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# Molecular epidemiology, microbiological features and infection control strategies for carbapenem-resistant *Acinetobacter baumannii* in a German burn and plastic surgery center (2020–2022)

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## Abstract

**Background** Carbapenem-resistant *Acinetobacter baumannii* (CRAB) frequently causes both healthcare-associated infections and nosocomial outbreaks in burn medicine/plastic surgery and beyond. Owing to the high antibiotic resistance, infections are difficult to treat, and patient outcomes are often compromised. The environmental persistence capability of CRAB favors its transmission in hospitals. A comprehensive analysis and understanding of CRAB epidemiology and microbiology are essential for guiding management.

**Methods** A three-year retrospective cohort study (2020–2022) was conducted in a German tertiary burn and plastic surgery center. In addition to epidemiological analyses, microbiological and molecular techniques, including whole-genome sequencing, were applied for the comprehensive examination of isolates from CRAB-positive patients.

**Results** During the study period, eight CRAB cases were found, corresponding to an overall incidence of 0.2 CRAB cases per 100 cases and an incidence density of 0.35 CRAB cases per 1000 patient-days. Six cases (75%) were treated in the burn intensive care unit, and four cases (50%) acquired CRAB in the hospital. Molecular analyses comprising 74 isolates supported the epidemiologic assumption that hospital acquisitions occurred within two separate clusters. In one of these clusters, environmental CRAB contamination of anesthesia equipment may have enabled transmission. Furthermore, molecular diversity of CRAB isolates within patients was observed.

**Conclusions** CRAB can pose a challenge in terms of infection prevention and control, especially if cases are clustered in time and space on a ward. Our study demonstrates that high-resolution phylogenetic analysis of several bacterial

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isolates from single patients can greatly aid in understanding transmission chains and helps to take precision control measures.

**Keywords** *Acinetobacter baumannii*, Carbapenem, Resistance, Infection prevention and control, Epidemiology, Whole-genome sequencing, Microbiology

## Background

*Acinetobacter baumannii* is a Gram-negative, nonfermenting bacterium with high environmental persistence [1, 2]. Carbapenem resistance in *Acinetobacter baumannii* is enabled mainly by carbapenemases, such as blaOXA-23 [3]. Both carbapenem-resistant *Acinetobacter baumannii* (CRAB) and susceptible isolates are well known for their ability to cause both healthcare-associated infections and nosocomial outbreaks [4–10]. Common infections caused by *Acinetobacter* species are bloodstream infections, pneumonia and soft tissue infections [11]. CRAB is listed within the priority 1 group (critical) of the WHO list of antibiotic-resistant bacteria recommended for prioritization for new antibiotics research and development [12]. In summary, CRAB represents a relevant global infection prevention and control (IPC) challenge. For these reasons, our hospital has implemented a comprehensive general IPC strategy for highly resistant Gram-negative bacteria, including CRAB [13], based on national and international recommendations. CRAB plays a particularly prominent role in burn medicine [14–16]. Patients with extensive skin and soft tissue damage are especially susceptible to infection and colonization with CRAB. In addition, burn medicine involves the frequent application of medical procedures that are associated with a high risk of environmental contamination, including extensive dressing changes and hydrotherapeutic applications.

Owing to the unfavorable resistance spectrum, the therapy of infections caused by CRAB is challenging [17]. Promising new therapeutic options, such as sulbactam/durlobactam or cefiderocol, have recently come into focus [18].

In this context, detailed epidemiological knowledge is highly useful for optimizing the IPC management of CRAB. Therefore, we conducted a comprehensive retrospective epidemiologic, microbiologic and molecular analysis of CRAB in our plastic surgery and burn medicine department (other departments were not considered) from 2020–2022.

## Methods

### Setting, study design, data acquisition and definitions

A retrospective study was conducted in the Department of Plastic, Aesthetic, Hand and Reconstructive Surgery

at Hannover Medical School, a German university clinic with a burn center for adults. The study period was from January 2020 to December 2022 (i.e., 36 months). The data collection and analysis took place from January 2023 to April 2024. All procedures were performed in accordance with relevant laws and institutional guidelines. The ethics committee of Hannover Medical School approved this study (No. 10682\_BO\_K\_2022).

The study included a burn intensive care unit (BICU) with six beds for adults in single rooms and a regular ward with 20 beds (two 4-bed rooms, two 3-bed rooms, two 2-bed rooms and two single rooms). The BICU included a room with a hydrotherapy tub and an adjacent operating theatre. Patient data, including microbiology results, were retrieved from the hospital information system, the laboratory information system and patient records. The hospital's controlling department provided the total number of inpatient cases (inpatient stays) and patient-days. A CRAB case was defined as an inpatient stay in which CRAB was cultured from at least one microbiologic sample (screening and clinical samples). Acquisition was epidemiologically classified as nosocomial (hospital-acquired) when CRAB was found for the first time on day three or later of the hospital stay. The incidence of CRAB was calculated as CRAB cases per 100 inpatient cases, and the incidence density was calculated as CRAB cases per 1000 patient-days.

### Microbiologic diagnostic

Screening samples for carbapenem-resistant Gram-negative bacteria were cultured on CHROMagar™ mSuper-CARBA™ (CHROMagar, Paris, France). Clinical samples were analyzed via standard liquid and solid culture media according to internal laboratory standards. Species identification was performed via matrix-assisted laser desorption/ionization time-of-flight mass spectrometry using a Vitek MS system (bioMérieux, Marcy-l'Étoile, France), and initial antimicrobial susceptibility testing (AST) was performed with a Vitek 2 system (bioMérieux, Marcy-l'Étoile, France). Carbapenem resistance was confirmed for at least the first isolate of every case by minimum inhibitory concentration (MIC) determination with the Merlin Micronaut system (Merlin Diagnostika, Bornheim-Hesel, Germany). European Committee on Antimicrobial Susceptibility Testing (EUCAST) standards

were followed in the version valid for the respective year of the study (breakpoint tables v10.0 to v12.0). For this study, we also tested representative CRAB isolates for susceptibility to cefiderocol using the UMIC Cefiderocol (Bruker Daltonics, Bremen, Germany) and for the novel antimicrobial sulbactam/durlobactam [19] as described by Karlowsky et al. [20]. In brief, sulbactam (Thermo Fisher Scientific, Waltham, United States) was tested in twofold serial dilutions with a fixed durlobactam (Targetmol Chemicals, Boston, United States) concentration of 4 mg/L in cation-adjusted Mueller Hinton II Broth (BD, Heidelberg, Germany) following EUCAST recommendations for MIC determination (media preparation v7.0, reading guide v4.0).

Environmental samples were collected via RODAC plates (Tryptone Soya Agar with Disinhibitor, Oxoid, Wesel, Germany) and swabs (eSwab, Copan, Brescia, Italy).

#### **Routine infection prevention and control management of carbapenem-resistant *Acinetobacter baumannii***

In accordance with our hospital IPC standards, cases with CRAB were always assigned to single rooms. Staff wore gowns and gloves when entering the room of a CRAB-positive patient. In the BICU personal protective equipment (gloves and gowns) were mandatory in all patient rooms (due to immunocompromised patient status and for IPC reasons). Furthermore, the BICU staff always left the rooms of CRAB-positive patients via a separate corridor and re-entered the ward after changing their unit gowns. As our study took place during the coronavirus disease 2019 (COVID-19) pandemic, a universal masking (surgical masks) protocol was also in place.

As long as a patient with CRAB was hospitalized in a ward, all other patients in that ward were screened weekly for carbapenem-resistant bacteria, as described previously [13]. Moreover, admission screening for carbapenem-resistant Gram-negative bacteria and prophylactic isolation was recommended for patients who had previously been treated at hospitals outside of Germany. Room contact patients (if any) of CRAB-positive cases were preemptively isolated until negative swabs were obtained. Onsite medical staff were trained in dealing with patients with CRAB through targeted face-to-face and digital educational information provided by the IPC team on an event-related basis.

#### **Sequencing of isolates and bioinformatic analysis**

CRAB isolates available in our local strain collection were recultured for molecular typing purposes. DNA was extracted (DNeasy PowerSoil Pro Kit, Qiagen, Venlo, Netherlands) for library preparation (Illumina

DNA Prep, Illumina, San Diego, United States) and subsequent sequencing on an Illumina NovaSeq 6000 in paired-end mode (2×150 bp). Raw reads were processed as described previously [21]. In brief, the reads were quality filtered via fastp (v0.19.5) and assembled via SPAdes (v3.15.5). Subsequent gene calling was performed with Prokka (v1.14.6), and the average nucleotide identity (ANI) was calculated using fastANI (v1.33). A dendrogram was constructed in R (4.2.2) with dendextend (v1.17.1). SNP calling was performed via snippy (v4.6.0) at the contig level, with representatives of each clade of the dendrogram taken as references; a threshold of 30 SNPs was set to define a group. Carbapenemase-encoding genes were identified as described previously [22] using ariba (v2.14.4) and the CARD database (version July 2023). The Pasteur scheme from PubMLST.org [23] was used for multilocus sequence typing (MLST). In addition, we performed core genome multilocus sequence typing (cgMLST) analysis for *Acinetobacter baumannii* [24] with the SeqSphere+ software suite (Ridom, Münster, Germany; client software version 10.0.4). Using the software's default settings, de novo assembly with SKESA was performed, and a minimum spanning tree based on the cgMLST results was generated.

## **Results**

### **Basic epidemiology and clinical characteristics**

During the study period, 3999 cases were hospitalized in the two wards for a total of 22,796 patient-days. Of those, 694 (17.4%) cases and 4470 patient-days (19.6%) were in the BICU.

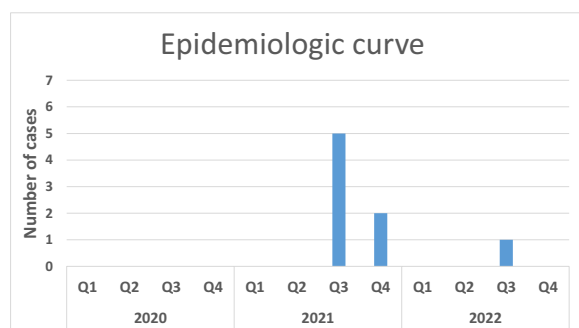
CRAB was detected in eight cases (six male and two female), corresponding to an overall incidence of 0.2 CRAB cases per 100 cases and an incidence density of 0.35 CRAB cases per 1000 patient-days. Six cases (75%) were treated in the BICU. Considering the BICU alone, we observed an incidence of 0.86 CRAB cases per 100 cases and an incidence density of 1.34 CRAB cases per 1000 patient-days. A summary overview of the CRAB cases, including the patient clinical characteristics, is shown in Table 1. One of the eight patients developed a bloodstream CRAB infection.

Four cases (50%; case 2, case 5, case 6 and case 7) acquired CRAB within the hospital (nosocomial). The other four cases (case 1, case 3, case 4 and case 8) were found to be CRAB positive on admission (brought in). Those patients were all directly transferred from hospitals outside Germany (two patients from Poland and one patient each from Romania and Ukraine).

**Table 1** Epidemiological and clinical characteristics of the eight cases with carbapenem-resistant *Acinetobacter baumannii*

Item	Number (percentage)
Total number of cases	8 (100%)
Female cases	2 (25%)
Nosocomial cases	4 (50%)
Cases with direct transfer from a foreign country hospital	4 (50%)
Median age in years [IQR]	54.5 [36.6–56.5]
Median length of stay in days [IQR]	27 [13.5–41.5]
Cases with stay in the BICU	6 (75%)
<i>Cases according to underlying disease</i>	
Explosion trauma and related burn injury	3 (37.5%)
Burn injury	4 (50%)
Fournier gangrene	1 (12.5%)
<i>Cases with positive sample sites</i>	
Rectal sample(s) positive	5 (62.5%)
Nasopharyngeal sample(s) positive	3 (37.5%)
Skin/wound sample(s) positive	8 (100%)
Urine sample(s) positive	2 (25%)
Respiratory sample(s) positive	5 (62.5%)
<i>Cases with cocarriage of other multidrug-resistant bacteria</i>	
Vancomycin-resistant enterococci	0 (0%)
Methicillin-resistant <i>Staphylococcus aureus</i>	1 (12.5%)
Carbapenem-resistant <i>Klebsiella pneumoniae</i>	2 (25%)
Carbapenem-resistant <i>Pseudomonas aeruginosa</i>	1 (12.5%)
<i>Cases with surgeries during hospital stay</i>	
One surgical intervention	7 (87.5%)
Two surgical interventions	6 (75%)
More than two surgical interventions	5 (62.5%)

IQR = Interquartile range; BICU = burn intensive care unit



**Fig. 1** Epidemiologic curve of cases with carbapenem-resistant *Acinetobacter baumannii*

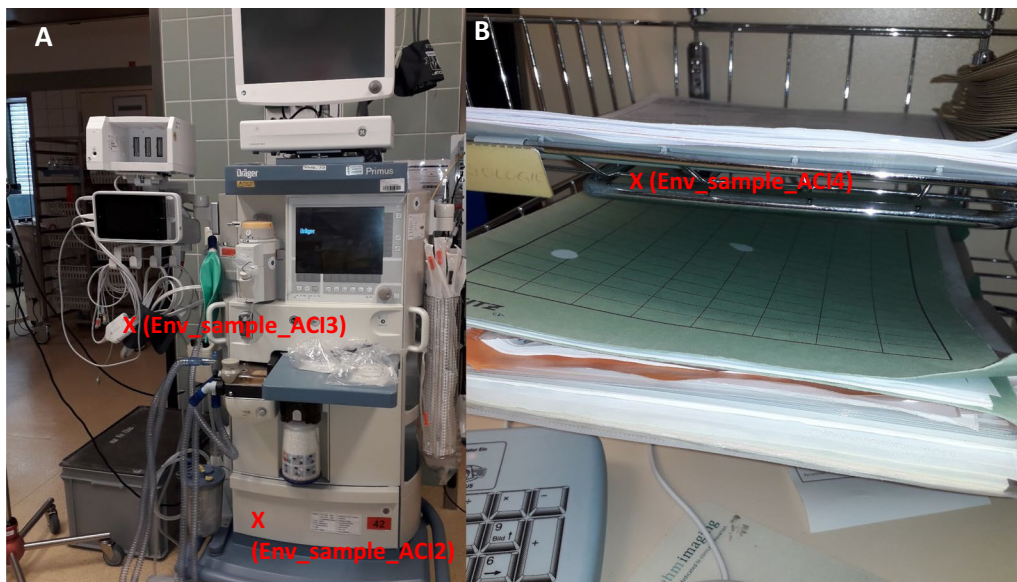
### Infection prevention and control measures, clusters and environmental samples

Figure 1 (epidemiologic curve) shows the distribution of the eight CRAB cases over the study period, demonstrating an increase in the number of cases in the 3rd and 4th quarters of 2021. Given the epidemiological situation at

that time (e.g., joint/overlapping or subsequent stay in the BICU, care by joint staff, stay in the same functional medical units), we assumed two separate transmission events (denoted as epidemiologic clusters 1 and 2). On the one hand, we suspected transmission from Case 1 (index case) to Case 2 (cluster 1). The two impacted patients had a temporal overlap in their stay in the BICU, stayed in neighboring rooms and were cared for by the same staff. These two cases also both received hydrotherapeutic care in a tub in the BICU, but environmental examinations using swabs and contact plates revealed no evidence of CRAB in the therapy tub. The situation was resolved by strengthening the existing IPC measures and training in the ward.

Second, shortly after the first transmission event, a second epidemiological cluster appeared (cluster 2) with connections to the BICU (overlapping and subsequent stays at the BICU, care provided by the same staff), consisting of cases 3, 5, 6 and 7, with case 3 most likely representing the index case. Three of these four cases were also repeatedly treated in the operating theatre next to





**Fig. 2** Positive environmental samples in the operating theatre. **A** Anesthesia tower in the operating theatre. **B** Documentation workplace in the operating theatre. Positive sites are marked with "X"

the BICU, and CRAB was found at three environmental sample sites in the operating theatre (e.g., the anesthesia tower; see also the Phylogeny section and Fig. 2) after standard cleaning/disinfection procedures had been performed. Intensified patient screening (twice a week), intensified cleaning/disinfection in the BICU and the operating theatre, and an extensive onsite audit, training and education program for all staff (e.g., healthcare workers, cleaning staff) ended the suspected transmission chain in cluster 2. Case 4 and case 8 were not epidemiologically linked to each other or to the other cases.

#### MLST and antimicrobial susceptibility

In total, 88 CRAB isolates were identified in patient samples (screening and clinical) from the department during the study period (median of seven isolates per case). Among those, 71 (80.7%) were available for sequencing. These patient isolates and the three environmental sample isolates were subjected to molecular analyses (in total, 74 isolates, see Supplementary Material 1). As a first step, we performed MLST according to the Pasteur scheme. All eight cases were colonized with ST2 isolates and case 3 was additionally colonized with ST1 isolates and ST636 isolates (see Supplementary Material 1). Table 2 shows the MIC results of selected CRAB isolates. All tested isolates were resistant to ciprofloxacin, levofloxacin, imipenem, meropenem, gentamicin and amikacin. Two isolates were susceptible or susceptible under increased exposure to trimethoprim/sulfamethoxazole; one isolate was susceptible to tobramycin, and all isolates were susceptible to colistin. All isolates but one were susceptible

to cefiderocol, and all isolates but two were susceptible to sulbactam/durlobactam.

#### Phylogenetic analysis and distribution of carbapenemase genes

ANI and SNP analyses revealed seven distinct groups (G\_#1 to G\_#7) encompassing phylogenetically closely related isolates each (Fig. 3). In accordance with the results from the MLST analyses presented above, all of the ST2 isolates clustered closely together in the dendrogram, except for E1, which displayed lower nucleotide similarity to the other strains of this group. The ST636 and ST1 isolates formed separate clades; however, the ANI values were still well within the species boundary of 95% similarity, confirming that all isolates were *Acinetobacter baumannii*. SNP analyses largely confirmed the clustering determined on the basis of ANIs, except for ACI\_34, which was linked to group G\_#1 by SNP analysis, but clustered separately by ANI analysis. This discrepancy is probably due to the acquisition of additional genomic material in ACI\_34, which is supported by the detection of blaOXA-72 in ACI\_34 but no other G\_#1 member (see below). ACI\_52 was assigned to G\_#5 (22 and 29 SNPs to references, respectively); however, it displayed only 35 SNPs to the reference of G\_#6. Group G\_#5 comprised isolates from the cases 1 and 2 (cases in epidemiologic cluster 1). Group G\_#2 comprised isolates from the cases in epidemiologic cluster 2 (Cases 3, 5, 6 and 7), including the three CRAB-positive environmental samples. In addition, several isolates from Cases 3 and 5 (which were part of cluster 2) clustered within another

**Table 2** Minimum inhibitory concentrations (MICs) for established antimicrobials as well as sulbactam/durlobactam for representative CRAB isolates from all cases

Strain	Case1_ ACI55	Case1_ ACI59	Case2_ ACI68	Case3_ ACI21	Case3_ ACI41	Case3_ ACI46	Case3_ ACI33	Case4_ ACI62	Case5_ ACI9	Case6_ ACI73	Case7_ D1	Env_ sample_ ACI4	Case8_ E1
Host	Case1 Wound	Case1 Resp.	Case2 Wound	Case3 Wound	Case3 Wound	Case3 Wound	Case3 Wound	Case4 Skin (groin)	Case5 Wound	Case6 Wound	Case7 Wound	Env Env	Case8 Wound
Source	2	2	2	1	636	636	2	2	2	2	2	2	2
MLST (Pasteur) MIC (µg/mL)	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R
Ciprofloxacin	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R
Levofloxacin	8 R	>8 R	>8 R	4 R	4 R	4 R	8 R	>8 R	>8 R	>8 R	>8 R	>8 R	8 R
Imipenem	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R
Meropenem	>16 R	>16 R	>16 R	>16 R	>16 R	>16 R	>16 R	>16 R	>16 R	>16 R	>16 R	>16 R	>16 R
Trimethoprim/sulfamethoxazole	>8 R	>8 R	>8 R	>8 R	>8 R	<b>4 I</b>	>8 R	>8 R	>8 R	>8 R	>8 R	>8 R	<b>≤1 S</b>
Gentamicin <sup>†</sup>	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R
Tobramycin <sup>†</sup>	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	<b>1 S</b>
Amikacin <sup>†</sup>	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R	>32 R
Collistin <sup>†</sup>	<b>≤1 S</b>	<b>≤1 S</b>	<b>≤1 S</b>	<b>≤1 S</b>	<b>≤1 S</b>	<b>≤1 S</b>	<b>≤1 S</b>	<b>≤1 S</b>	<b>≤1 S</b>	<b>≤1 S</b>	<b>≤1 S</b>	<b>≤1 S</b>	<b>≤1 S</b>
Cefiderocol <sup>*</sup>	<b>1 S</b>	<b>.25 S</b>	<b>1 S</b>	<b>.5 S</b>	<b>1 S</b>	<b>1 S</b>	<b>.25 S</b>	<b>.5 S</b>	<b>.5 S</b>	<b>.5 S</b>	<b>.5 S</b>	<b>.5 S</b>	<b>32 R</b>
Sulbactam <sup>++</sup>	8 I	64 R	64 R	16 R	8 I	8 I	32 R	32 R	16 R	16 R	16 R	16 R	16 R
Sulbactam/durlobactam <sup>#</sup>	<b>4 S</b>	<b>4 S</b>	<b>2 S</b>	<b>1 S</b>	<b>1 S</b>	<b>2 S</b>	<b>8 I</b>	<b>4 S</b>	<b>4 S</b>	<b>4 S</b>	<b>4 S</b>	<b>4 S</b>	<b>4 S</b>

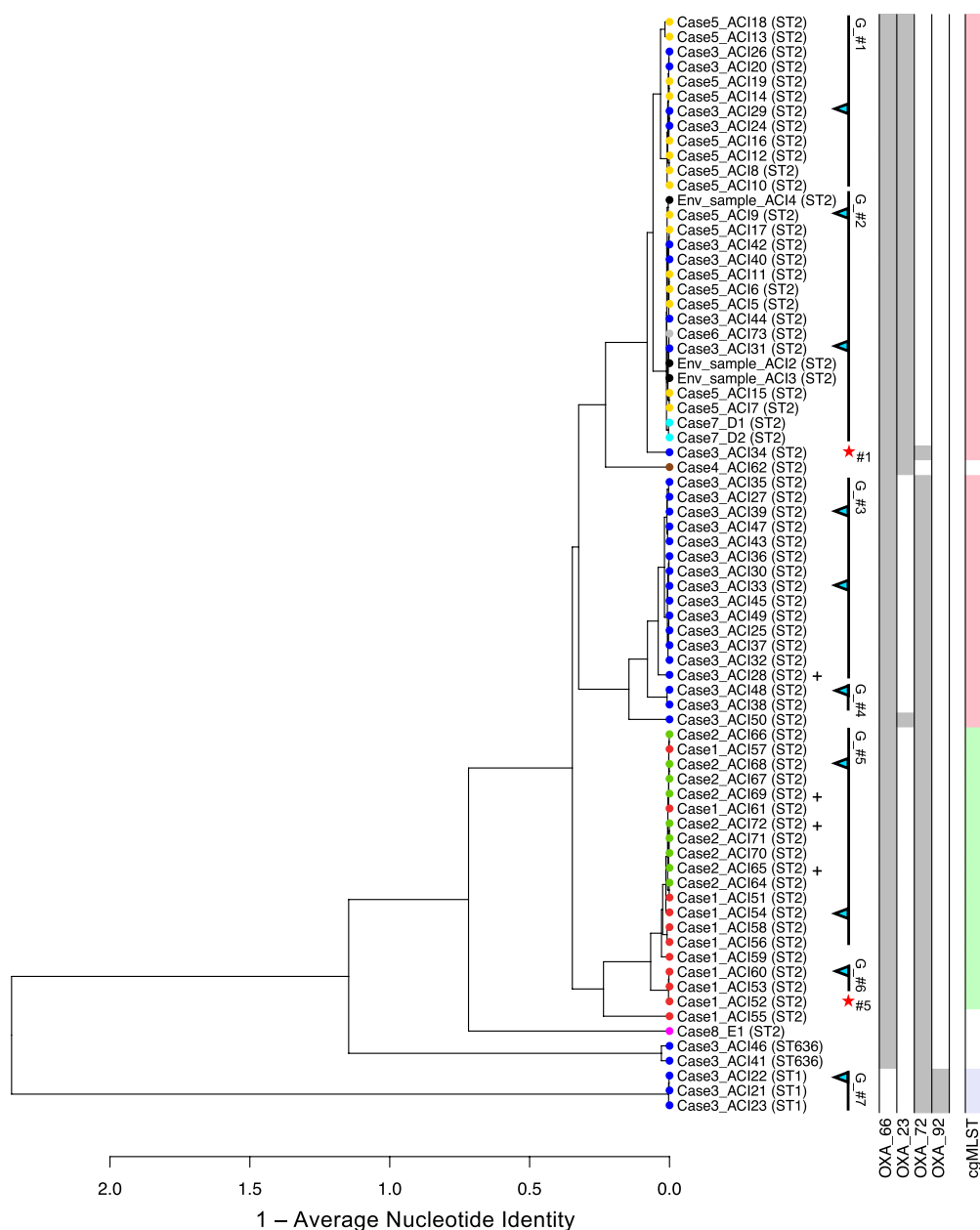
Breakpoints are according to EUCAST v13.1, unless otherwise stated. Breakpoints for antimicrobials that could be considered for treatment are printed in bold (resp. – respiratory; env. – environmental; MLST – multilocus sequence type)

<sup>†</sup> If isolate is reported susceptible, use of antimicrobial can be considered in combination with another effective agent

<sup>\*</sup> CLSI M100Ed33 Breakpoint

<sup>++</sup> Based on CLSI M100Ed33 Breakpoint for Ampicillin/sulbactam

<sup>#</sup> Preliminary CLSI breakpoint:  $S \leq 4/4 \mu\text{g/mL}$ ;  $R \geq 16/4 \mu\text{g/mL}$ ;  $R \geq 16/4 \mu\text{g/mL}$ . Only sulbactam concentration is shown



**Fig. 3** Dendrogram based on the average nucleotide identity (ANI) values of carbapenem-resistant *Acinetobacter baumannii* isolates (n = 74), along with the detected carbapenemase genes, sequence types (STs) and cgMLST results. The leaf color indicates the individual patient; environmental isolates are shown in black. Strains were grouped on the basis of their phylogenetic relatedness (G\_#) via ANI and SNP analysis (30 SNPs was considered the cut-off for group designation). Cyan arrows show references for SNP calling; red stars signify deviations of SNP results (indicating the group) from ANI analysis. +: = <math>\le 35</math> SNPs to one reference of the group

group (G\_#1). Case 1, Case 3 and Case 5 carried phylogenetically distinct CRAB isolates, indicating intrahost diversity of CRAB strains.

Additionally, a cgMLST analysis was performed to add another molecular method frequently used for epidemiological analysis. The minimum spanning tree based on the cgMLST analysis was largely congruent

with the ANI based results (Fig. 3); a detailed analysis (minimum spanning tree) is shown in Supplementary Material 2.

For all isolates, genes encoding carbapenemases were detected, explaining their resistance phenotypes (Fig. 3). However, the individual enzyme types differed between groups. All isolates except those linked to G\_#7 (ST1)

exhibited blaOXA-66. The isolates in G\_#1 and G\_#2, along with ACI\_34, ACI\_62 and ACI\_50, additionally contained blaOXA-23. The strains in groups G\_#3 – G\_#7 possessed genes encoding blaOXA-72. Notably, all three OXA types were detected in ACI\_34 and ACI\_50. The strains in G\_#7 (ST1) also presented genes associated with blaOXA-92.

## Discussion

In the present retrospective study of the Department of Plastic, Aesthetic, Hand and Reconstructive Surgery covering the years 2020–2022, we detected a higher incidence (0.2 CRAB cases per 100 cases in the entire department, 0.86 CRAB cases per 100 cases in the BICU) than did a previous study covering the years 2015–2019, where an overall CRAB incidence of 0.019 CRAB cases per 100 inpatient cases was observed in our entire hospital [13]. This was mainly attributable to two transmission clusters and there was no change in the overarching IPC concept compared with our prior study. An Australian study focusing on a BICU reported a higher incidence density, 3.3 per 1000 patient days from July 2019 to June 2020 [25]. In addition, studies from the U.S., South Africa, India and Singapore reported high numbers of infections caused by *Acinetobacter baumannii*, including carbapenem-resistant isolates [26–29], emphasizing the global importance of this pathogen.

The literature describes hospital clusters/outbreaks caused by CRAB in burn medicine [7, 30] and in other settings [10, 31]. High-resolution molecular analyses are helpful in providing support for epidemiologically suspected transmission clusters [4, 10]. In our case, the epidemiological assumption (two separate clusters) was confirmed by the molecular typing methods used (applying ANI and SNP analyses as well as cgMLST). We performed analyses based on ANI and SNPs to deduce the phylogenetic relationship between strains and obtain detailed insights at the whole-genome level. Furthermore, cgMLST, which represents a standardized method for investigating epidemiological events, was effective for understanding the relevant transmission patterns. Notably, within the two epidemiologically defined clusters (cluster 1 and 2), cases (patients) with genetically different CRAB isolates were found (e.g., within case 3). This emphasizes the necessity of investigating multiple isolates (for example, those collected at different time points or at different sample sites) from patients to draw appropriate conclusions and fully comprehend the overall picture of transmission.

In principle, rigorous and timely interventions to interrupt transmission chains are necessary from an IPC perspective. Some reported CRAB outbreaks required harsh measures, such as temporary closure of the affected ward,

to stop the outbreak [7, 32]. The fact that environmental contamination may also have facilitated individual transmission events in the present work underlines the importance of thorough cleaning/disinfection.

Importantly, adherence to basic IPC measures (such as hand hygiene, thorough cleaning/disinfection [14] and correct handling of medical devices) is crucial for controlling CRAB in endemic and epidemic contexts, as previously reported [31]. Notably, in our case, transmission events occurred despite the use of comprehensive IPC measures and hygiene-supportive framework conditions, such as general single-room accommodations in the BICU. We have therefore strengthened adherence to known and established IPC measures through repeated training sessions and audits by the IPC team, an intervention that has been highlighted previously in a CRAB outbreak in a Swedish burn center [14].

As described by others [32], we also observed the introduction of CRAB by patients who were previously treated in hospitals outside Germany. Admission screening and prophylactic isolation for transferred patients are cornerstones to address this challenge and should be implemented.

In the event of an infection, CRAB is difficult to treat. Reserve antibiotics such as ceftiderocol or colistin may be important therapeutic options in such cases [33–35]. The antimicrobial resistance tests carried out on selected isolates in this study showed broad susceptibility to these substances. Every isolate was susceptible to at least two antimicrobial substances that have been approved for use in Germany. As recent studies from India have reported resistance to colistin [36, 37] and colistin resistance has also been observed in ST2 (Pasteur) isolates in the U.S. [38], novel antibiotics such as sulbactam/durlobactam have gained importance and have been shown to be effective against CRAB infections [39]. Notably, durlobactam decreased the MIC of sulbactam by at least twofold compared with sulbactam alone, except for the isolate Case4\_ACI62 in our study. One possible explanation for the phenotype of Case4\_ACI62, is that the previously reported single-nucleotide polymorphism A515V in penicillin-binding protein 3 (PBP3) [40, 41] was identified in this isolate. According to a previous case report, sulbactam/durlobactam was effectively used in a critically ill burn patient [42].

In some cases, we identified isolates with differing antimicrobial susceptibility phenotype within the same patient. This may support the need for repeated MIC testing of clinically relevant CRAB isolates for a broad range of antimicrobial substances via high-quality methods.

The molecular (Pasteur sequence type) distribution of the isolates in our study is comparable to those found in



Europe in the recent overview of global CRAB epidemiology by Müller et al. [43]. Notably, our three ST1 isolates (all from case 3) carry a blaOXA-92 (OXA-51-like) variant, which is not represented in the global collection analyzed in that study [43].

This study has several limitations. First, we collected data retrospectively and focused on a single burn and plastic surgery department, which may limit the generalizability of our findings to other healthcare settings (e.g., other medical specialties, different countries, other types of hospitals). However, investigating the epidemiology of CRAB in our entire hospital, including all departments, was beyond the scope of this study. Another limitation concerns the environmental sampling methods used in this study. Specifically, common contact plates and swabs were used and we did not use more sensitive sampling methods, such as premoistened sponge swabs (e.g., the commercially available product POLYWIPE™ Range, Medical Wire & Equipment, Corsham, England) or other comparable products. This could have led to a lower recovery rate in the environmental samples.

## Conclusions

The present study shows that in a country such as Germany, which has a comparatively low prevalence of carbapenem resistance within Gram-negative bacteria, CRAB can still occur and may be challenging in terms of IPC, particularly when clusters occur on a ward. We demonstrated that analyzing many available bacterial isolates from the same patients is an advantage for understanding transmission chains, as it allows the elucidation of potential intrahost diversity, whereas analyses of single isolates might mask transmission events. Furthermore, in our case, environmental sampling was useful for CRAB management. Finally, our results indicate that CRAB will continue to be an IPC challenge in burn medicine and beyond.

## Abbreviations

ANI	Average nucleotide identities
AST	Antimicrobial susceptibility testing
cgMLST	Core genome multilocus sequence typing
BICU	Burn intensive care unit
CLSI	Clinical and Laboratory Standards Institute
CRAB	Carbapenem-resistant <i>Acinetobacter baumannii</i>
IPC	Infection prevention and control
IQR	Interquartile range
MIC	Minimum inhibitory concentration
MLST	Multilocus sequence typing
ST	Sequence type

## Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13756-024-01459-5>.

Supplementary Material 1

Supplementary Material 2

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## Further note

Partial and preliminary results of the second cluster connected with the BICU were presented as an online poster at the European Congress of Clinical Microbiology and Infectious Diseases (ECCMID) 2022.

## Author contributions

All authors contributed to the manuscript according to the International Committee of Medical Journal Editors recommendations. All authors were involved in data acquisition, analysis and interpretation. LK and DS carried out the microbiological analysis. LK performed sequence type analysis. MV and SW performed the isolate sequencing and subsequent bioinformatic analyses. CB, F-CB, EE, PV, TD and NK were involved in infection prevention and control management and the epidemiologic workup. PV, TD, NK and KD were responsible for clinical management. CB, LK and MV wrote the manuscript and organized the drafting process. All authors have read and agreed to the final draft before submission.

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## Availability of data and materials

The patient data used in this study are confidential in accordance with the German Data Privacy Act, the ethics committee and the data protection commissioner of Hannover Medical School. Patient-related data such as date of ward admission, age, sex, underlying disease or length of stay are indirect identifiers that might enable patient identification. To protect patient confidentiality and participant privacy, the data used for this study can be obtained in anonymized and condensed form only, according to the Data Privacy Act. Interested researchers who meet the criteria for access to confidential data may contact the data protection commissioner of the Hannover Medical School ([datenschutz@mh-hannover.de](mailto:datenschutz@mh-hannover.de)) and one of the corresponding authors (e.g., [baier.claas@mh-hannover.de](mailto:baier.claas@mh-hannover.de)) to obtain access to anonymized data, as approved by the data protection commissioner and the ethics committee of the Hannover Medical School.

## Declarations

### Ethics approval and consent to participate

The institutional review board (ethics committee) of Hannover Medical School approved this study (10682\_BO\_K\_2022). Given that this was a retrospective, quality-assuring study, the need for informed consent was waived by the Ethics Committee and the Data Protection Commissioner of Hannover Medical School.

### Consent for publication

Not applicable.

### Competing interests

The authors declare no competing interests.

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