those reported from Addis Ababa, Ethiopia (60.3%; Dabsu et al., 2014), Iraq (17.8%; Nasser et al., 2013), and Nigeria (20.2%; Uneke et al., 2014). However, higher contamination rates have been reported from Tigray, Ethiopia (88.4%; Darge et al., 2019), Sodo, Ethiopia (90.2%; Bisetgent et al., 2017), Jimma, Ethiopia (85.5%; Shiferaw et al., 2013), and Navi, India (90%; Singh et al., 2013). Our finding was in line with a study conducted in Turkey (78.5%; Kilic et al., 2011). Aside from the Navi, India study (Singh et al., 2013), this suggests a generally high rate of bacterial contamination of medical equipment across Ethiopia compared with other countries. This could be due to inadequate decontamination of medical equipment and inanimate surface, the types of decontaminants used, improper health professional practices, and the nature of the medical equipment and inanimate surfaces studied.

The bacterial contamination rates for medical equipment (58.9%) and inanimate surfaces (42.6%) detected in our study were lower than those reported from Ayder Comprehensive Specialized Hospital, Ethiopia, where the contamination rates for medical equipment and inanimate surfaces were 83.3% and 97.8%, respectively (Darge et al., 2019). A report from Jimma, Ethiopia found a higher bacterial contamination rate for medical equipment (85.5%) (Shiferaw et al., 2013), while a report from Black Lion Hospital, Ethiopia was more in line with our study (60.3%) (Dabsu et al., 2014). On the other hand, a study conducted in eastern Ethiopia reported a contamination rate of 53.8%, which was lower than our figure (Weldegebreal et al., 2019). Findings from other countries, such as Iraq (17.8%; Nasser et al., 2013) and Nigeria (20.2%; Uneke et al., 2014), have shown lower contamination rates.

Table 2
Bacterial contamination rates for medical equipment, inanimate surfaces, and indoor air in the NICU and pediatric ward, HUCSH, October 20 to December 30, 2020 ($N = 229$).

Category	NICU		Pediatric ward		NICU and pediatric ward
	Sampled n (%)	Positive n (%)	Sampled n (%)	Positive n (%)	Total positive n (%)
Medical equipment ($n = 56$)	52 (33.3)	30 (26.8)	4 (5.5)	3 (5)	33 (58.9)
Inanimate surfaces ($n = 61$)	40 (26.6)	18 (16)	21(28.8)	8 (13.6)	26 (42.6)
Indoor air ($n = 112$)	64 (41)	64 (57.1)	48 (65.6)	48 (81.4)	112 (100)
Total ($n = 229$)	156 (68.1)	112 (71.8)	73 (31.9)	59 (80.8)	171 (74.7)

NICU: neonatal intensive care unit, HUCSH: Hawassa University Comprehensive Specialized Hospital.

Table 4
Distributions of bacteria recovered from medical equipment, inanimate surfaces, and indoor air, HUCSH, October 20 to December 30, 2020 (*N* = 284).

Bacterial isolates	Medical equipment, *n* (%)	Inanimate surfaces, *n* (%)	Indoor air, *n* (%)	Total, *n* (%)
Gram-positive				
Micrococcus species	14 (36.8)	2 (4.8)	102 (48.1	118 (41.5)
S. epidermidis	6 (15.9)	–	9 (4.2)	15 (5.3)
S. saprophyticus	3 (7.9)	2 (4.8)	7 (3.3)	12 (4.2)
Total	23 (60.5)	4 (9.5)	118 (55.7)	145 (51.1)
Gram-negative				
K. pneumoniae	1 (2.6)	5 (11.9)	23 (10.8)	29 (10.2)
K. rhinoscleromatis	2 (5.3)	10 (23.8)	11 (5.2)	23 (8.9)
K. oxytoca	–	4 (9.5)	11 (5.2)	15 (5.3)
K. ozanae	–	–	6 (2.3)	6 (1.4)
Acinetobacter species	10 (26.3)	9 (21.4)	20 (9.4)	39 (13.7)
Pseudomonas species	2 (5.3)	2 (4.8)	19 (8.9)	23 (8.1)
E. coli	–	–	4 (1.9)	4 (1.4)
Total	15 (39.5)	30 (71.2)	94 (44.3)	139 (48.9)
Total	38 (13.4)	34 (12)	212 (74.6)	284 (100)

HUCSH: Hawassa University Comprehensive Specialized Hospital, NICU: neonatal intensive care unit.

Table 5
Bacteria isolated from medical equipment and inanimate surfaces in the NICU and pediatric wards of HUCSH, October 20 to December 30, 2020 (*N* = 72).

Bacteria isolated from medical equipment and inanimate surfaces	NICU *n* (%)	Pediatric ward *n* (%)	Total *n* (%)
Micrococcus	14 (25)	2 (12.5)	16 (22.2)
S. epidermidis	6 (10.8)	–	6 (8.3)
S. saprophyticus	5 (8.9)	–	5 (6.9)
K. pneumoniae	5 (8.9)	1 (6.3)	6 (8.3)
K. rhinoscleromatis	10 (17.9)	2 (12.5)	12 (16.7)
K. oxytoca	2 (3.6)	2 (12.5)	4 (5.6)
Acinetobacter species	11 (19.2)	8 (50)	19 (26.4)
Pseudomonas species	3 (5.4)	1 (6.3)	4 (5.6)
Total	56 (77.8)	16 (22.2)	72 (100)

NICU: neonatal intensive care unit, HUCSH: Hawassa University Comprehensive Specialized Hospital.

Table 6
Bacteria isolated from various medical equipment and inanimate surfaces in the NICU and pediatric ward of HUCSH, October 20 to December 30, 2020 (*N* = 72).

Medical equipment and inanimate surfaces	Types of bacteria, *n* (%)								Total, *n* (%)
	Micrococcus	*S. saprophyticus*	*S. epidermidis*	*K. pneumoniae*	*k. rhinoscleromatis*	*k. oxytoca*	*Acinetobacter*	*Pseudomonas* species	
Incubators	1 (33.3)	–	2 (66.6)	–	–	–	–	–	3 (4.2)
Oxygen hoods	4 (44.4)	1 (11.1)	–	1 (11.1)	–	–	1 (11.1)	2 (22.2)	9 (12.5)
Radiant warmers	8 (61.6)	2 (15.4)	2 (15.4)	–	1 (7.7)	–	–	–	13 (18.1)
Weighing scales	–	–	–	–	1 (100)	–	–	–	1 (1.4)
Phototherapy units	–	2 (50)	2 (50)	–	–	–	–	–	4 (5.6)
Stethoscopes	–	–	–	–	–	–	4 (100)	–	4 (5.6)
Thermometers	–	–	–	–	–	–	1 (100)	–	1 (1.4)
Ultrasound	–	–	–	–	–	–	1 (100)	–	1 (1.4)
X-ray	–	–	–	–	–	–	1 (100)	–	1 (1.4)
Beds	3 (12.5)	2 (8.3)	–	2 (8.3)	7 (29.2)	2 (8.3)	7 (29.2)	1 (4.2)	24 (33.3)
Tables	–	–	–	2 (18.2)	2 (18.2)	2 (18.2)	4 (36.4)	1 (9.1)	11 (15.3)
Sinks	–	–	–	1 (50)	1 (50)	–	–	–	2 (2.8)
Total isolated bacteria	16 (22.2)	5 (6.9)	6 (8.3)	6 (8.3)	12 (16.7)	4 (5.6)	19 (26.4)	4 (5.6)	72 (100)

HUCSH: Hawassa University Comprehensive Specialized Hospital.

The variation in contamination rates observed might be due to differences in methodology, or in the frequency of decontamination of medical equipment and inanimate surfaces in respective hospitals.

All indoor air samples collected in this study were culture positive. This finding was higher than those from Sodo Hospital, southern Ethiopia (90.2%; Bisetgent et al., 2017) and Ayder Referral Hospital, northern Ethiopia (66.8%; Tesfaye et al., 2015); however, it was in line with previous reports from HUCSH, Ethiopia (Hailemariam et al., 2016), Jimma University Specialized Hospital, Ethiopia (Genet et al., 2011), and University of Gondar Teaching Hospital, Ethiopia (Gizaw et al., 2016). In general, bacterial contamination of indoor air in hospital environments needs attention, since these are settings where severely sick patients (in our case, neonates and children) are admitted. Bacterial contamination of indoor air may be due to temperature, humidity, the presence of unhygienic attached toilets, poor waste management systems, and inadequate ventilation and cleaning methods.

The proportions of Gram-positive (51.1%) and Gram-negative (48.9%) bacteria detected in our study were not comparable with those reported from Jimma, Ethiopia, where 78.9% and 21.1% of bacteria were Gram-positive and Gram-negative, respectively (Shiferaw et al., 2013), or with a study in Tigray, Ethiopia, where the proportions were 68.4% and 31.6%, respectively (Darge et al., 2019). In all cases, Gram-

Table 7

Bacteria isolated from indoor air of the NICU and pediatric ward, HUCSH, October 20 to December 30, 2020 ($N = 212$).

Types of bacteria	NICU *n* (%)	Pediatric ward *n* (%)	Total *n* (%)
Micrococcus	59 (50.4)	43 (45.2)	102 (48.1)
S. epidermidis	5 (4.3)	4 (4.2)	9 (4.2)
S. saprophyticus	4 (3.4)	3 (3.2)	7 (3.3)
K. pneumoniae	14 (11.9)	9 (9.5)	23 (10.8)
K. rhinoscleromatis	3 (2.6)	8 (8.4)	11 (5.2)
K. oxytoca	7 (5.9)	4 (4.2)	11 (5.2)
K. ozaenae	2 (1.7)	4 (4.2)	6 (2.8)
Acinetobacter species	9 (7.7)	11 (11.6)	20 (9.4)
Pseudomonas species	12 (10.3)	7 (7.4)	19 (8.9)
E. coli	2 (1.7)	2 (2.1)	4 (1.9)
Total	117 (55.2)	95 (44.8)	212 (100)

NICU: neonatal intensive care unit, HUCSH: Hawassa University Comprehensive Specialized Hospital.

positive bacteria were predominant. This might be due to the direct contact of the medical equipment and inanimate surfaces with normal human skin flora, which contains more Gram-positive than Gram-negative bacteria. Moreover, the lifespan of Gram-negative bacteria outside the human body is short, whereas Gram-positive bacteria can remain viable for a longer period in the external environment.

Of the 284 bacteria isolated in this study, most were *Micrococcus* (118; 41.5%), which are assumed to be non-pathogenic. The rest of the isolates were potential human pathogens that can cause HAIs. These included *Acinetobacter* species (13.7%) and *K. pneumoniae* (10.2%). However, in other studies, the predominant bacteria were found to be coagulase-negative *Staphylococcus* (CoNS) (Dabsu et al., 2014; Dargeet al., 2019; Bisetgent et al., 2017). The proportion of *Pseudomonas* species in our study was 8.1%, which was higher than that reported in Sodo, southern Ethiopia (5.3%; Bisetgent et al., 2017) and Jimma, Ethiopia (1.2%; Shiferaw et al., 2013). It should be noted that *P. aeruginosa* is often acquired from hospital environments and contaminated medical equipment (Bisetgent et al., 2017). The observed differences in the distributions of bacteria across various studies might be due to differences among wards, in the laboratory methods used, and in infection prevention strategies.

Of the 139 Gram-negative bacteria isolated, 47.5% were *Klebsiella* species, which is assumed to be the most antibiotic-resistant bacteria. The predominant *Klebsiella* species was *K. pneumoniae* (10.2%), followed by *K. rhinoscleromatis* (8.9%), and *K. oxytoca* (5.2%). According to one study and personal communication, the predominant bacteria isolated from the blood of newborns with sepsis were *Klebsiella* species (23.9%) (Alemayehu et al., 2019). This might be due to contamination of medical equipment, inanimate surfaces, and indoor air by *Klebsiella* species, which eventually leads to infection of newborns who are born into the hospital environment.

In our study, the antimicrobial resistance rates of the isolated bacteria ranged from 3% (amikacin) to 34% (cefazolin). In contrast, higher antimicrobial resistance rates were reported from Sodo, Ethiopia, ranging from 7.5% to 87.5% (Bisetgent et al., 2017). In our study, high proportions of bacteria were resistant to cefazolin (34%), ciprofloxacin (28%), ceftazidime (25.9%), and cefuroxime (25.8%). Rates for gentamicin- and ciprofloxacin-resistant bacteria were 11.9% and 28%, respectively, whereas a study in Ayder Comprehensive Specialized Hospital, Ethiopia found relatively low rates of gentamicin resistance (8.6%) and ciprofloxacin resistance (13%) (Darge et al., 2019).

In our study, MDR was observed in 21.4% of bacterial isolates, which was lower than rates detected from Mekelle, northern Ethiopia (36.5%; Tesfaye et al., 2015), Sodo, southern Ethiopia (75.3%; Bisetgent et al., 2017), and Jimma, Ethiopia (88.9%; Shiferaw et al., 2013). The highest rate of MDR in our study was observed among *K. pneumoniae* (37.9%), followed by *K. oxytoca* (33.3%), and *S. epidermidis* (33.3%). A study from Ayder Comprehensive Specialized Hospital identified a high proportion of MDR among CoNS (28.3%), *S. aureus* (58.7%), and *E. coli* (72.7%) (Darge et al., 2019). None of the *E. coli* isolated in our study were MDR. These differences in antibiotic-resistance profiles might be attributed to inappropriate administration of antimicrobials, or variations in hospital environmental conditions, self-medication practices, and personal hygiene.

Table 8

Antimicrobial susceptibility profiles for Gram-negative bacteria isolated from equipment and inanimate surfaces at HUCSH, October 20 to December 30, 2020 ($N = 139$).

Types of bacteria	AST result	AMK	IMP	CIP	CZ	CAZ	TS	CN	CXM
K. pneumoniae	S	28 (96.6)	27 (93.1)	19 (65.5)	15 (51.7)	19 (65.5)	27 (93.1)	22 (75.9)	17 (58.6)
($n = 29$)	I	–	–	–	–	1 (3.4)	–	–	–
	R	1 (3.4)	2 (6.9)	10 (34.5)	14 (48.3)	9 (31)	2 (6.9)	7 (24)	12 (41.4)
K. rhinoscleromatis	S	22 (95.6)	20 (87)	12 (52.2)	11 (47.8)	12 (52.2)	19 (82.6)	21 (91.3)	ND
($n = 23$)	I	–	2 (8.9)	1 (4.4)	–	2 (9.0)	–	–	ND
	R	1 (4.4)	1 (4.4)	10 (43.5)	12 (52.2)	9 (39.1)	4 (17.4)	2 (8.7)	ND
K. oxytoca ($n = 15$)	S	14 (93.3)	13 (86.7)	8 (53.3)	10 (66.7)	7 (46.7)	11 (73.3)	13 (86.7)	11 (73.3)
	I	1 (6.7)	2 (13.3)	3 (20)	–	1 (6.7)	–	–	–
	R	–	–	4 (26.7)	5 (33.3)	7 (46.7)	4 (26.7)	2 (13.3)	4 (26.7)
K. ozaenae ($n = 6$)	S	6 (100)	5 (83.3)	3 (50)	4 (66.7)	4 (66.7)	–	6 (100)	3 (50)
	I	–	1 (6.7)	–	–	–	–	–	1 (16.7)
	R	–	–	3 (50)	2 (33.3)	2 (33.3)	6 (100)	–	2 (33.3)
Acinetobacter	S	37 (94.9)	34 (87.2)	33 (84.6)	33 (84.6)	33 (84.6)	ND	36 (92.3)	35 (89.7)
($n = 39$)	I	–	–	–	1 (2.6)	1 (2.6)	ND	–	–
	R	2 (5.1)	5 (12.8)	6 (15.4)	5 (12.8)	5 (12.8)	ND	3 (7.8)	4 (10.6)
Pseudomonas	S	23 (100)	20 (60.6)	15 (65.2)	ND	20 (87)	22 (95.7)	21 (91.3)	ND
species ($n = 23$)	I	–	–	3 (13.1)	ND	–	–	–	ND
	R	–	3 (13)	5 (21.7)	ND	3 (13)	1 (4.3)	2 (8.7)	ND
E. coli ($n = 4$)	S	4 (100)	4 (100)	3 (75)	ND	ND	3 (75)	ND	2 (50)
	I	–	–	–	ND	ND	–	ND	–
	R	–	–	1 (25)	ND	ND	1 (25)	ND	2 (50)
Overall	S	134 (96.4)	123 (88.5)	93 (66.9)	73 (65.2)	95 (70.4)	82 (82)	119 (88.1)	37 (39.8)
	I	1 (0.72)	5 (3.6)	7 (5.3)	1 (0.94)	5 (3.7)	–	–	1 (1.1)
	R	4 (3)	11 (7.9)	39 (28.1)	38 (34)	35 (25.9)	18 (18)	16 (11.9)	34 (25.8)

HUCSH: Hawassa Comprehensive Specialized Hospital, AST: antimicrobial susceptibility test, S: susceptible, I: intermediate, R: resistant, AMK: amikacin, IMP: imipenem, CIP: ciprofloxacin, CZ: cefazolin, CAZ: ceftazidime, TS: trimethoprim sulfamethoxazole, CN: gentamicin, CXM: cefuroxime, ND: not determined.

Table 9
Antimicrobial susceptibility profile for Gram-positive bacteria isolated from the NICU and pediatric wards of HUCSH, October 20 to December 30, 2020 ($N = 15$).

Type of bacterium	Antibiotics, *n* (%)								
	AST result	E	F	OX	P	VAN	FOX	TS	DA
S. epidermidis (*n* = 15)	S	13 (86.7)	13 (86.7)	11 (73.3)	13 (86.7)	14 (93.3)	7 (46.7)	4 (26.7)	11 (73.3)
	I	–	1 (6.7)	–	–	1 (6.7)	–	–	–
	R	2 (13.3)	1 (6.7)	4 (26.7)	2 (13.3)	–	8(53.3)	1 (6.7)	4 (26.7)

HUCSH: Hawassa Comprehensive Specialized Hospital, AST: antimicrobial susceptibility test, S: susceptible, I: intermediate, R: resistant, E: erythromycin, F: nitrofurantoin, OX: oxacillin, P: penicillin G, VAN: vancomycin, FOX: cefoxitin, TS: trimethoprim sulfamethoxazole, DA: clindamycin.

Table 10
Multidrug resistance patterns for bacteria isolated from medical equipment, inanimate surfaces, and indoor air of the NICU and pediatric ward at HUCSH, October 20 to December 30, 2020 ($N = 154$).

Types of bacteria	**Types of antibiotic**	**MDR, *n* (%)**	**Total MDR, *n* (%)**
K. pneumoniae (*n* = 29)	IMP, CIP, TS, CXM	1 (3.5)	11 (37.9)
	CIP, CAZ, CN, CXM	1 (3.5)	
	CZ, CAZ, TS, CXM	2 (3.5)	
	CIP, CZ, TS, CXM	1 (3.5)	
	IMP, CIP, TS, CXM	1 (3.5)	
	CZ, TS, CXM	1 (3.5)	
	CZ, CAZ, TS	1 (3.5)	
	IMP, CIP, CAZ,	1 (3.5)	
	TS, CN, CXM	1 (3.5)	
	CN, CXM, CZ	1 (3.5)	
K. rhinoscleromatis (*n* = 23)	AMK, IMP, CIP, CAZ, CN, CZ	1 (4.3)	5 (21.7)
	AMK, CIP, CZ, CAZ, CN	1 (4.3)	
	CIP, CAZ, TS,	1 (4.3)	
	CIP, CZ, TS	2 (8.7)	
K. oxytoca (*n* = 15)	CZ, CAZ, TS, CN	1 (6.7)	5 (33.3)
	CIP, CZ, CAZ, CXM	1 (6.7)	
	CIP, CZ, CAZ, CTX	1 (6.7)	
	CZ, TS, CXM	1 (6.7)	
	CIP, CZ, TS	1 (6.7)	
K. ozaenae (*n* = 6)	CIP, CZM, TS,	1 (16.7)	1 (16.6)
Acinetobacter species (*n* = 39)	AMK, IMP, CXM, CIP, CAZ, CN, CZ	1 (2.6)	5 (12.8)
	AMK, IMP, CIP, CAZ, CXM	1 (2.6)	
	AMK, CIP, CAZ, TS, CN	1 (2.6)	
	AMK, CIP, CAZ, CN	1 (2.6)	
	AMK, IMP, CIP	1 (2.6)	
Pseudomonas species (*n* = 23)	IMP, CIP, CAZ, CN	1 (2.6)	1 (4.3)
S. epidermidis (*n* = 15)	E, OX, P, FOX	1 (6.7)	5 (33.3)
	DA, E, FOX	1 (6.7)	
	DA, OX, FOX	3 (20)	
Overall			33 (21.4)

HUCSH: Hawassa University Comprehensive Specialized Hospital, AMK: amikacin, IMP: imipenem, CIP: ciprofloxacin, CZ: cefazolin, CAZ: ceftazidime, TS: trimethoprim sulfamethoxazole, CN: gentamicin, CTX: cefotaxime, DA: clindamycin, E: erythromycin, FOX: cefoxitin, P: penicillin G, OX: oxacillin, CXM: cefuroxime.

Limitation of the study

Our study did not assess the factors that might have increased the contamination rates for medical equipment, inanimate surfaces, and indoor air in the NICU and pediatric ward at HUCSH.

Conclusions

A high bacterial contamination rate was observed for medical equipment, inanimate surfaces, and indoor air. *Micrococcus* species, *Acinetobacter* species, *Pseudomonas* species*, K. pneumoniae,* and *K. rhinoscleromatis* were the most commonly isolated bacteria. Most of the bacterial species isolated were potential pathogens and known causes of HAIs. A relatively a high proportion of Gram-negative bacteria were resistant to ciprofloxacin, cefazolin, and ceftazidime. The majority of Gram-positive bacteria were resistant to the antibiotics tested (including oxacillin), with the exception of vancomycin. Furthermore, around one-quarter of the bacteria were MDR.

Authors' contributions

KB: laboratory work, data collection, data analysis, writing the original draft. DDG: supervision, data analysis, writing the original draft. MMA: conception and design of the study, supervision, data analysis, manuscript preparation and review. All authors read and approved the manuscript.

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Ethical approval and consent to participate

Ethical approval was obtained from the Institutional Review Board of Hawassa University College of Medicine and Health Sciences (Ref. IRB/024/13). Data were collected after written permission was obtained from the study site.

Consent for publication

Not applicable.

Data availability

All relevant data are available within the paper.

Competing interests

The authors have declared that no competing interests exist.

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