Confined Space Medicine and the Medical Management of Complex Rescues: A Case Series

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ABSTRACT

Objective: A variety of hazards can precipitate the full or partial collapse of occupied structures. The rescue of entrapped survivors in these situations can be complex, require a multidisciplinary approach, and last for many hours.

Methods: The modern discipline of Urban Search and Rescue, which includes an active medical component, has evolved to address such situations. This case series spans several decades of experience and highlights the medical principles in the response to collapsed structure incidents.

Results: Recurring concepts of confined space medicine include rescuer safety, inter-disciplinary coordination, patient protection, medical resuscitation in austere environments, and technical extrications.

Conclusion: Strategies have been developed to address the varied challenges in the medical response to collapsed structure incidents. (*Disaster Med Public Health Preparedness*. 2014;8:20-29)

Key Words: urban search and rescue, confined space medicine, collapsed structure, earthquake, prehospital care

Occupied structures collapse in a variety of situations, trapping victims in the resultant debris. Causes of the collapse include seismic hazards, explosions, poor construction, and structural overload. As earthquakes are the most frequent cause of widespread structural failure, they can result in geographically distributed entrapment situations. Bystanders and first responders accomplish many post-collapse rescues,[1] but some victims may be deeply entombed, making detection difficult and requiring sophisticated rescue resources.[2] This type of entrapment is particularly common in collapsed reinforced concrete and large steel-frame structures.

Urban search-and-rescue (US&R), which includes a robust medical capability, has evolved as an internationally recognized discipline to address these challenging situations.[3,4] Medical management of a prolonged rescue from a collapsed structure can be complex and pose significant risk to the rescuers themselves.[3] The required medical sophistication for this task was recognized several decades ago, and designed into the US-based US&R response resources.[2,5] The complexity of US&R and the risk to rescuers are now reflected in the decision of many international teams to invest in training physicians, midlevel providers, nurses, and/or paramedics to operate alongside rescue teams in this environment. Medical resources with US&R teams are primarily focused on care for the team members, including trained canines. In addition, US&R personnel are trained and equipped to provide medical care to entrapped individuals throughout the extrication process. If the multiple issues surrounding confined space medicine are not adequately addressed, the result may be the extrication of a deceased person.

Few published reports document the specific medical challenges encountered in these rescues.[6-8] More commonly, the medical literature focuses on the patients' condition after entrapment, as patients are treated in either field-based[9-12] or fixed health care facilities[13-17] after an earthquake. This report focuses on the care of persons trapped in confined spaces, beginning with the initial contact by US&R members while survivors are still entrapped in the rubble, and extending through their delivery to definitive medical care after extrication.

METHODS

The complexities related to rescuing patients entrapped in collapsed structures are illustrated through a series of 5 cases. Thereafter the important concepts related to confined space medical care are summarized. Each of the people described in these cases was located within heavily reinforced concrete structures that collapsed during earthquake incidents. The data come from response records of the Fairfax County, Virginia, US&R program. This task force (designated as Virginia Task Force 1 [VATF-1] when deploying in this capacity) is jointly sponsored by the local jurisdiction and the US government. Federal support is provided through 2 funding streams: (1) the Federal Emergency Management Agency (FEMA)/Department of Homeland Security for domestic deployments; and (2) the US Agency for International Development /Office of US Foreign Disaster Assistance (OFDA)[18] (designated as USA-1 for international deployments). This case series is representative of the experience of the Fairfax Task Force. It not intended to be a comprehensive case series or to provide statistically significant findings.

CASE 1

The Entrapment Situation

An adult man in his early 20s was sitting in a large, first-floor conference room of a 6-story hotel when an earthquake struck around 4:00 PM. The front half of the hotel separated from the rear section, collapsed into the basement, producing a pancake collapse of the first through third floors. The man was trapped on his back, with the ceiling less than 1 ft above him. He was pinned at his hips by a tubular metal chair. A large slab of concrete compressed his left thigh and calf, and his left ankle was trapped under a load-bearing beam from the floor above.

During that night, local rescuers crawled through a small hole and reached his trapped leg; they freed the thigh but not his hips or ankle. One rescuer threaded intravenous (IV) tubing up to the victim's face; he refused the Ringer lactate solution due to its taste, but drank fruit juice squeezed from the IV bag through the tubing. A subsequent settling of the building closed the hole used to gain access to the patient, and initial rescue efforts were abandoned by local rescuers.

The USA-1 team arrived at the site approximately 48 hours after the earthquake. Significant aftershocks continued several times each hour, and the building shifted intermittently.

Patient Access and Initial Evaluation

USA-1 personnel confirmed that the victim was still alive by speaking with another trapped victim who could talk with the target victim. New access was established by rescuers cutting from 3 floors above and removing rubble, furniture, and other debris manually. At one point the victim began screaming; a small hole was cut in the final ceiling panel, and the patient stated that he was being suffocated by the re-suspended dust. A non-rebreather oxygen mask was passed to him, and his airway was protected with bottled oxygen as the final debris was removed.

Access to the man was reached 6 to 7 hours after the operation began, approximately 54 hours after the earthquake struck. The opening allowed only access to the left side of his body; his head was one meter away under the low ceiling. His entrapped left ankle also could only be accessed by reaching one meter into the tight space under the collapsed ceiling.

The patient spoke limited English; he was initially alert and cooperative, complaining only of severe pain in his left leg. His entire left leg was markedly swollen, constrained tightly in his jeans; he screamed in pain when his leg was touched or manipulated. No other major injuries were identified by rapid survey.

The tubular chair trapping the patient's hips was cut and removed. The rescue personnel attempted to raise the beam trapping his left ankle using a rescue air bag, but it did not move the beam. The rescue team estimated that it would take 4 to 6 hours to uncover, stabilize, and then cut the reinforced concrete trapping the ankle.

Medical Interventions and Extrication

Shortly after the man's hips were freed, he became anxious, tachycardic, and pale, grabbing at rescuers and vainly trying to self-extricate. Two large-bore IVs were rapidly established in his left arm, and 2.5 L of normal saline (NS) solution were pressure infused on the presumption that the patient's extracellular fluid was shifting into his formerly compressed buttock and crush-injured proximal thigh. An IV ampule of 50% dextrose was administered, followed by a slow-push IV ampule of sodium bicarbonate. Verbal reassurance was also provided.

The patient's tachycardia resolved and he again became alert and cooperative after these interventions. He then received several 2- to 3-mg doses of IV morphine sulfate as the left pant leg was carefully cut. His leg was evaluated and noted to be externally rotated, with his ankle trapped at the malleoli under the beam. The medical team noted that the primary entrapping structural element was a wooden skirt at the bottom of the beam. Under the direction of the physician, a rescuer used an air powered chipping tool to carefully remove the wooden skirt behind the patient's heel and over the forefoot. An attempt to pull the leg free was planned, and 3 mg of morphine was placed into the IV tubing near the hub, with the line closed and the pressure infuser inflated. The rescuer was positioned with his hands in front and behind the man's left knee. When the IV was opened and the patient visibly relaxed, a rapid knee flexion and strong pull of the leg freed the foot, heel first, through the opening in the skirt, with no complaint from the man.

The patient was then removed from the space, placed on a backboard, and strapped in for a descent from the building by ladder. The patient was awake, alert, and expressing gratitude for his rescue. He was rapidly re-evaluated, given IV cefazolin sodium due to his multiple open wounds, and his IV fluid bags were replaced before he was removed from the building. Handoff to waiting local emergency medical services (EMS) personnel then occurred, but it was suboptimal because of a surge from the large number of uncontrolled bystanders.

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Outcome

The total time the man was entrapped in the rubble was approximately 55.5 hours. Total time for USA-1 rescue efforts with this patient was 7.5 hours. The patient was transported via local ambulance to an earthquake-affected hospital with no electricity, running water, or functioning laboratory/monitoring equipment. At the hospital, the surgeons elected to perform an above-knee amputation of the injured left leg. The rescued patient otherwise fully recovered and returned to his job.

CASE 2

The Entrapment Situation

A 32-year-old man was asleep in bed on the fifth floor of his 12-story high-rise apartment (12 stories plus a multistory underground garage) when an earthquake struck. The resulting major collapse of the lower floors into the subgrade parking structure caused the man to be entrapped 1 level below grade after the earthquake (the garage floors were in a pancake collapse; the first 5 floors above ground underwent variable collapse, and the top floors remained intact). He was initially located by a concerned family member.

The patient was buried approximately 15 m into the structure and 6 m below grade and inaccessible to direct physical touch. Little physical space was around the man, prohibiting co-location of a provider next to him until debris was removed. As the collapse occurred, the patient's leg had been circumferentially wrapped by a blanket and his foot was pulled into a crack in the floor, which then settled as a vertical concrete slab. His coil-spring mattress was also tightly pinned against his leg, complicating access to him. He settled in an upside-down position, in which he was partially suspended by the pinned leg, with just his shoulders touching a flat concrete surface. He was conscious and able to move his other extremities in the narrow void space.

Patient Access and Initial Evaluation

Initially, local responders worked to extricate the patient but were unable to fully gain access to him. They unsuccessfully attempted to free his leg by remotely looping a rope behind his knee and pulling on it. On arrival in-country, USA-1 was assigned to assist with this rescue; they arrived on the scene 31 hours after the earthquake struck. Initial access to the patient was limited by debris. Although the rescuers could see him, he was below them by about 4.5 m. The patient was lucid, spoke English, and joked with the USA-1 rescuers at the initial encounter. His only complaints were the inability to move the trapped extremity and his uncomfortable position.

Gaining access to the patient was a major challenge, because it required carefully cutting through debris, concrete, and mattress elements hanging directly above him. The rescue was also complicated by 2 major aftershocks, prompting temporary site evacuation each time. Local rescuers originally reported that the electrical utilities to the building were off. Further investigation of the scene by the USA-1 safety officer disclosed a second, still active electrical feed to the building. The rescue was briefly delayed while this feed was secured.

Before physical contact was established, the patient was fed an IV line to enable him to drink a flavored electrolyte solution. As in case 1, voice contact with the man was maintained through remote physiologic assessment while rescuers slowly worked toward him. A helmet, protective eyewear, and a dust mask were lowered to him to protect him from excavated debris. He chose to wear these items intermittently when the space became dust filled.

Medical Interventions and Extrication

Once the rescuers made physical contact with the man, an IV line was started. The following medications were given during the next 6 hours that the patient remained entrapped:

- Electrolyte solution, orally administered (2 L)
- NS solution, IV (4 L)
- Sodium bicarbonate (1 ampule)
- Cefazolin sodium, IV (1 gm)
- Morphine sulfate, 3 separate IV administrations (3-mg doses)
- Fentanyl, IV(50-μg dose) to facilitate freeing of extremity

The patient spontaneously voided twice during the rescue, which assisted in evaluating volume status. The spring mattress, bed clothes, rebar, and other debris were carefully removed, and the man's lower extremity was noted to be drawn tightly into the concrete crack at the ankle. The proximal leg appeared pale and was insensate from the midthigh to the entrapped element. The patient remained awake and lucid until late in the extrication of the leg, when he became anxious and slightly combative. Knee disarticulation of the entrapped limb was briefly considered owing to concern for further deterioration in his condition. However, with rapid IV fluid resuscitation and pain control, he became cooperative and remained clinically stable. The extremity was ultimately manipulated from the concrete without pain, confirming its insensate condition.

Once disentangled, the patient was immobilized on a rescue stretcher (Skedco). Simultaneously, a corridor was established between the building portal and the transport unit using on-scene military personnel (a large crowd had gathered, and the media presence was significant). The patient was rapidly re-evaluated inside the entrance to the building, as control over the situation became tenuous, due to a crowd surge as they exited the structure.

USA-1 medical personnel requested that the local rescuers and military personnel carry the patient from the building to the waiting EMS unit, which provided local personnel media exposure and credit for their extensive efforts in rescuing this person. A strong crowd surge did occur, but the corridor to the EMS vehicle was maintained by the previously warned soldiers. Inside the vehicle, the patient was briefly re-evaluated, including a first manual blood pressure reading. The patient was transported to an intact local multispecialty hospital and later transferred to a national trauma center.

Outcome
The man was entrapped in the rubble for a total time of 38 hours and 45 minutes. The total time the USA-1 team worked on extricating the man was 8 hours. He underwent an above-knee amputation of the affected leg by surgeons at the tertiary referral center after a period of watchful waiting. The patient survived his injuries without further physiologic sequelae.

CASE 3
The Entrapment Situation
A 28-year-old woman was entrapped in a first-floor hotel bar after an earthquake. The 5-story structure was almost completely collapsed. The woman was located through voice call out by a local bystander who had been searching for another person in the area adjacent to the bar. The second individual was also located by the bystander, but died before any rescue attempts could be made.

The surviving woman was entrapped in an upright crouching position, with one hand pinned in a position outstretched and abducted from her body. She was unable to move from this crouching position, and could only move the unpinned upper extremity. The space in which the patient was trapped bordered the bar itself; the "roof" above her was supported by a large metal cage used to safeguard liquor. The ceiling of the bar had collapsed to only one meter above the floor, forcing the patient into her crouching position.

Patient Access and Initial Evaluation
The USA-1 team first gained voice contact with the woman approximately 36 hours after the earthquake's impact, and worked on gaining access to her for another 10 hours before initiating medical care. The structure did not have a basement, so access to the patient was accomplished through the laborious task of hand-tunneling through dirt under the foundation of the structure to reach the area, then breaching the concrete floor slab to reach her from below. The tunnel was approximately 9 m long. Loose soil and heavy overhead structures slowed progress, as shoring measures were required to ensure the safety of the rescuers within the tunnel.

Once the rescuers reached the woman, the only accessible body part was the left buttock. The patient spoke limited English, but careful conversation indicated an altered mental status. At one point she stated that she had been drinking some of the alcohol in the bar, confusing the picture as to the cause of her altered sensorium. She conversed nonsensically with rescuers throughout extrication and intermittently broke out singing.

Medical Interventions and Extrication
When the rescuers initially gained access to the woman, they realized that the disentanglement would take several more hours. No IV access was possible with the presenting body part, so 500 mL of subcutaneous fluid (ie, hypodermoclysis) was administered to provide some initial rehydration. The woman received a low dose of intramuscular morphine sulfate at one point when she complained of pain. The debris removal and her extrication evolved in such a manner that no further medical care was possible. Unfortunately, just as the patient was being extricated, a strong aftershock occurred and the woman's other hand was pinned. This complication prolonged her full extrication by another 30 minutes.

Recognizing the potential for crush injury and possible sudden patient decompensation, the USA-1 members had prepared a patient assessment area at the exit from the tunnel. Once the woman was brought out, IV access lines were attempted. Due to dehydration, these lines were initially unsuccessful, and a central line was placed in the left femoral vein; peripheral IVs were established later. An initial assessment with a cardiac monitor demonstrated a sinus tachycardia with normal-appearing T waves. The woman was able to move all 4 extremities in a limited fashion. IV resuscitation was initiated through the central line, and 1 ampule of sodium bicarbonate was administered along with morphine, as the patient appeared to be experiencing pain. She maintained a strong pulse throughout. The patient was securely immobilized and transported with medical providers in a van to a field hospital. Extrication occurred 58.5 hours after the earthquake's impact.

Outcome
The total time the woman was entrapped in the rubble was 58.5 hours. The total time for USA-1 rescue efforts with this patient was approximately 12.5 hours. At the field hospital, the patient underwent intubation for respiratory failure, and was diagnosed with crush syndrome resulting from the injuries to her extremities. The patient subsequently underwent amputation of one hand and one leg. Extubation took place on day 3 postextrication; renal impairment persisted, but the woman did not require dialysis. She was alive 1 month after the earthquake.

CASE 4
The Entrapment Situation
A 25-year-old woman was entrapped in a 5-story university building that underwent nearly complete pancake collapse as the result of an earthquake. She had been attending classes, and presumably attempted to escape the building when the

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shaking started. She was entrapped in a collapsed spiral staircase among 16 dead persons and 1 living man. He was trapped near the woman but closer to the rubble surface.

The man was originally located by local responders (fire fighters) through voice call out. During his rescue, the USA-1 team determined that the woman was also alive, deeper into the rubble. Initial recognition of her presence occurred about 2.25 days after the earthquake. Efforts to extricate her were initiated after the man was successfully rescued, providing a route of access to reach her.

Patient Access and Initial Evaluation

The woman was entrapped in a supine position, with the head as the presenting portion of her body. She was in a very tight confined space, which prevented any other physical access than barely touching the top of her head. She was alternately lucid and confused, and spoke no English (local rescuers assisted with translation). Later, it was discovered that her right shoulder and both legs were tightly pinned by debris.

Extrication was complicated by the volume of debris and the number of deceased bodies that entrapped the patient; she was essentially encased from the neck down. In addition, the numerous decomposing bodies around her required construction of an extensive contact and fluid barrier, using heavy-duty plastic sheeting (intended as roofing for shelters) to line a tunnel. Efforts to dig her out were slowed by shifting debris, requiring frequent monitoring of the building's stability, which interrupted rescue activity. The breaching of concrete was required in several instances. Also, the patient's body was actually intertwined with those of several deceased persons.

Using telescoping cameras, the rescuers were presented with a confusing picture; they initially thought that the woman's thigh was impaled by rebar. As the rescue progressed, laborious efforts were undertaken to disentangle the patient's leg using telescoping cameras to assist, since direct visualization was not possible. Finally, it was discovered that the impaled leg being freed was not the patient's. This delay further prolonged the total rescue time.

Medical Interventions and Extrication

Before better access to the patient was achieved, she was given oral rehydration fluids in limited amounts during her periods of lucidity. About 10 hours before full extrication, access to her left hand was possible, and a peripheral IV was established by a medical team specialist lying on his back below the patient and using his nondominant hand. IV resuscitation with NS fluid was initiated, using a pressure bag, as the limited space prevented gravity flow of IV fluids. Throughout the remainder of the extrication, the patient alternated between being lucid and helpful to combative; at one point, she was grabbing at a rescuer. Due to the extremely long extrication period, this patient was attended by at least 3 different task force physicians. Working in shifts, they "signed over" the patient to each other to maintain continuity of care. The woman received the following medications during a period of 10 hours:

- NS, 4.5 L
- Sodium bicarbonate, 2 ampules, given early and late in the rescue
- Morphine sulfate, IV, 27 mg given as aliquots over time
- Cephazolin sodium, IV, 1 g

An assessment area had been established on a table near the collapsed structure. Evaluation at that time showed the patient to be well rehydrated; tears were present. Due to the uncertainty of follow-up medical capabilities, additional peripheral IV access was established. A quick evaluation with a cardiac monitor demonstrated sinus tachycardia with normal-appearing T waves.

Outcome

The total time the woman was entrapped in the rubble was 98.5 hours after the initial impact, and 44 hours after rescue efforts were initiated by the USA-1 team. The last USA-1 physician to care for the patient was concerned about potential airway compromise, and the patient underwent intubation, with the use of rapid-sequence induction. The medical team accompanied the woman to a field hospital using a nonmedical military vehicle. Traffic conditions in the postimpact environment made a rapid transport challenging, and the oxygen supplies failed before arrival at the facility (the patient was ventilated using ambient air without significant desaturation). At the field hospital, the patient underwent a single lower extremity amputation, followed by fasciotomies to the other extremities. She was then transported to a medical facility out of the impact area, and was alert and giving interviews to the media 2 weeks later.

CASE 5

The Entrapment Situation

A 25-year-old woman was attempting to exit a 2- to 3-story urban residence during an earthquake when the structure collapsed. The upper floors fell in a pancake collapse toward the street, falling over the woman at a 45° angle. She was entrapped under 3 concrete slabs in a void created by a steel door and a large storage drum among the debris. She was located through voice call out by bystanders. The woman was lying prone at street level, pinned by her right upper extremity under the pancaked slabs of concrete; her fingers could be seen from the other side of the concrete slabs. The area where the woman was entrapped could be accessed from the side of the debris. The rescue situation was a collaborative effort; the USA-1 team was brought in to assist a non-US international US&R team. Both teams contributed rescue and medical resources to this effort.

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Patient Access and Initial Evaluation

The patient could be heard screaming intermittently and appeared delirious during initial contact. She could not be adequately visualized, and complete access to her was not possible throughout much of the rescue.

Medical Interventions and Extrication

The patient complained of pain during the debris-removal process, and a 50-μg intramuscular dose of fentanyl was administered in her left shoulder, the only accessible body part at that time. A significant amount of debris, some supporting the concrete slabs leaning over the patient, had to be removed carefully to prevent further collapse. During this process, an acetylene torch was used by the international team to cut portions of the metal door supporting the debris pile, and a small fire was ignited by embers. This fire was extinguished very quickly using a local water source, and the woman was not burned. As access increased to the backside of the woman, she remained prone, with her right arm remaining trapped by the concrete slabs. After medical consultation with structural engineers on both teams and the rescue officers, it was determined that an amputation of the trapped upper extremity was the only feasible method to free her from the collapse situation due to instability of the slabs and other debris. The woman's positioning made full access difficult, so a left humeral intraosseous needle was placed for IV access. Her pinned extremity was exposed as distally as possible, a topical antiseptic was used to clean the extremity, and a commercially available tourniquet was placed. The patient was then given IV ketamine, atropine, and midazolam through the intraosseous line.

The tourniquet was then tightened, the skin was incised at the most distal point possible, the bone was exposed, and the extremity was amputated with use of a wire saw. The stump was covered with a dressing, and the patient was pulled up from the collapse, placed on a backboard, and brought to a commercial box truck, which functioned as an assessment area. Once there, the patient was reassessed and additional IV lines were placed, to administer the patient NS solution and pain medications. The patient was subsequently transferred in the box truck to a field hospital for additional care, a process which took 2.5 hours.

Outcome

The total time the woman was entrapped in the rubble was approximately 125.5 hours. The total time for USA-1 rescue efforts in collaboration with the other international rescue team was 6.5 hours. The patient was discharged from the field hospital in ambulatory condition 3 days after admission.

DISCUSSION

The approach to confined space medicine differs significantly from most other medical situations. Enough experience has been gained internationally during the past 2 decades that certain important practice concepts have been memorialized by international medical working groups working specifically on search and rescue.[19] The following concepts applied to our reported cases.

General Approach to Confined Space Medical Interventions

Hazard Risk Management

As highlighted in several of these cases, a wide variety of hazards are present in the confined space environment. These hazards can affect both the rescuer and patient, mandating that medical personnel coordinate closely with people in other disciplines to reduce the potential of further harm or injury. The safety issues alone make the case against the deployment of untrained medical personnel into this type of situation to avoid injury or death of the ill-prepared rescuer.[20] Examples of hazardous considerations, beyond the obvious physical ones, include ambient temperature extremes, inhalation hazards (dust, carbon monoxide, spilled volatile chemicals), biohazards from living and deceased victims, unsecured utilities such as natural gas or electricity (case 2), and explosive/incendiary hazards (eg, methane, gasoline).

Rapid but careful risk assessment of the collapsed structure must be conducted, and hazards addressed as they are identified. Aftershocks may force the rescuers to at least temporarily evacuate a rescue scene due to the risk of secondary collapse. This situation should be explained to the entrapped persons ahead of time, assuring them that the goal is to return to the rescue as soon as is safe.

Integration with Local Emergency Management Authorities

All work conducted should be integrated appropriately with local authorities. For example, other operations being conducted near the worksite could cause the unstable structure to weaken further, threatening collapse with the rescuers inside. International mechanisms to coordinate these actions have been established through the IS&R advisory group (INSARAG). This coordinating body was established through a United Nations (UN) resolution; it reports to the UN Office for Coordination of Humanitarian Affairs (OCHA), Field Coordination Support section.

Other examples of necessary integration with local authorities may involve the handoff of extricated patients and disposition of the deceased. Working closely with and showing respect for local rescue and field medical teams are important. The local workers likely are exhausted and psychologically traumatized by the time international teams arrive, and may feel a sense of failure when US&R resources begin operations on trapped survivors who they did not locate or reach. Conflict or competition can result in adverse outcomes. This issue was realized early in the USA-1 medical team's experience, and medical personnel now reach out to local rescue and medical personnel to maintain their involvement in rescue activities.

As seen in case 2, when the USA-1 physicians arrived, they kept the local rescuers involved when the local team started to depart the confined space. An emergency physician from the country was used as a translator and as a medical resource for arranging patient transport; he also was the liaison when a USA-1 physician suggested that the patient be carried out by local rescuers and military personnel. This maneuver generated warm cooperation throughout the remainder of the search and rescue mission.

Scene Control at the Rescue Worksite

Rescue sites may become chaotic, with large crowds often congregating at the scene. Ensuring adequate crowd management may be difficult, but it is necessary to maintain safety. In multiple settings in a range of countries, crowd surge has been experienced when a victim emerges from the collapse after a prolonged extrication. This occurrence should be anticipated and a controlled perimeter should be prepared.

Maintaining at least a corridor through the crowd to the transport vehicle was problematic in both cases 1 and 2 once the person was removed from the building. In case 2, the situation was anticipated, and the military unit's commander was forewarned by the US&R medical team. The site perimeter was breached by the crowd, but the corridor to the EMS vehicle was maintained by the soldiers. Family members of trapped survivors may be present at the site and identified by US&R personnel. They should be kept informed of the rescue operations, and may be helpful in providing information about victims, such as the last known location in a structure for missing persons, or any concurrent medical problems, medications, or allergies for an identified trapped survivor.

Language and Cultural Issues

Many confined space incidents occur in the international arena, and access to appropriately protected translators can be essential as extrication begins. The protective equipment and just-in-time safety training for the confined space should be provided to translators and other assistants. Use of a local translator was critical to the successful extrication of the person in case 4.

As in any international medical operation, an understanding of local customs and culture can facilitate response. In confined space rescue situations, this understanding may be more acute when drastic measures such as limb amputation are being considered. Having an operational relationship with recognized medical experts from local or host national health care organizations can help in identifying sensitive issues and maintaining respect for all cultures and customs.

Patient Access and Remote Interventions

Specialized Medical Capability

Traditional medical training assumes full access to a patient for evaluation and interventions. Caring for persons entrapped in collapsed structures commonly precludes this access. Adaptations to patient evaluation and treatment must be considered beforehand, and the medical team must be equipped and trained for remote assessment and adapted interventions before deployment.[21]

Presenting Parts and Patient Evaluation

People can be entrapped in a multitude of positions, allowing varying degrees of access by rescuers. In situations such as those described here, people were not physically accessible until hours after their discovery. As in case 3, the left buttock was the only portion of the patient's body that could be seen and evaluated during the first 3 hours of the extrication. This limitation restricts medical interventions to therapies that can be administered subcutaneously and intramuscularly.

Assembling equipment outside of the collapsed structure and prioritizing equipment or supplies that are subsequently brought into the confined space prevents cluttering in what can be a very tight situation. Mobility in the space can be very limited, with restricted access to the patient, and often at odd angles (as in case 4), as compared to usual patient evaluation and treatment. In some situations, rescuers have to back out of a space and re-enter it at a different angle to perform a procedure. Careful evaluation of the egress from the structure early in the rescue is important to prevent surprise impediments once the patient is freed and is being transported through the debris.

Mental Status

If a patient is capable of verbal interaction during the rescue, this ability can provide a valuable means of assessment. A person's ability to speak not only indicates some functioning level of vital systems, but it also provides a means to assess mental status and ask about signs and symptoms. A verbally given physical assessment requires attention to detail. For example, asking the entrapped person not only what hurts, but what areas may now be numb may be important. It can be reassuring if the patient is cognitively intact and able to report the ability to void after rehydration, as occurred in case 2.

Equipment to Assist with Evaluation

Advanced US&R task forces often possess sophisticated tools that can be repurposed for medical evaluation and treatment, as indicated by the situation. For example, a telescoping search camera can be positioned to evaluate a person's condition before personnel have physical access. This capability was essential in clarifying the woman's status in case 4, in which her intertwined position with the impaled leg of a deceased victim caused confusion.

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Limited space can prohibit the use of bulky monitors and other equipment. The ability to work around impediments, such as with the use of extra-long cables for cardiac monitors so that a monitor could be placed outside of the immediate confined space and watched by another provider. All devices intended for use should be evaluated during a training for harsh conditions in an austere environment, as experience has demonstrated that dust, cold, and rough handling can compromise equipment function.

Remote Interventions

Simple interventions may be possible in spite of a lack of immediate physical access. Medical judgment may be used in evaluating the risk or benefit of providing oral rehydration to the alert patient in a prolonged entrapment situation. Passing oral rehydration fluids, blankets for warming, and protective equipment (eg, HEPA filter mask, helmet, and eye protection) through the rubble to the patient may minimize risk while access is obtained. These interventions were performed during several of the cases noted here.

Common Medical Problems and Treatment Considerations

Airway Compromise

Severe airway compromise during structural collapse is usually fatal before access to the entrapped person can be achieved. For those who survive the initial impact, however, dust impaction in the airway is very common, and inhaled beta-agonists can be useful. Protection of the airway from dust that is re-suspended during rescue efforts is essential, and should be accomplished as soon as feasible (eg, providing a protective mask to the person). With proper equipment, a victim may be furnished with fresh air using the compressed air that drives the rescue team's power equipment. If a medical non-rebreather oxygen mask is used, valuable medical oxygen can be conserved for more appropriate conditions. It is important to avoid the need to perform an intubation within the confined space if at all possible, because provider control of the person's airway can be technically complicated to achieve and maintain (eg, limited portable oxygen supplies, maintaining mechanical ventilation during extrication) As noted in case 5, use of analgesic and amnestic agents such as ketamine sodium worked very well in the confined space environment.

Hypothermia or Hyperthermia

Either hypothermia or hyperthermia can be encountered, depending on the potential range in ambient temperature. Hypothermia is a particular concern, as immobilization against concrete or other dense surface in minimal clothing can result in low body temperatures, even during relatively mild weather

Hypovolemia

Prolonged entrapment times increase the probability of dehydration and starvation. Severe hemorrhagic injuries and co-existing morbidities (eg, diabetes) can exacerbate a hypovolemic condition. Adequate IV access should be rapidly achieved, and can be facilitated by adapting techniques to the confined space. The use of intraosseous infusion devices; the Seldinger wire technique to increase small vein access; or intraosseous access, such as used in case 5; and other methods may be considered. Central vascular access can be complicated, and may potentially injure the patient, given the restricted patient positioning and uncertain follow-up (eg, inability to check an X-ray after placement of an internal jugular or subclavian line) and should be reserved as a procedure of last resort. Femoral access has a lower risk of traumatic complication, and is best performed in the assessment area, as in case 3. Hypodermoclysis may even be considered in the extreme situation in which only soft tissue is available to the medical provider. The need for a pressure infuser when providing IV fluids can be helpful, as confined space constraints will likely prohibit gravity-driven fluid flow during extrication. This approach was mandatory in our cases 1 and 4.

Crush Injury With the Potential for Crush Syndrome

Compressed muscle tissue can rapidly develop crush injury, a condition that precipitates myocyte death and cell dissolution more severely than simple ischemia.[22] Only a relatively light but constant pressure load is required to create this condition (eg, the patient's own body weight), and crush injury can develop within hours after entrapment.[23] The effects from this injury remain localized until the compression is released and the injured tissue reperfused. The systemic effects of third-spacing of fluids and dissemination of toxic products from a pressure-induced, ischemic muscle injury can rapidly become profound. Cases of sudden deterioration and death after rescue are well documented, and common enough in seemingly stable patients that historically they were tagged as "the grateful dead" and "smiling death" by disappointed rescuers.[24]

Experiential evidence has demonstrated that rapid treatment begun before or simultaneously with extrication can prevent or minimize many of the serious elements of crush syndrome, including hypovolemic shock, cardiac dysrhythmias, renal failure, and adult respiratory distress syndrome.[25] Protocols for the treatment of crush injury are available elsewhere but dictate that treatment be initiated while the patient is still entrapped, before extrication.[26-35]

Delayed Treatment of Traumatic Injuries

Patients may be entrapped for lengthy periods with significant traumatic injuries before medical intervention can occur. Lacerations, puncture wounds, and blunt trauma can all exist, and evaluation and treatment regimens can be complicated by poor access to the survivor. Secondary infection may already be an issue on initial evaluation. Rapid cleaning and covering of wounds may prevent additional contamination during extrication.

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Entrapped Limbs

Collapsed patterns may entrap a victim by their upper or lower extremities. The decision process to amputate a limb in this environment is beyond the scope of this report but should be considered as a last resort and is fraught with complexities.[36] Understanding the many other options for freeing entrapped limbs, planned and executed in conjunction with US&R task force engineering and rescue experts, is critical for any medical personnel intending to provide confined space medical care and may result in saving a limb.

Behavioral Health Issues

The behavioral health effects of entrapment in the confined space can complicate extrication. Emotions can vary from despondency to extreme elation. Many of those entrapped have experienced near rescues and then abandonment, so it is important to reassure them that the rescue will continue until they are freed, even if the rescuers must briefly retreat for safety reasons such as during aftershocks. In case 4, patient sedation was necessary, because the woman's erratic behavior was interfering with rescue efforts. It is important to consider patient agitation as a sign of hypoxia, hypovolemia, impending shock, hypoglycemia, early crush syndrome, or another potential physical cause.

Pre-existing Medical Conditions

Common chronic medical issues such as diabetes, asthma, chronic obstructive pulmonary disease, coronary artery disease, and pregnancy have been encountered during collapsed structure rescues. During the rescue described in case 1, local rescuer workers extricated a nearby woman who was in her eighth month of pregnancy and experiencing abdominal pain every 5 minutes. The US&R medical team prepared for a confined space labor and delivery before her extrication. She delivered a healthy baby within hours of her evacuation.

Patient Extrication and Hand Off to Local Medical Care

Patient Destination

Before the person is extricated, a carefully orchestrated plan to remove the patient from the collapse site should be developed in consultation with local authorities. Selecting a medical destination with the highest functional capabilities will enhance the patient's chances of survival.

Patient Transport Through Rubble

Evacuation from the entrapment area to the exit portal in the collapse may require specialized equipment to move the patient, including rope rigging for vertical lifting or lowering, or for horizontal drag through tight spaces. The medical team must be skilled in appropriate immobilization and protection of the patient for these difficult maneuvers. It is important that they maintain access to monitoring equipment and have the ability to intermittently re-evaluate the patient, as indicated. Ensuring that all exit passageways will accommodate the immobilized patient within the required extrication equipment (eg, long board, wire basket) should be accomplished well before the patient is moved. Establishing an assessment area proximate to the collapsed structure in a safe and controlled space will allow the treatment team to reassess the patient's medical condition and perform critical interventions (eg, airway management, intravenous access, pain management, antibiotics).

CONCLUSIONS

Confined space medicine involves not only unusual clinical conditions as they directly relate to entrapped patients, but also presents unique patient management challenges. The medical capability within a US&R task force is primarily prepared to conduct preventive medicine and provide indicated medical care to team members. The cases described demonstrate that this medical capability can expedite the successful, live rescue of entrapped patients in a multihazard environment.

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The opinions expressed in this manuscript are those of the authors alone and should not be construed to represent official policy or opinion of the Fairfax County Urban Search and Rescue Program, Federal Emergency Management Agency (FEMA), or the Office for US Foreign Disaster Assistance (OFDA)/ United States Agency for International Development (USAID) or of the US government.

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