CP 599

Title: **"The Provision of Intensive Care Medicine in Austere Field Locations"**

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Introduction: The single most difficult challenge providing intensive care in an austere field location is overcoming logistical hurdles. However, the recent commercial development of small lightweight portable advanced medical devices has greatly expanded the potential of sophisticated intensive care medicine in such locations. In contrast to the Viet Nam era, where cardiac monitors and mechanical ventilators were not only extremely uncommon, but were unreasonably large, we now have choices among many remarkably capable machines that are small and lightweight. These include mechanical ventilators, cardiac respiratory and invasive monitor, and precision infusion pumps. Many of these devices are highly sophisticated and can provide a technical level of care equivalent to that of an intensive care unit in a fixed medical facility. During this talk the following elements were discussed:

1. A review of necessary field elements to provide quality intensive care.
2. A discussion of unique logistical requirements imposed by an austere environment.
3. A discussion of unique clinical consequences of this environment.

Discussion:

The Portable ICU:

General Considerations: When considering the general equipment requirements for the development of a portable intensive care unit the following universal considerations are important. First of all, all medical devices should be small and lightweight and should be clearly portable, as opposed to luggable. For a military field environment this equates to getting the equipment on the same litter as the patient. All medical devices should have an extended battery life with a minimum useable time of at least four to six hours. This is especially important given the unpredictable nature when medical transport is involved. For example, it is common to arrive at a location expecting your next level of transportation to be in place, but in fact, to find that you must wait (and that further battery capabilities are required).

All medical devices should have prominent visual alarms. An austere field environment is commonly characterized by high ambient noise levels so that a dependence on auditory alarms can easily lead to medical mishaps. All medical devices should be durable, that is water and dust resistant. Again, because of the inherent transport nature required for these patients, all medical devices should be certified for aeromedical usage. Certification includes an assessment of electromagnetic interference with navigational instruments as well as an ability to withstand a high vibration environment. Finally, in general these devices should avoid proprietary peripheral interfaces. For example, many small transport ventilators now in use include a proprietary tubing circuit as opposed to a standard 22 mm diameter set up. If the care of these patients is past from one critical care team to another an additional confusion may occur related to the transfer to other medical devices with differing machine patient interfaces. This is additionally true, as another example, for many IV infusion pumps.

Mechanical Ventilation. The prototypical transport mechanical ventilator is oxygen powered and electrically controlled. In general these machines are time and/or pressure triggered, volume limited, and time cycled. Because many of these machines are oxygen powered and therefore lack an internal compressor as well as an air oxygen blender, they can consume excessive amounts of oxygen. As suggested above, nonstandard proprietary tubing circuit setups can also be problematic.

The ideal transport mechanical ventilator for a field environment is small and lightweight, uses a standard 22 mm internal diameter tubing circuit, has an internal compressor and blender, has easily seen alarms and knobs that utilize standard conventions, has a long battery life, is durable, and is electromagnetically well shielded. This run-on sentence encapsulates all of the necessary and desirable features of a field mechanical ventilator. While this may seem to describe wishful thinking, in fact machines are now coming on to the commercial market (in the less than 15 pound category) that meet all of the above described specifications.

The Cardiac Monitor. A filed utilizable transport cardiac monitor should include ECG monitoring with multiple leads, noninvasive blood pressure monitoring, pulse oximetry, and as a nice to have feature capnography. Audible alarms are especially problematic for these devices. They should have a high threshold for filtering artifactually generated monitor noise from either patient movement or excessive vibration. Challenges that remain to be solved for these monitors, especially since visual alarms are required, include a central monitoring station capability, a reliable arrhythmia and abnormal vital signs notification capability, nurse and physician charting, and a clear link to telemedicine.

Intravenous Drug Delivery System. As described above, the proliferation of proprietary cartridges and IV tubing sets can make the movement and care of a field critical care patient very frustrating. Most IV pumps in use are either cartridge or piston driven or of a syringe pump version. Issues of importance with this include size and portability, battery performance, and again electromagnetic interference. Commercially available machines are now available that can simultaneously infuse IV fluids, blood and enteral tube feedings, all from the same cartridge and tubing circuit. The watchword for an austere environment is standardization.

Oxygen Source. During the last 50 years of medical support for military conflicts and wars, adequate availability of oxygen and the logistical requirements this imposes, has been essentially the largest materiel problem to be solved. In this regard, it is essential that we seek medical devices that are very frugal with their oxygen utilization. We are additionally looking at a variety of machines that include oxygen generation capabilities from ambient air. Unfortunately, at this time, many of these remain quite large and bulky, or their oxygen flow generation rates are not sufficient to reliably drive a mechanical ventilator.

In general, most transport mechanical ventilators require a reliable 40 psi oxygen source for proper utilization. This oxygen must not include any contaminants and must be logistically well placed. Most of this oxygen comes in two forms, either gaseous storage or liquid oxygen storage. Both have advantages and disadvantages. Liquid oxygen is smaller and more compact, and for Air Force purposes is typically more available than gaseous oxygen. However, in a high-temperature environment, liquid oxygen containers must be frequently refilled. In contrast, gaseous oxygen, while more stable is provided in containers which are larger, bulkier, and heavier. Transport of these gaseous oxygen canisters in a hypobaric environment is also potentially dangerous.

Laboratory Devices. As the level of sophistication increases for the transport and care of these patients, interval assessment of laboratory status becomes critical. These devices must be small and portable and should easily accompany the patient. They should be insensitive to environment changes and should be easily calibrated They should usable by a bedside care provider, and should not require laboratory personnel. Fortunately, at this time a variety of point-of-care laboratory devices that fulfill these requirements are now available. Many of these include arterial blood gases as well as simple chemistries and other studies such as hemoglobin and hematocrit. In the near future, these will additionally include magnesium, ionized calcium, and phosphorus capabilities as well.

Other Medical Devices. In order to provide quality critical care in an austere environment other clinical considerations must also be met. These include the availability of a powered, portable suction apparatus, a defibrillator, an ability to humidify inspired gases, and a reliable mechanism to warm hypothermic patients. Hypothermia greatly compounds morbidity and mortality for traumatized critically ill patients.

Other requirements for austere critical care include sufficient intravenous fluids including crystalloid and colloid solutions, vasoactive medications, advanced resuscitation cardiac drugs, antibiotics, sedative hypnotic and analgesic agents, muscle relaxant drugs, anti-seizure medications and other common formulary agents such as $D_{50}W$, thiamine, narcotic reversal agents, etc.

Logistical Challenges:

Planning Factors. In order to safely care for patients such as these in an austere environment as well as transport them to definitive care a variety of planning factors need to be considered:

1. Anticipated casualty loads drives the number of providers required, the number of medical devices required, and the consumable medical supplies.
2. Weight and cube issues. In order to be forward deployed these should be relatively portable with the largest mass considerations being IV fluids and oxygen.
3. Personnel utilization. The pace of these types of deployment can be quite hectic and issues of crew duty and crew cycle times need to be additionally considered.
4. Communications. As has been discussed, it is assumed that these patients will be transported from a forward location to a definitive care site. Appropriate coordination and communication to successfully complete this transport is vital. Inpatients with multisystem medical diseases, the volume of analytical and clinical data that need to be communicated on each individual patient can be immense. Communications is especially important for these patients.

The ultimate goal is to define a seamless continuum of care from the point of injury to definitive treatment. We can anticipate difficulties to arise at the interface points. Again, the emphasize communication of specific patient needs is especially important. In addition, coordination of transport vehicles, differences in available treatment modalities, equipment and compatabilities and medical device requirements must be considered as well. Finally, interoperability of team members is vitally important in this environment. As an example, a critical care nurse must facile with trouble shooting of ventilator and conversely a respiratory therapist must be able to start a peripheral intravenous line.

Clinical Issues:

There are three universal rules of patient transport and care of critically ill patients in a field environment. These include:

1. Remember the A-B-C's, when bad things happen in this environment it is almost always airway or breathing (oxygenation) related.
2. Things deteriorate at light speed, if you have not previously practiced a variety of clinical scenarios, then it is difficult to assign tasks and successfully resuscitate a patient in this environment "on the fly."
3. Never leave a secure clinical environment until you are certain you have everything you may need.
4. Travel light.

Given the above, when caring for or moving the mechanically ventilated patient in an austere environment, it is important to estimate and/or calculate the supplemental oxygen needed prior to leaving a secure environment. This can be simply done using a patient's known minute ventilation while on the mechanical ventilator and ensuring that you do not proceed to an austere environment unless you are carrying at least one and a half to two times that amount of oxygen. Furthermore, it is important to know the battery life of the medical devices prior to entering this environment. Be sure to consider additional consumption based on increased use (example, cycling the noninvasive blood pressure device). It is extremely important to have a backup plan in case something breaks enroute such as the mechanical ventilator. Are you going to carry an additional ventilator or would you simple bag the patient until a secure environment is obtained? Finally, it is important to use checklists wherever possible to ensure all potential problems are considered before entering an environment that does not lend itself well to "heat of the moment" decisions.

Hemodynamic Support and Resuscitation. In this section we will briefly delve into the treatment and transport of "shock treated" casualties. Clearly "shock treated" is in the eyes of the beholder. For some this may mean establishing sufficient IV access, while for others this means their hemodynamic resuscitations has been completed. Understand that even hospitalized patients may require further resuscitation. Finally, be vigilant for the development of new problems in these patients such as other surgical emergencies as in rebleeding or compartment syndromes or the like. Ensure maximum patient accessibility in this environment. If you are going to transport a patient do not load them below the knee level or higher than the chest level, think of trying to emergently intubate a lost airway in either of those two extreme positions.

If aeromedical resuscitation is required, understand that the hypobaric environment exacerbates resuscitation requirements. It is important to ensure hemodynamic assessment is adequate and in this regard profusion status is assessed by the usual methods. This includes heart rate, blood pressure, urine output, capillary refill, and pulse oximetry observing the morphology of weight form as well as respiratory variation. It is important for all treatment teams to adhere to a established trauma life support algorithms or other clearly defined "A-B-C" type approaches.

In many patients hemodynamic monitoring is desirable. For the majority, this is limited to placement of arterial lines in patients with blood pressure instability or severe respiratory failure requiring serial arterial blood gas determinations. Pulmonary artery catherization is rarely needed in this patient population. All invasive lines should be well secured and sewn down.

Before initiating transport, vital signs should be "relatively stable." Again, "relatively stable" is an ambiguous term and requires further delineation. In general, this means that all traumatic injuries have been identified and that transport time does not impose an unacceptable delay until surgery and that non-surgical treatment for these major traumatic injuries is at least "in progress." For patients with nontraumatic causes of shock, therapy should also be " in progress." These etiologies in this environment potentially include sepsis, cardiac failure, and allergic reactions.

Respiratory Failure. In many regards this is clearly the "all or nothing bet" of austere critical care provision. Mistakes or lapses in judgment as they relate to the respiratory system will most quickly lead to patient demise. In other words, the pulmonary respiratory system is the most dependent on external medical device support. It is also the system most at risk for complications such as barotrauma. Finally, it is the system that is most easily affected by an aeromedical/hypobaric environment.

If transport of these patients is required then a variety of criteria need to be met before this process is undertaken. First of all, if you cannot adequately oxygenate and ventilate this patient on the ground then you will on exacerbate the situation by placing the patient in a hypobaric environment. Adequate oxygenation is defined as an oxygen saturation greater than 92% by pulse oximetry, a minute ventilation equal to or less than 15-20 liters per minute, and a PCO_2 less than 55-60 tor, and/or a pH greater than 7.25-7.30. Furthermore, the mechanical ventilator must not require excessive pressures to deliver tidal volume. This is defined as a peak airway pressure equal to or less than 45-50 cm of water, pulmonary calculated compliance greater than 25, and/or an I:E ratio equal to or greater than 1:1. If the above parameters are not met, then the patient is at high risk for respiratory deterioration enroute while in the airplane.

Most current transport ventilators are nothing more than modified oxygen regulators that depend on the psi from the oxygen source in order to generate a title volume. As mentioned earlier in this paper, newer machines are incorporating small, low volume displacement, high rpm internal compressors and blenders.

In order to use these mechanical ventilators in a hypobaric environment, the clinician must be cognizant of the effects of altitude on ground level calibration of these medical devices. Problem areas include measured versus actual delivered oxygen concentration, delivered gas volumes, lung distending pressures, endotracheal tube cuff volumes, and accurate assessment of positive and expiratory pressure (PEEP). As a general rule of thumb, these transports cannot be successfully accomplished without the on scene presence of a respiratory therapist. The respiratory system is simply too unstable to endure many mistakes without rapid recognition of ventilator problems.

Other important clinical adjuncts for patient transport with respiratory failure include humidification which is generally accomplished using a heat and moisture exchanger as opposed to a humidifier. A colorimetric carbon dioxide detector may also be useful as well as portable bronchoscopy.

Other Organ System Support Requirements. Acute brain injury can be easily exacerbated in an austere environment. Two general clinical rules of management include:

1. Avoid maneuvers that may exacerbate elevated intracranial pressure. These include loading patients head to the front during take-off and reversing their position for landing as well as a liberal use of sedatives and muscle relaxants to minimize oxygen consumption.
2. Ensure adequate volume resuscitation for these patients. It has been previously accepted dogma that relative dehydration limits the effects of brain swelling with acute brain injury. We now know that this is clearly flawed and that the inpoint for volume resuscitation should be uvolemia. Furthermore, given that these patients come from a field environment, most are already relatively dehydrated.

Management of elevated intracranial pressure in a field environment is generally limited to the use of Manitol as an osmotic dehydrating agent and selected use of hyperventilation only in order to temporize. Seizure prophylaxis should be liberally undertaken for all patients with significant head trauma. In this environment it is defined as a loss consciousness which exceeds 5-10 minutes in duration. Drugs of choice for this include benzodiazepines, phenytoin and a variety of barbituates. Finally as a general rule of thumb, inpatients with elevated intracranial pressure avoid activities which may cause nasopharyngeal stimulation such as placement of nasogastric tubes or nasotracheal intubation. These maneuvers may precipitate herniation.

Summary:

Recent advances in portability of advanced medical devices have exponentially increased our abilities to provide far forward and enroute intensive care medicine. This is a rapidly evolving and changing area. In contrast to a mere decade ago, our ability to provide sophisticated field critical care has dramatically increased as has the risk for complications and mishaps. In summary, we can provide far forward sophisticated intensive care, but this must remain in the hands of skilled clinicians as the margin for error is truly paper thin.