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# Preparedness for chemical crisis situations: experiences from European medical response exercises

R.K. DAVIDSON[1,6], S. MAGALINI[2], K. BRATTEKÅS[1], C. BERTRAND[3], R. BRANCALEONI[2], C. RAFALOWSKI[4], E. ROSTRUP NAKSTAD[5]

[1]Comprehensive Defence Division, Norwegian Defence Research Establishment, Kjeller, Norway
[2]Department of Surgery, Fondazione Policlinico Universitario A. Gemelli – IRCCS, Università Cattolica del Sacro Cuore, Rome, Italy
[3]Director of the Emergency Medical Center - SAMU 94, CHU Henri Mondor (AP-HP), Créteil, France
[4]Director General Office, Magen David Adom, Tel Aviv, Israel
[5]Department of Acute Medicine, Norwegian CBRNE Centre, Oslo University Hospital, Ullevål, Norway
[6]Section for Pathology Oslo and Tromsø, Norwegian Veterinary Institute, Tromsø, Norway

**Abstract. – OBJECTIVE: This study investigated how European first responders and hospital personnel, along with CBRN experts, approach an overwhelming surge situation after a chemical incident. Surge capacity and capability bottlenecks were discussed.**

**MATERIALS AND METHODS: Two chemical warfare agent (CWA) scenarios were developed: in the first, a nerve agent was released indoors; in the second, there was an outdoor explosion containing a blister agent. CBRNE experts, first responders and hospital specialists from across Europe participated in a two-day table-top exercise to discuss pre-hospital and hospital CBRNE preparedness, triage, surge capacity and communication issues. This was followed by a medical response exercise at a level 2 Emergency Department in Italy.**

**RESULTS: Several surge capacity challenges and lessons were identified. Critical resources were rapidly exhausted and sourcing from national/international medical stockpiles was not feasible in the time critical scenarios. Secondary contamination in the blister agent scenario was considered plausible and hospitals are currently unprepared for this situation. The medical response exercise highlighted further training needs.**

**CONCLUSIONS: The majority of the lessons are not new and have been reported in North American studies. However, this study is the first to describe these CWA challenges from a European perspective. Medical facilities across the region should consider these lessons to evaluate and improve their surge capacity, capability and response.**

*Key Words:*

Blister agent, CBRNE, Chemical warfare agents, Nerve agent, Terrorism, Surge capacity.

## Introduction

Natural disasters, accidents, pandemics and terror events can all result in sudden large-scale escalations (surges) for medical care needs[1,2]. The principles of health system surge capacity are built on four pillars (the four "S"s): staff, stuff, structure and systems[3] and go beyond classic estimates of hospital bed capacity requirements for infectious and non-infectious mass casualty scenarios (Figure 1). The systems aspect is often overlooked but is vital to bridge the gap between capacity (the availability of resources) and capability (utilisation of the available resources)[1,2]. It has been recommended that surge capacity planning should be based on casualty and resource estimates from specific scenarios[4]. The general consensus of the North American medical fraternity is summarised in a 2006 special issue publication of Academic Emergency Medicine[3,5,6] and the 2014 CHEST consensus statements[4,7-13]. They recognised that responding to surges would depend on the degree to which thresholds were exceeded between conventional care, contingency care and crisis care; the surge continuum taxonomy. The availability of resources would not only

*Corresponding Author:* Rachele Brancaleoni; e-mail: rachele.brancaleoni@unicatt.it

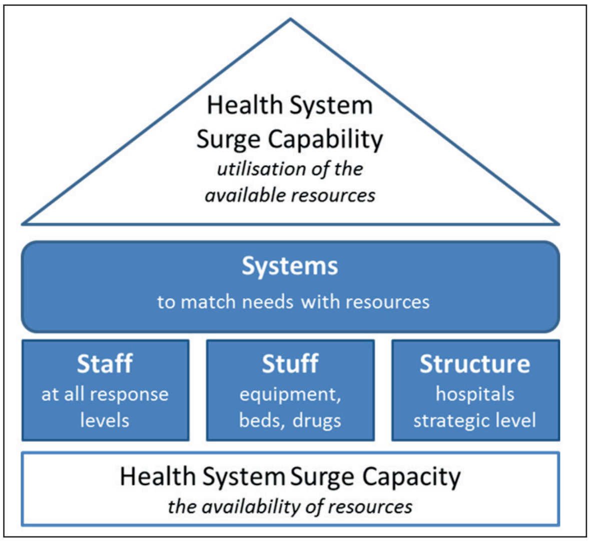


**Figure 1.** The four Ss of health system surge capacity that can lead to surge capability: staff, stuff, structure and systems.

depend on the scope of the disaster (local, regional or national) and number of casualties, but also on the quality of situational awareness and whether the disaster has sudden impact (like the scenarios described in this paper) or a slower onset (like pandemics or hurricanes), which can be anticipated and prepared for. CHEST recommendations[4,7-13] indicate that in crisis situations, with limited resources, the medical management has to shift from patient-orientated to population-orientated to maximise available assets for saving as many lives as possible. Crisis care levels would in all likelihood require resources from outside the hospital, which would take time to mobilise. Each hospital should carry out testing of all the components to fully assess the system capacity. Resource-sparing strategies should focus on conserving, substituting, adapting, re-using and re-allocating[4]. The hospital should also have a plan to free capacity for handling the crisis[12] and, at the same time, also be able to handle routine emergencies. As part of the EU FP7 project EDEN (End User Driven Demo for CBRNe) we wished to explore how European first responders and first receivers (hospital personnel) would approach an overwhelming surge in patients requiring medical attention after terrorist attacks using chemical agents. We looked at the medical response only and not other components of the first response. Two chemical warfare agent (CWA) scenarios, with two agents, were developed to put extreme pressure on medical incident response in a fictional, small central European country. This scenario was explored by European first-responders, first receivers and CBRN specialists during table-top and demonstration exercises, including a two day full-scale CWA medical exercise at the Policlinico Gemelli (Rome, Italy). We were particularly interested in how surge capacity and capability bottlenecks (triage, decontamination, patient transport, ICU availability, pharmacological treatment options, and communication) could be solved with local, national or international assistance and resources, as well as what areas presented the greatest challenges to responding effectively to such an overwhelming incident.

## Materials and Methods

### *CWA Table-Top Scenarios*

The scenarios developed involved two separate attacks, on the same day, in the capital city of a fictional European country with medical resources proportioned for the national population of 137 000 inhabitants, of which 90 000 lived in the capital. The city had two hospitals, one large and one small, with a bed capacity of 600 and 168 beds, respectively. The first attack occurred at noon at the national conference centre with 1200 people of all ages exposed to a chemical agent, from a device left by terrorists. Mild intoxication occurred within minutes, whilst serious injuries and fatalities occurred about 20 minutes after release. Given the symptomology, a nerve agent was rapidly suspected[14]. Half of the people at the conference centre showed evidence of intoxication: 120 had severe respiratory distress, 180 were incapacitated with significant symptoms whilst 300 had mild to moderate clinical symptoms, but were ambulatory. Two hours later a bomb detonated in one of the city squares, at an open-air concert with 1000 spectators. There were 10 fatalities at the scene and around 100 casualties that required medical treatment for trauma. The detonation disseminated a blister agent in the form of aerosol particulates and droplets. Small aerosol particulates were inhaled whilst the droplets were deposited on persons and surfaces. The development of clinical symptoms took time. An hour after the explosion preliminary results from chemical detectors used by first responders indicated the use of a chemical agent whilst it took four to five hours for unequivocal laboratory confirmation. At this point, nearly 100 patients were being treated in a number of different hospital departments, and dozens of first responders had worked at the blast scene. Two hours after the explosion, the first signs of tissue damage, ocular discomfort and irritation appeared in some of the patients. Four hours after the detonation and during the night and next day the number of people with skin inflammation, breathing difficulties, pain and nausea increased. Some first responders and hospital staff also developed symptoms and required treatment for chemical burns.

### *Table-Top Exercise*

A total of 20 first responders and hospital specialists as well as 25 CBRNE specialists from 11 countries (Austria, Czech Republic, France, Germany, Israel, Italy, Norway, Poland, Spain, Sweden and the UK) participated in the table-top exercise[15]. The scenario was presented, with video and audio inserts, before the participants were divided into six groups to discuss two of four potential discussion topics per chemical agent. Each group contained one moderator with a list of discussion topics and questions. Discussion topics were built upon relevant CBRNE gaps identified earlier in the EDEN project[16]. Each group had 30 minutes per topic before presenting their conclusions in the plenary session. Each topic was discussed by three different groups. The discussions focused on (1) hospital CBRNE preparedness plans for nerve or blister agents; (2) onsite triage and patient tracking challenges; (3) tackling surge capacity issues (pharmaceutical preparedness, intensive care capacity; mutual assistance agreements); and (4) – last but not least – the communication strategy was considered. The results from the communication discussions are not presented in this paper.

### *Medical Response Exercise*

The full-scale medical exercise took place at a 1400 hospital bed facility with a level 2 Emergency Department that had a CBRNE preparedness plan. There were 207 participants: 66 live demonstrators, 141 support staff and observers (national and international), in addition to an evaluation team of eight. The exercise had a two-fold aim: to test current hospital surge response capacity and to evaluate new technological solutions that could be integrated with current procedures. The CWA scenario was based on a 2 hour period from the Emergency Department receiving a call from the dispatch centre, recognising that a chemical event had taken place, and then following the protocol for non-conventional mass casualty response. Hospital staff donned PPEs, security officers cordoned off access points and decontamination tents were set up by the in-house fire fighters. Patients arrived via ambulance or self-evacuation. Triage and decontamination was carried out on 26 patients on day 1. They were assigned to red, yellow or green treatment rooms (5, 8 and 13 patients respectively) according to medical needs. The end of the emergency was announced two hours later, once no further patients awaited triage or decontamination. PPEs were then doffed. On day 2 the same scenario was run with staff in new positions (to avoid a learning effect) and new technological solutions and procedures were tested. This paper focuses on lessons identified on day 1 that supported or contradicted the findings from the table-top exercise.

## Results

A number of bottlenecks and challenges in dealing with the surge capacity were identified. These points have been loosely categorised under the 4 "S"s below and in Table I.

### *Health System Surge Capacity: Staff*

Treatment of victims from chemical agents requires large numbers of care providers due to the need to provide airway management and ventilation of acute patients. These staffing issues are compounded by the fact that personnel have to wear a PPE and thus can only work for a limited period before they have to be rotated out. Health care workers need to be familiar the unique characteristics of medical care when working in PPE whilst following safety procedures. Health care providers, unless trained, are not used to the physiological and psychological stress inherent in working in PPE. The live exercise highlighted the need for medical staff to train more frequently whilst wearing PPEs especially under low light conditions, such as at night. The training exercise showed that additional triage and decontamination carried out at the hospital entrance was not straightforward. The triage criteria used in CWA exposure is different from the "regular" hospital criteria, thus not always easy. The setting up a "decontamination site" requires a "command structure" that is not familiar to hospital providers. Having a hospital incident leader to coordinate this process as well as staff rotation was recommended. The hospital staff should primarily be focused on treating the patients and not

**Table I.** Medical surge capacity and capability challenges in a chemical crisis: lessons identified during European table-top and medical response exercises.

| | Staff | Stuff | Structure | System |
|---|---|---|---|---|
| **Respiratory support** | Need training in intubation whilst wearing PPE. Staffing shortage since dealing with such a large number of patients. Adaptations: asking non-medical personnel to help ventilate by hand using manual ventilation bags but what about need for repeated antidote treatments? | Equipment shortages with such large numbers needing respiratory support. Using a Y connector to simultaneously ventilate two patients on one machine was suggested but was considered controversial and doesn't take into account limitations to oxygen supplies. | | Distributing patients between care facilities to avoid overloading the main facility – only two hospitals in this scenario therefore would need international help which would take too long to arrange for the nerve gas patients. |
| **PPE** | Increased pressure on staff levels since faster turnover given limited amount of time can work in PPE. More training required especially for giving medical interventions. A dedicated person for tracking staff PPE working times was needed to ensure sufficient rotation. | Medical staff required non-bulky PPEs which have a low physiological burden and can be worn easily. A large visor is beneficial so that the health care providers can see and be seen by the patients. | | |
| **Secondary contamination** | Resistance to the secondary contamination scenario and general assumption that all patients are decontaminated at incident site or in pre-hospital area. Staff initially contaminated: have to remove them and replace with new staff in PPEs. | Equipment with limited availability was reused and moved between contaminated and uncontaminated zones. Contamination of ambulances – not realistic to remove from service during acute phase. | Replacement of contaminated equipment and the closure of contaminated departments, until decontamination is completed, needs to be factored into response and recovery plans. | Discussion on how clean is safe vs. how clean is clean – but no consensus reached. |
| **Drugs and antidotes** | Staff need to know where additional supplies can be sourced. | Quickly run out of antidotes available in ambulances and at on stockpiles hospital in nerve gas scenario, given need for repeated doses. | Share information on stockpiles Access to military protocols and reserves – would require authorisation to use on civilian population | Arrangements to get disaster boxes from NGOs or other logistical supply units. Pharmaceutical companies and pharmacies minimum stocking level requirements in national warehouses Sharing sensitive information between countries currently challenging – need an EU protocol |
| **Triage systems** | Simple, rapid easy to remember for first responders – e.g. traffic light system which can be read by people in PPEs – yet avoiding pitfall of too many "yellow" patients. | First responders also need access to a clinical symptomology database: record symptoms seen, narrow potential field of agents. Ideally, digitised to get direct transmission from the field to the hospitals regarding each patient, clinical symptoms and treatments given. | Divide "exposed but healthy" from "exposed and sick": those who could walk to go to one side away from the hot zone, for self- decontamination and evacuation so further focus is on non-ambulatory patients with life-signs. | Triage needs to be simple, fast, based on clinical symptoms (algorithms) and agreed best practice. |

*Table continued*

**Table I** ***(Continued)*****.** Medical surge capacity and capability challenges in a chemical crisis: lessons identified during European table-top and medical response exercises.

| | Staff | Stuff | Structure | System |
|---|---|---|---|---|
| **Tracking exposed people** | Call centre staff should have access to a pre-defined FAQ for different CBRN events, as well as trigger questions for self-evacuees,: performing phone triage and giving best possible advice. | Badges, bar codes, bracelets or RFID (radio-frequency identification) tags can be used but the system adopted needs to be simple given first responders may not have access to special tracking/registration devices. Tracking via mobile phones controversial given national privacy laws, risk of casting the net too wide even though potential to detect at risk cases | A triage hotline for people that have self-evacuated or are concerned that they could have been exposed: using a stand-by call centre (like HSNI in the UK) to increase non-emergency number capacity providing self-help and other advice. | Suggested that the framework for tracking contaminated patients linked to similar frameworks for tracking communicable diseases. |

distracted by the setting up of the pre-hospital decontamination facilities. Requesting assistance from other countries (i.e. patient transfer to other hospitals abroad) to ease staffing challenges and resource bottlenecks was only considered possible after patients had been stabilised.

### Health System Surge Capacity: Stuff

The nerve gas scenario treatment options include pharmaceutical drugs and antidotes (like atropine) already present in ambulances and first responder kits. Alternative antidotes (like pralidoxime) may not be part of the first responder kit in some countries. As the organophosphate intoxication is time dependent, any delay in the provision of the antidotes to the patients might have a negative influence of the outcome of those exposed. Some countries (e.g., UK, France) have national stockpiles of antidotes for nerve agents, but sharing information on availability is challenging. The volume of drugs and antidotes required for the repeated treatments in the nerve agent scenario would quickly exhaust local hospital pharmaceutical supplies and additional stocks would need to be sourced rapidly. Other essential equipment was not available or was in short supply in the medical response scenario, necessitating reuse of critical items like monitoring and intubation equipment with no guarantee of sufficient decontamination.

### Health System Surge Capacity: Structure

It was suggested that the EU could work towards harmonising antidote protocols and that medical reserves could be stockpiled at strategic locations to help with more rapid delivery in case of emergency. Activation of mutual assistance agreements between countries would be needed to request medical assistance with hospital capacity, like burn units in the blister agent scenario, or for help with laboratory capacity for both medical samples and CWA sampling, or for sourcing additional medical supplies. The EUs Emergency Response Coordination Centre (ERCC) would play a vital role. The explosion scenario with trauma patients contaminated with a slower acting blister agent challenged established dogma. Despite some resistance to this contamination scenario, participants acknowledged that severe trauma cases could be evacuated to the hospital for life saving treatment prior to the suspicion of chemical agents. There was agreement that neither hospitals nor ambulances were prepared for such a scenario and that response protocols had been based on pre-hospital decontamination with no contaminated patients entering ambulances or hospitals.

### Health System Surge Capacity: Systems

All agreed that as soon as a CWA agent was suspected, decontamination protocols would be activated at the incident site and hospital. Protocols might include a complete lock down with diversion of other incoming patients to alternative locations. Preventing capacity overload at any one hospital is a primary goal with the most critically affected patients sent to the nearest and best care centre for their needs. Resource limitations will require first responders to shift from patient oriented to population oriented care protocols. In the table-top scenarios, assistance from neighbouring countries would be needed. The flow of information between the incident site and receiving hospitals is critical. Up to date situational awareness and a dynamic picture of resource availability is needed on a much larger scale than during routine operations. The suspicion and subsequent confirmation of a chemical agent needs to be rapidly communicated to all first responders as well as relevant hospitals since detection and identification at the incident site will in all likelihood be carried out by non-medical first responder agencies. The lines of communication between different jurisdictions (health care, law enforcement, military/civil defence) need to be effective to ensure the correct information is sent to those that require it. This information then needs to be disseminated from the dispatch centre to all the hospital departments and staff dealing with patients from the incident. The discussions regarding systems for triage and patient tracking highlighted that the simple traffic light system often categorises too many patients as yellow, in an abundance of caution. Whilst there are a number of guidelines that address self-triage and dealing with "yellow" patients, not all agree[17,18]. A best practice approach was discussed but no conclusions reached. Tracking of patients once registered at the hospital is routine. However, tracking all potentially exposed persons (not just those with clinical symptoms) from the incident site to different treatment centres or other locations is very challenging, especially for those that self-evacuate.

### *Health System Surge Capability*

The medical response training exercise highlighted the challenges in dealing with sudden surges complicated by having to decontaminate and treat patients whilst wearing air impermeable PPEs. Critical resources were rapidly exhausted and routines related to contaminated and uncontaminated equipment were, at times, not followed sufficiently. The medical response exercise identified a number of improvement areas including the need for clearly defined warm and cold zones each with their own dedicated equipment. Further training was needed since the medical response exercise also highlighted aspects of the decontamination procedures and patient handling that were carried out incorrectly. Contaminated equipment has to be disposed of correctly and not, as in some cases, returned to the ambulances after patient transfer. The testing of surge capacity in the table-top and medical response training exercises highlighted the importance of such activities for identifying bottlenecks and areas for improvement. Just having the equipment available, capacity, was not enough to ensure surge capability nor did it ensure that procedures were followed correctly. Involving the tool providers allowed them to see the benefit of, and requirements for, equipment upgrades like the air-permeable suits with overpressure hoods, which were used in the exercise, and the need for external lighting sources on the PPE.

## Discussion

Surge capacity issues that were identified were very similar to those described by the medical fraternity in North America (CHEST consensus statements 2014). In Europe the proximity of neighbouring countries and major urban centres is beneficial to successful mutual assistance agreements. Activating mutual assistance agreements was not considered feasible in the nerve agent scenario given the short treatment window to stabilise the patients. There was a consensus that hospital capacity, antidotes, supportive treatment, intensive care, and respiratory support (including oxygen supply) capacity would all be considerable bottlenecks. There was consensus that each country should have a national, and if possible a pan-European, registry of antidotes, hospital capacity, medical supplies and stockpiles with real time capability to help maintain an overview of a dynamic crisis situation. The second attack with a blister agent had a longer timeframe, so mutual medical assistance could be requested for the transport of patients to other treatment centres. Such assistance was offered after a catastrophic fire in a Romanian nightclub in 2015 when patients were transferred to burn units in other European countries for further treatment[19]. The greatest challenge in the blister agent scenario was dealing with secondary contamination inside the hospital and the ambulances. This scenario had not been considered previously given the general assumption that the casualties would have been decontaminated before entering the medical facilities and ambulances. This meant that all of the four-surge capacity "S"s faced problems during these CWA scenarios: staff, structure, stuff and, as the medical response exercise showed, systems challenges in linking capacity and capability. The psychological impact and after care for the population and first responders was not discussed during these exercises but a considerably body of work has investigated this aspect[20].

The length of time a person can work in PPE, without a break, is considerably shorter than if they are not working in PPE. Therefore, the first responder and medical services need to increase training and staffing levels to cover this shortage of manpower. A number of studies have looked at staffing challenges and failure to appear in different disaster settings. In one study 30% and 40% of health care workers said that they would remain at home if there was risk of chemical or radiological exposure respectively[21]. The demonstration highlighted the necessity of having a PPE adapted to local conditions (with cooling vests, external lighting, and full face plates) supporting the findings of the EU IF REACT project where additional medical PPE functionality was investigated[22].

Whilst reverse triage, to identify patients that can be safely discharged early to free bed capacity, can increase capacity in time, in an acute situation like the nerve gas scenario, time is eceedingly limited[23]. In an acute situation like the nerve gas scenario; time is exceedingly limited. Evaluation of resource allocation has found that 30 % of counties in the USA do not meet the Health Resources and Services Administration benchmark target of 500 hospital beds per million inhabitants for disaster surge capacity[24,25]. Such European benchmarks have not been defined, although one Dutch study concluded that in a severe flu epidemic ICU resources would be depleted in two to three weeks[26]. The acute nature of CWA attacks does not give as much room to manoeuvre in comparison to relatively slower biological threats. There is a paucity of literature on the subject of first responder and hospital surge capacity for European crisis management, which, as our study shows, is dependent on more than just bed capacity.

Stress testing the response system with worst case scenarios can reveal previously concealed vulnerabilities. However, there are limitations with this approach since the findings are often based on a series of assumptions and not empirical research[27]. In this case we identified that the initial assumption of mutual medical assistance or using remote stockpiles for the nerve gas scenario was implausible and only feasible once patients stabilised after the acute response phase. This agrees with the findings of Moore et al[28], who conclude that policies which delegate responsibility for medical stockpiles outside of the hospital environment, even when at strategic locations, can leave a hospital vulnerable to shortages in acute surge situations. However, maintaining reserve capacity at hospitals costs and could complicate distribution should drugs or equipment like ventilators be needed at another distant location[29]. In the end, the question of stockpiling or distribution may depend on local needs, hazards and risk assessments. One size does not fit all[29].

The majority of the issues identified are not new and are widely known and accepted, including information sharing on regional hospital capacity, expert networks and medical stockpiles, as well as decontamination protocols, communication strategies and patient tracking. One discussion that did not come up in depth, but that is critical for such a scenario, is how to deal with the change in prioritisation from patient-centred to population-centred triage protocols in crisis care situations. The emergency health care personnel may have to prioritise medical interventions for those with the greatest survival chance given the limitations on finite resources. It is important, therefore, that the ethical and medical considerations behind that prioritisation, and the subsequent reduction in standards of care, have previously been discussed when preparing triage and treatment protocols[2,30].

## Conclusions

Hopefully, such events as described in the scenarios will remain fiction. Yet, by planning, training and exercising for such a contingency[30], we can identify vulnerabilities and bottlenecks, thus instigating mitigation measures to ensure a more robust and resilient civil preparedness across the EU. The lessons that have been identified here should be considered by medical facilities across the region. These facilities can use a similar methodology to evaluate and improve their surge capacity, capability and response.

### Conflict of Interest

The Authors declare that they have no conflict of interests.


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