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Preparedness of German emergency departments for chemical, biological, radiological and nuclear (CBRN) incidents

Main results of a nationwide survey

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Introduction

Emergency departments (ED) must have the ability to deal with ingestions, poisonings, chemical burns, and infectious diseases—as these are part of the usual spectrum of illness that presents for emergency management. Beyond the ability to treat individual patients, EDs must also have the capability to deal with mass casualty events, both accidental and deliberate. Chemical plants and nuclear power plants are usually located in or near densely populated areas, where there is enough labor force and infrastructure available. Due to this proximity, there is potential for significant impact on large numbers of people. As a result of growing globalization, urbanization, and climate change, our world has also become increasingly prone to the spread of infectious diseases and to the development of pandemics [1, 2]. Terrorist threats and armed conflicts involving the use of hazardous materials also present unique challenges to EDs and emergency medical services (EMS).

Unlike in a hazardous material spill or an industrial accident, in the case of a terrorist attack, EMS and EDs can be confronted with a largely unknown threat. In these cases, it is likely that ambulatory contaminated patients will look for help at the nearest available hospitals, bypassing on-scene decontamination. This phenomenon was demonstrated during the 1995 sarin attack in Tokyo, where over 5500 casualties presented themselves to the nearest hospitals [3].

Internationally, preparedness for chemical, biological, radiological, nuclear (CBRN) mass casualty incidents gained attention after the 9/11/2001 terrorist attacks on the World Trade Center in New York and the subsequent anthrax attacks. In Germany, it was the 2006 World Cup that served as the impetus to improve pre-

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Abstract

Background: Post-pandemic considerations, as well as lessons learned from terrorist attacks, wars, and disasters worldwide demonstrate that emergency departments must be prepared for mass casualty events related to chemical, biological, radiological, and nuclear (CBRN) hazardous materials. Our aim was to evaluate whether German emergency departments are sufficiently prepared for such events.

Methods: We developed a survey and distributed it to all chairpersons of emergency departments in Germany via the German Emergency Department Directory. Results of the survey were described using total numbers and percentages. Capacity for decontamination at different sites was graphically displayed using box-and-whisker plots. The primary endpoint of this study was whether German emergency departments are sufficiently prepared for CBRN incidents.

Results: Of 963 emergency departments, 262 (27.21%) answered the survey: 80.43% (189/235) of the hospitals had a plan for biological incidents, 49.36% (116/235) for chemical incidents, and 34.47% (81/235) for radionuclear incidents. Furthermore, 50% (116/232) reported some kind of decontamination site, but only 31.42% (71/226) reported having a water supply to their decontamination area. Sufficient protective equipment was only available in 27.51% (63/229) of emergency departments. Only 12.02% (25/208) of hospitals were able to decontaminate supine patients properly, following a decontamination scheme.

Conclusion: Most German hospitals are not adequately prepared to handle casualties resulting from chemical, biological, radiological, or nuclear hazardous materials. Given these results, there is a need for systemic intervention at the national level in order to improve preparedness.

Keywords
Hazmat · Hazardous materials · Disaster medicine · Civil protection · ABC · Mass casualty incidents

paredness for CBRN mass casualty events. Specifically, the goal was to implement a new approach to on-scene decontamination of injured and contaminated patients, as well as to set up special units for this purpose [4]. In addition, a survey was conducted by the German Federal Office of Civil Protection and Disaster Assistance (BBK; "Bundesamt für Bevölkerungsschutz und Katastrophenhilfe") in 2007, regarding preparedness of hospitals for CBRN mass casualty events—demonstrating a serious and concerning lack of preparedness among many German hospitals [5].

We conducted this research to assess the current preparedness of German emergency departments for CBRN mass casualty incidents and to evaluate whether preparedness has improved since 2007.

Methods

A descriptive, cross-sectional study was performed, for which a questionnaire was developed to evaluate preparedness of German EDs to CBRN mass casualty events.

The questions were developed by a group of experts from the task group for Disaster Medicine of the German Interdisciplinary Society for Emergency Medicine (DGINA; "Deutsche Gesellschaft Interdisziplinäre Notfall- und Akutmedizin"). The survey was validated regarding face content and construct validity by 8-member expert group of emergency medicine (EM) physicians from different institutions.

The survey consisted of 28 questions covering basic data regarding the ED, questions relating to incident management in general, logistics, the physical buildings and structures to be utilized, as well as questions relating to training of personnel, triage processes, patient decontamination processes, and capacity. The ethics committee of the state chamber of physicians deemed that ethics approval was not necessary for this survey. The survey was conducted online from May–June 2023, using umfrageonline.com (enuvo GmbH, Pfäffikon, Switzerland) as the platform. A link to the survey was sent via the German Emergency Department Directory (GEDD), which is run by DGINA and the German Interdisciplinary Association of Intensive Care and Emergency Medicine (DIVI; "Deutsche Interdisziplinäre Vereinigung für Intensiv- und Notfallmedizin") together, to the chairperson of every German ED. After the initial e-mail, we sent two reminder e-mails after 2 and 4 weeks and concluded the survey after 6 weeks.

We invited all chairpersons of EDs that are included in the GEDD, who are responsible for 963 EDs throughout Germany, to take part in our survey. The data were collected and transferred to a spreadsheet in Excel (Excel, Microsoft, Redmond, WA, USA). Results were described using percentages and total numbers. Capacities for decontamination were graphically displayed as box-and-whisker plots using R (R Core Team 2022, Vienna, Austria).

Results

Of 963 EDs that were contacted via the GEDD, the chairpersons of 27.21% (262/963) German EDs answered the survey, corresponding to 20.17% (91/451) of all level I EDs (basic treatment), 38.46% (90/234) of all level II EDs (advanced treatment), and 41.57% (69/166) of all level III EDs (comprehensive treatment). The EDs of 4 respondents were not assigned to a level and 8 did not disclose the level.

Hospital disaster planning

Procedures for a mass casualty event with infectious patients were included in hospital disaster planning in 80.43% (189/235) of the hospitals, chemical incidents were included in 49.36% (116/235), and radionuclear incidents were included in 34.47% (81/235) of hospitals, while 18.30% (43/235) of respondents disclosed that they were not aware of any of the aforementioned scenarios being a part of their hospital disaster plan.

Organizational, structural, and logistical aspects

A separate area with a separated access for patients with infectious diseases was present in 27.04% (63/233) of EDs, while 24.46% (57/233) had a separate area but not a separated access. In 35.62% (83/233) of EDs patient flows can be separated, but a physical separation is not present, while in 12.88% (30/233) of EDs, due to their construction, separation of patients is not possible at all.

There was wide variability in terms of decontamination practices among respon-

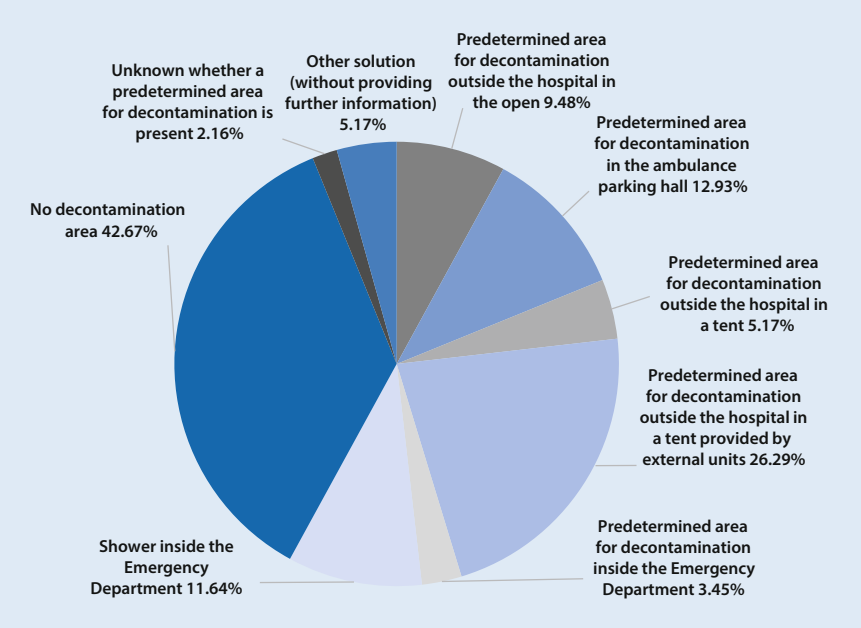

Fig. 1 ▲ Answers to "Is there a predetermined area for decontamination at your emergency department?" *N* = 232

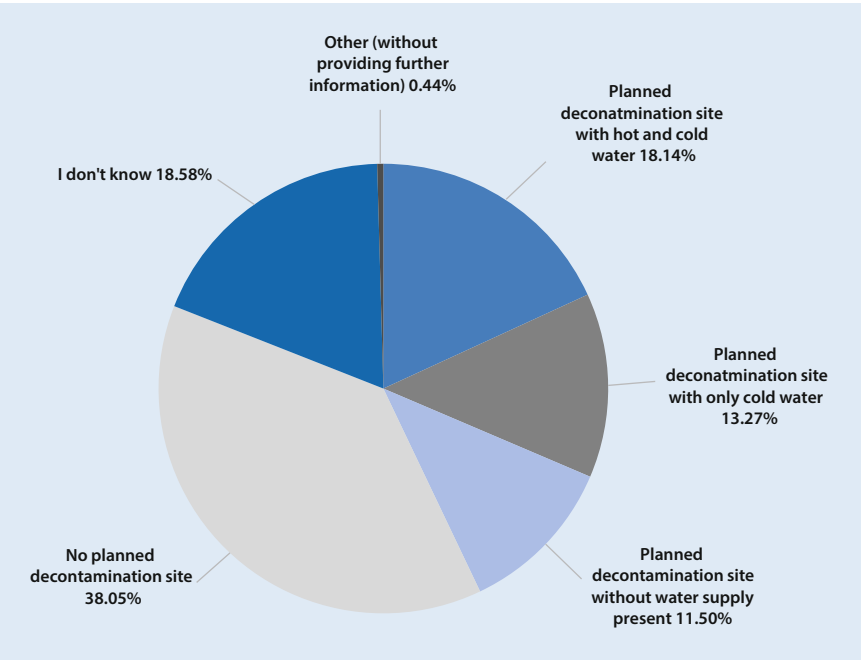

Fig. 2 ▲ Answers to "Is your decontamination area equipped with a water supply?" *N* = 226

dents. Details relating to the presence and location of predetermined decontamination areas are displayed in ◘ **Fig. 1**.

Water supply availability was limited and varied among centers. Details relating to the availability of a water supply at the decontamination area are displayed in ◘ **Fig. 2**.

Regarding wastewater management: 9.25% (21/227) of the hospitals were able to contain and dispose wastewater properly and 5.29% (12/226) reported to have a temporary ability to do so. Planned disposal of wastewater into the sewer was reported by 15.42% (35/226) of the hospitals according to consultation with responsible authorities, while 6.61% (15/226) reported to do so without an agreement with authorities. Furthermore, 26.87% (61/226) reported no decontamination capacity and 35.68% (81/226) reported that they do not know how wastewater is handled at their hospital.

Regarding disposal of contaminated clothing: 45.81% (104/227) reported that they have ready special disposal bags, while 23.79% (54/227) reported that contaminated clothing is kept in usual bags for patient belongings. 30.40% (69/227) reported no ability to collect and store the clothing or to carry out decontamination.

Personal protective equipment

Appropriate personal protective equipment (PPE) was available in 27.51% (63/229) of the EDs. Details relating to the highest class of available PPE in the ED are displayed in ◘ **Fig. 3**.

Education and training

Training of ED employees in CBRN emergencies and mass casualties was relatively infrequent. Detailed results are displayed in ◘ **Table 1**.

Decontamination process and capacities

Answers relating to staff responsible for decontamination demonstrated widely varying practices among different hospitals. Details relating to staffing for decontamination are summarized in ◘ **Fig. 4**.

Supine, injured patients could be properly decontaminated (e.g., following a decontamination scheme like the 1-3-2 scheme) by 12.02% (25/208) of the EDs, while injured, but ambulatory patients could be decontaminated by 16.35% (34/208). In addition, 17.31% (36/208) reported being able to decontaminate ambulatory but otherwise uninjured patients. Only a makeshift emergency decontamination was possible in 39.90% (83/208) of hospitals, while 25.96% (54/208) reported no ability to decontaminate patients whatsoever. 13.46% (28/208) declared that they do not know whether or which patients they would or would not be able to decontaminate.

Information on how many patients could be decontaminated per hour was provided by 9.66% (20/207) respondents

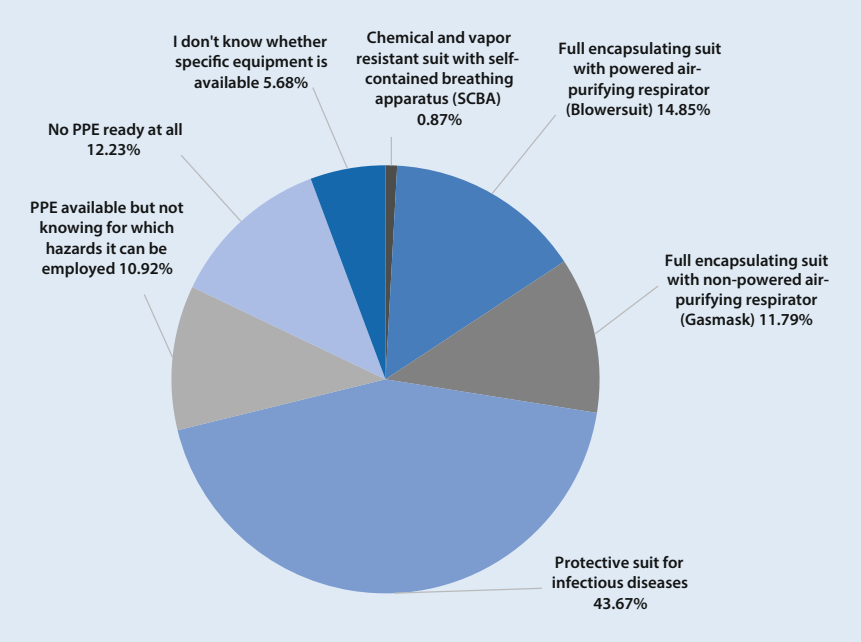

Fig. 3 ▲ Answers to "What is the highest class of personal protective equipment (PPE) available in your emergency department?" *N* = 229

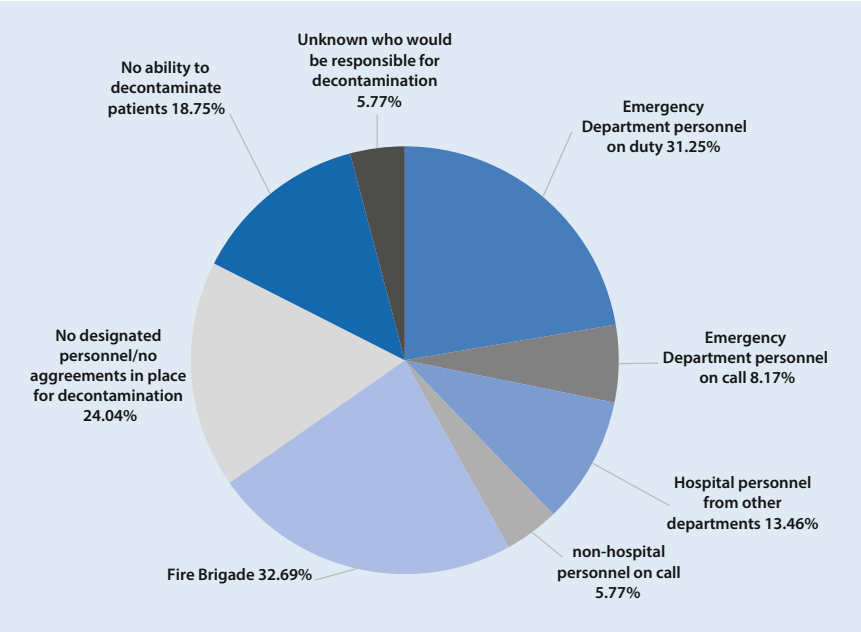

Fig. 4 ▲ Answers to "What personnel are responsible for performing decontamination in your emergency department?" *N* = 208

for supine patients and by 14.01% (29/207) for ambulatory patients. Details relating to decontamination capacity are summarized in ◘ **Fig. 5**.

Discussion

Previous studies evaluating preparedness for CBRN emergencies and mass casualties in the USA [6–14], the UK [15–20], Canada [21], Poland [22], Belgium [23], the Netherlands [24], Austria [25], China [26], Australia [27], Germany [5], and Israel [28] have demonstrated that most hospitals lack the ability to deal with contaminated patients—with the exception of Israeli hospitals.

In 2007, Martens evaluated the ability of 859 German hospitals with more than 200 beds to deal with CBRN casualties. Of the 859 hospitals, 388 (45.2%) responded to his survey. Though 94% (363/388) had a hospital disaster plan, only 22% (84/388) specifically planned for CBRN casualties [5]. When compared to our data, planning for CBRN casualties has improved in the intervening years, with 80.43% (189/235) of hospitals having a plan for biological incidents, 49.36% (116/235) for chemical incidents, and 34.47% (81/235) for radionuclear incidents.

While Martens reported that isolation of patients in the ED was possible in only 20.36% of the hospitals (79/388), we found that 87.12% of the EDs had some kind of ability to isolate patients (203/233), although only 27.04% of the EDs (63/233) had a completely separated access route to the isolation area [5]. This might in part be a result of recent improvements owing to the coronavirus disease 2019 (COVID-19) pandemic, as evidenced by a high percentage of hospitals having plans for biological incidents compared with the lower percentage for chemical or radionuclear incidents.

Martens reported that only 14.95% (58/388) of hospitals had a decontamination area [5], while in the present survey 50% (116/232) of hospitals reported some kind of decontamination site. However, Martens' study did not specify the location of decontamination sites, while our survey asked more granular questions to better understand decontamination plans.

We found that 15.09% (35/232) of hospitals reported their decontamination site to be inside the hospital doors and 9.48% (22/232) reported the decontamination site to be outside in the open, both of which are not ideal. Ideally, decontamination should be performed before patients enter the ED, to prevent further contamination of the hospital and (limit) exposure of ED personnel and patients to hazardous materials. Location of a decontamination site inside the ED means risking the hospital's ability to respond to the event altogether. Furthermore, decontamination should be performed as early as possible, to stop or minimize the detrimental effects of these substances to the patient. As decontamination from

Table 1 Training and instruction intervals of emergency department employees in chemical, biological, radiological, and nuclear (CBRN) emergencies and mass casualties

Question	More frequently than once per month	More frequently than once per 6 months	More frequently than once per year	More frequently than once per 3 years	Less frequently than once per 3 years	None	I don't know	Other answers[a]
Total answers, (*n*)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)
How often are employees trained in the hospital disaster plan (252)	2 (0.79)	13 (5.16)	58 (23.02)	74 (29.37)	61 (24.21)	41 (16.27)	3 (1.19)	0 (0)
How often are employees instructed on intoxications (208)	3 (1.44)	12 (5.77)	38 (18.27)	52 (25.00)	48 (23.08)	48 (23.08)	5 (2.40)	2 (0.96)
How often are employees instructed in care for contaminated patients (208)	1 (0.48)	4 (1.92)	27 (12.98)	37 (17.79)	56 (26.92)	75 (36.06)	7 (3.37)	1 (0.48)
How often are employees instructed in donning/doffing (207)	1 (0.48)	4 (1.93)	23 (11.11)	27 (13.04)	59 (28.50)	79 (38.16)	13 (6.28)	1 (0.48)
How often is the decontamination process trained (208)	1 (0.48)	2 (0.96)	11 (5.29)	30 (14.42)	49 (23.56)	106 (50.96)	8 (3.85)	1 (0.48)

[a]Other answers refers to those written in a free-text field that could not be interpreted

chemical and/or radioactive materials is usually achieved by undressing and washing patients with soap and water, patients are also at risk for hypothermia. Given these issues, decontamination should ideally take place in an installed decontamination site that is outside the ED, like in the ambulance parking hall or tent, which can be heated and where both hot and cold water are available.

Of note, 26.29% (61/232) reported that decontamination will be performed in a tent outside the ED by the fire brigade, which in real-world practice is also likely problematic. Units of the fire brigade that are capable of decontaminating injured patients, especially if supine, are stationed in relatively few locations and it is highly likely that during a mass casualty incident, these units will already be deployed to decontaminate patients at the scene of the incident [28].

In addition, only 18.14% (41/226) respondents reported that their hospital had both access to hot and cold water in their decontamination area, while at least cold water was available in 13.27% (30/226) of the hospitals. This suggests that a decontamination area matching minimum requirements is only available at roughly 30% of hospitals responding to this survey. In line with this capacity estimate were answers relating to wastewater, where only 29.96% (68/227) had made appropriate arrangements for post-decontamination handling.

Decontamination through undressing and washing patients with soap and water is considered relatively effective for exposures to chemical and/or radioactive materials. This approach is currently the recommended strategy for achieving decontamination in these settings, while biological exposures are primarily addressed by disinfection [29]. Given these commonly held standards, we did not ask questions about the availability of alternate decontamination strategies. However, there are some alternate approaches to achieving decontamination from chemical substances like dry powders (e.g., Fuller's earth) for absorbing liquid materials or chemicals that are reactant to the use of water [29]. Another more recent strategy is the use of decontamination foams that react with chemical contaminants and form less haz-

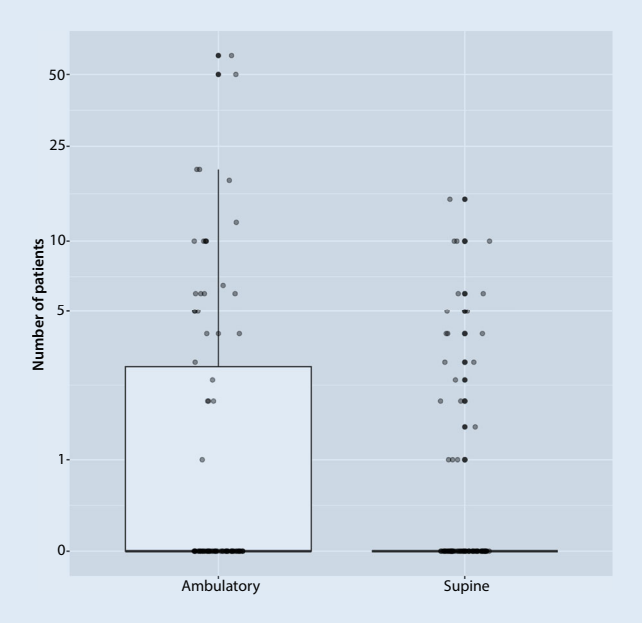

Fig. 5 ▲ Box-and-whisker plots showing the number of ambulatory (91/207) and supine (93/207) patients that can be decontaminated per hour. Included are respondents who reported a specific number of ambulatory (14.01%; 29/207) and supine (9.66%; 20/207) patients and respondents who reported that they are not able (= 0) to perform decontamination of ambulatory (29.95%; 62/207) or supine (35.27%; 73/207) patients. The number of patients that could be decontaminated per hour was not known by 56.04% (116/207) of the respondents for ambulatory patients and by 55.07% (114/207) for supine patients

ardous products [29]. The advantages of these newer techniques are that no water is needed and less wastewater is produced. The primary disadvantage is that these decontaminants must be stored in large quantities—while water is less expensive, more readily available [29], and can also be used for radiation decontamination. However, considering the relatively low number of hospitals that are well prepared for CBRN emergencies, alternate approaches for decontamination should be considered. In this context, the use of life-saving antidotes prior to performing decontamination is another important strategy for some substances [5].

With regards to PPE, Martens reported that 8.50% (33/388) of hospitals kept chemical resistant suits and 18.56% (72/388) had ready suits for infectious diseases [5]. In our study, 26.64% (61/229) kept suits with either powered (blower-suit) or non-powered (gasmask) air-purifying respirators ready, while a suit with a self-contained breathing apparatus (SCBA) was only available in 0.87% (2/229) of the EDs as highest class of PPE.

Training regarding donning and doffing (putting PPE on and off properly), as well as identifying and handling contaminated patients was reported to be relatively infrequent (◘ **Table 1**).

Especially in the case of a terrorist attack it is crucial that signs of contaminations (bleached clothes, spilling) as well as more than one patient presenting with signs of an intoxication be recognized by ED personnel. This early identification and subsequent triage is crucial for a safe and effective response. Apart from having the equipment to perform decontamination, adequate training of staff regarding decontamination process and appropriate handling of PPE is essential. The findings of our study, as well as those of Martens' prior work, suggest that few hospitals meet the minimum requirements for decontamination processes and staff training [5].

The decontamination process is expected to be carried out by the ED personnel on duty for 31.25% (65/208) of respondent hospitals, while 27.40% (57/208) reported having some kind of on-call service for this purpose. Assuming that on-duty ED personnel are fully engaged by other tasks during a mass casualty event, it is reasonable to establish a separate group for carrying out decontamination, in order to avoid removing staff from other critical duties during an event. In contrast to the present survey, Martens reported that only 5% of hospitals (18/388) had an on-call service for CBRN casualties [5].

Only 16.35% (34/208) of hospitals reported being able to decontaminate ambulatory patients properly (e.g., following a scheme). This should be of concern, as self-presenters will likely be ambulatory, while supine patients are more likely to undergo on-scene decontamination [29]. Given the potential of a high number of self-presenters quickly overwhelming the capacities of EDs, several approaches—including instructed self-decontamination—have been discussed [30, 31]. Nevertheless, appropriate facilities must be available. As obvious endpoints of effective decontamination are usually not available for chemical substances, the adherence to a decontamination scheme is the only way to complete this objective in a generally accepted way [29]. For radioactive substances, the use of radiation detectors can determine the effectiveness of decontamination. Fortunately, since ambulatory patients are able to shower themselves, a more thorough decontamination is generally expected in this population [29].

Of significant concern is the finding that only makeshift decontamination with improvised measures was available in 39.90% (83/208) of hospitals.

Very few hospitals were able to specify a number of patients they could decontaminate per hour. This is concerning, as EDs that are sufficiently prepared for CBRN casualties should be able to estimate this number. Even for those respondents who were able to provide an estimate, the number of patients decontaminated per hour are far below expectations for on-scene decontamination as specified in the framework of the BBK [4], where decontamination of 40 ambulatory patients and 10 supine patients per hour is expected (◘ **Fig. 5**).

Although there have been some improvements to CBRN preparedness since 2007, we conclude from this data that

most German hospitals are still not sufficiently prepared to deal with CBRN casualties. One main reason for insufficient preparedness of hospitals for CBRN mass casualties seems to be different responsibilities of authorities in different levels of the administration of the federal government and the federal states in Germany, as well as lack of legislation. While hospital laws in all federal states require a hospital disaster plan, these laws largely do not regulate the content of these plans. Planning and training of staff for managing CBRN casualties is predominantly elective and both are usually not reviewed by authorities, financed by the public, or covered by health insurance companies. Hospital managers are likely not aware of these risks and may not see the necessity of investing limited financial resources into hospital preparedness, unless required to do so by law [23, 24].

In comparison, in 2001, CBRN preparedness in England significantly improved after the English ministry of health decided to equip hospitals with appropriate PPE and self-expanding tents [18]. Subsequently, in 2005 the English government also passed legislation requiring hospitals to adequately prepare for chemical incidents [20]. In Israel, hospitals are required by law to have a full chemical practical drill every 3–5 years with 100–400 simulated patients, resulting in Israeli hospitals being well-prepared to deal with CBRN mass casualties [28]. These examples demonstrate that preparedness for CBRN incidents is possible, but has to be required by law, publicly financed, and enforced by responsible authorities through disaster drills.

Limitations

The study was performed as an online survey and sent to the chairpersons of 963 German EDs via the German Emergency Department Directory. Therefore, a limitation of our study design is that it relies on self-reported data.

With a response rate of 27.21%, the survey is subject to the usual biases (e.g., nonresponse/participation bias). As we do not know the motivations to take part, we can only speculate how this may have influenced our results. However, we suspect that those responding to this survey are likely more interested in this topic than those who did not. If this is the case, we would assume preparedness of nonrespondents to potentially be worse and for our data to actually underestimate the problem.

Questions relating to details of the decontamination processes were answered inconsistently by some participants, leading to different numbers of hospitals where no decontamination area was present. This may be a result of—and demonstrate—an insecurity and lack of knowledge in preparing for—and dealing with—CBRN incidents.

Unlike some prior work, in this survey we did not pose questions related to the availability of antidotes, the vicinity of high-risk installations (e.g., chemical or nuclear plants), the availability of devices for radiation detection, or the availability of expert advice, as this would have increased the length of the survey substantially. Despite these limitations, our survey represents a relevant proportion of German EDs and we believe that our results offer meaningful insights into the current state of CBRN preparedness.

Conclusion

Although our data suggests some improvements over the last 16 years, most German hospitals remain insufficiently prepared for chemical, biological, radiological, and nuclear (CBRN) mass casualty events.

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Author Contribution. M. Bollinger: conceived the study, designed trial, collected the data, drafted the manuscript and takes responsibility for the paper as a whole; S. Bushuven: designed the trial, collected the data; M. Bentele, S. Wenske, D. Goertz, P. Tralls, and B. Kumle: designed the trial; A.D. Shapeton: drafted the manuscript; M. Kohl: provided statistical advice and analyzed data. All authors contributed substantially to the manuscript revision.

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Declarations

Conflict of interest. M. Bollinger, S. Bushuven, M. Bentele, S. Bentele, S. Wenske, D. Goertz, A.D. Shapeton, M. Kohl, P. Tralls and B. Kumle declare that they have no competing interests.

For this article no studies with human participants or animals were performed by any of the authors. All studies mentioned were in accordance with the ethical standards indicated in each case.

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Zusammenfassung

Vorbereitung deutscher Notaufnahmen auf Notfälle mit chemischen, biologischen, radiologischen und nuklearen (CBRN) Gefahrstoffen. Hauptergebnisse einer nationalen Befragung

Hintergrund: Postpandemische Überlegungen und auch Lehren aus Terroranschlägen, Kriegen und Katastrophen weltweit zeigen, dass Notaufnahmen auf einen Massenanfall von Verletzten mit chemischen, biologischen, radiologischen und nuklearen (CBRN) Gefahrstoffen vorbereitet sein müssen. Ziel der vorliegenden Arbeit war es, die Vorbereitung deutscher Notaufnahmen auf derartige Ereignisse zu untersuchen.
Methode: Wir erstellten einen Online-Fragebogen, der über das gemeinsame Notaufnahmeverzeichnis an alle Leiter von Notaufnahmen in Deutschland versendet wurde. Die Ergebnisse der Untersuchung wurden in absoluten Zahlen und Prozentwerten dargestellt. Die Dekontaminationskapazitäten unterschiedlicher Notaufnahmen wurden grafisch in Box-Whisker-Plots dargestellt. Primärer Endpunkt war die ausreichende Vorbereitung deutscher Notaufnahmen auf CBRN-Ereignisse.
Ergebnisse: Von 963 Krankenhäusern mit Notaufnahmen beantworteten die Leiter von 262 (27,21 %) unseren Fragebogen. 80,43 % (189/235) der Krankenhäuser hatten Krankenhausalarm- und Einsatzpläne für biologische Ereignisse, 49,36 % (116/235) für chemische Ereignisse und 34,47 % (81/235) für radionukleare Ereignisse. Des Weiteren berichteten 50 % (116/232) über eine irgendwie geartete Dekontaminationsmöglichkeit, allerdings war nur in 31,42 % (71/226) der Kliniken ein Wasseranschluss in diesem Bereich verfügbar. Ausreichende Schutzkleidung war nur in 27,51 % (63/229) der Notaufnahmen verfügbar. Nur 12,02 % (25/208) der Krankenhäuser waren in der Lage, auch liegende Patienten fachgerecht – nach einem festen Schema – zu dekontaminieren.
Schlussfolgerungen: Die meisten deutschen Kliniken sind nicht ausreichend auf die Versorgung von Patienten nach einem CBRN-Ereignis vorbereitet. Vor dem Hintergrund der dargestellten Daten besteht aus Sicht der Autoren ein dringender Handlungsbedarf, die Vorbereitung von Krankenhäusern auf CBRN-Ereignisse bundesweit systematisch zu verbessern.

Schlüsselwörter
Gefahrstoffe · Gefährliche Güter · Katastrophenmedizin · Bevölkerungsschutz · ABC · Massenanfall Verletzter