Battlefield Anesthesia: Advances in Patient Care and Pain Management

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\textbf{Battlefield anesthesia}

Battlefield surgery in Iraq has moved ahead light-years compared with previous conflicts (Fig. 1). Despite the increasing lethality of insurgent attacks, the survival percentages of our troops have never been higher. A great part of this is because of improved protective gear—our troops drive armored high-mobility multipurpose wheeled vehicles (Humvees) and other vehicles and wear flak and Kevlar individual armor, ballistic glasses to protect their eyes, and even ballistic ear plugs that reduce the risk for damage to their ears \cite{1–3}. A higher percentage of injuries is to extremities, and more of our troops are surviving to reach the medical surgical help they need to continue to survive \cite{4–6}. Military medicine is traditionally sorted into five levels of care delivery for combat injuries.

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The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, or the US Government.

The authors have no commercial ties to any of the products mentioned in this article.

\textsuperscript{1932-2275/07/$ - see front matter. Published by Elsevier Inc.
doi:10.1016/j.anclin.2006.12.003
anesthesiology.theclinics.com}
Level 1

Level 1 is up to the level of the battalion aid station, from self-aid and buddy aid to aid by a hospital corpsman or medic (IV, morphine, antibiotics) to mobile emergency room setup, such as the shock trauma platoon (STP). Care at this level is provided by general medical officers or by specialists, depending on the setup, and is mostly advanced trauma life support with some exceptions. Diagnostic equipment can range from virtually nothing except a Propaq, to laboratory and radiograph support, ultrasound, and so forth. Care is modified in the face of tactical or battlefield circumstances and it is now performed with a focus on stopping or limiting hemorrhage (tourniquets and dressings) and hypotensive resuscitative technique [7–12]. Anecdotally, one-handed tourniquets and hemostatic dressings are credited with saving multiple lives. Additional review of treatments and outcomes is required for more definitive conclusions. Fluid resuscitation is given only up to the point of maintaining a blood pressure in the 80 to 90s range, with transport to a location with early surgical intervention being of paramount importance. Airway management at these forward units is currently provided by direct laryngoscopy and endotracheal tube placement or surgical airway as the only two options, and is variable with regard to provider competency. Before deployment, many of the providers brush up on intubating skills in the local military hospitals. The King LT-D is one prehospital modality that some providers are carrying.

Although the initial efforts focus on survival of the soldier, effective pain management is an important consideration because we have realized that pain is more than an unfortunate consequence of wounding and may be a disease process in and of itself [13]. Effective pain control may have
positive effects on recovery following trauma and may reduce morbidity over the long term [14]. For more than 200 years, morphine has been the mainstay of battlefield pain management. In the current Iraq conflict the United States military has evaluated the use of fentanyl lollipops with initial success in the treatment of combat casualties [15].

**Level 2**

The military defines Level 2 as the first level at which surgical intervention is performed. In the Navy this care can be provided by either a surgical company or a forward resuscitative surgical system (FRSS) [16,17]. In the Army the equivalent units are called forward surgical teams and in the Air Force they are known as mobile forward air surgical teams [6].

One or two FRSS teams are usually paired with an STP to form a surgical/shock trauma platoon (SSTP). The STP is staffed by two emergency medicine physicians, physician assistants, nurses, and hospital corpsmen and functions as an emergency department. The addition of the STP gives the unit limited holding capacity. The FRSS teams are made up of either two general surgeons or one general and one orthopedic surgeon, one anesthesia provider, a critical care nurse, a physician assistant, and surgical technicians.

These teams provide surgical care near the forward edge of the battle area. They were designed for expeditionary warfare and the teams can be deployed and ready to receive casualties within an hour. Such care is known as tactical surgical intervention, because it is modified by the physiologic status of the patients and the tactical situations occurring in the battlefield. Other factors that influence clinical decisions include numbers of patients, types of wounds, limited supplies, and medical evacuation time and availability [6,16–18]. Life-and-limb salvage or “damage control” surgery is the norm at these sites. Such surgeries would include revascularization techniques using primary repair or shunts, laparotomies to stop hemorrhage from liver or splenic damage and contamination from bowel injuries, thoracotomies for lung or vascular repair, and extremity wound explorations and possible external fixations of fractures. This type of surgery allows for the stabilization of those patients who would not otherwise survive transport to more distant surgical sites (Fig. 2).

Anesthetic equipment is lightweight, mobile, and able to withstand field conditions. Most surgical cases at this level are performed under general anesthesia. Total intravenous anesthesia (TIVA) can be achieved by way of a Bard infusion pump using ketamine or propofol, but no target controlled infusion capability is currently available. General anesthetics using inhaled agents are still the norm.

Surgical companies are outfitted with the Drager Narkomed M field anesthesia machine. This is a standard anesthesia machine, with a variable
bypass vaporizer and a gas-driven ventilator. It uses a Venturi-based design to decrease oxygen consumption [19]. It is capable of volume-controlled ventilation. Ventilator drive gas is user selectable to be either oxygen or air. Modular, lightweight, and rugged, The Narkomed M is well suited for field operations. The major limitation of this machine is high oxygen consumption. With mechanical ventilations and fresh gas flows of 1 L/min gas consumption, the Narkomed M can optimally be driven by approximately 6 L/m oxygen [19]. Practically speaking, when paired with a 10 L/min portable oxygen generator system (POGS), compressed air from the POGS should be used to drive the bellows so that the oxygen reservoir is not depleted. Using compressed gas to drive the bellows and 1 to 2 L/min oxygen for fresh gas flows, even patients who have poor lung compliance or hypermetabolic states can be ventilated.

FRSS and other forward surgical teams are equipped with the Ohmeda Universal Portable Anesthesia Complete (UPAC), more commonly known as the drawover vaporizer. This type of vaporizer was used in the 1973 Yom Kippur war and the 1982 Falkands conflict, and in Somalia, Desert Storm, Afghanistan, and Operation Iraqi Freedom (OIF). The drawover is a variable-bypass, calibrated, temperature-compensated, flow-over, low-resistance, agent-nonspecific vaporizer [20]. The UPAC also compensates for changes in barometric pressure. Compact, lightweight, and rugged, the UPAC meets the needs of these mobile surgical teams. The vaporizer can be used with no supplemental oxygen source applied, and delivers a fraction of inspired oxygen (FIO₂) of 21% [21] consistently. Only with extremely high percentages of end tidal agent (eg, 5% isoflurane) and no supplemental oxygen does the FIO₂ fall below 21%. When it is used with supplemental oxygen at 1 to 2 L/min it is capable of delivering FIO₂ concentrations of 40% to 50% with the use of oxygen reservoir tubing [22,23]. Isoflurane is
the only volatile agent currently used in Level 2 sites, but this vaporizer is also calibrated for use with halothane, enflurane, and diethyl ether. This flexibility is useful when deploying forces may have to depend on host nation supplies of anesthetic agents. Because the vapor pressure of sevoflurane is similar to enflurane it can be used with the drawover. The drawover is capable of delivering only 3% to 4% sevoflurane, however, and so is not optimal for inhalational inductions [24].

The Impact 754 Univent ventilator, which is used at Level 2 facilities, is a lightweight transport ventilator capable of functioning with room air, a high-pressure oxygen source, or low-flow supplemental oxygen. It can operate 3 to 4 hours on its battery and can withstand temperatures of up to 120°F. Exposure to extreme heat can decrease battery life. These ventilators are used for the ICU, patient transport, and in the operating room (OR) with the Ohmeda drawover vaporizer to provide positive pressure ventilation during surgery. The “pull through” method, described in the Emergency War Surgery Manual, is used (Fig. 3) [25]. The ventilator is

![Impact 754 ventilator with Ohmeda portable anesthesia complete drawover vaporizer. (Courtesy of Bruce Baker, Oceanside, CA.)](image-url)
positioned between the patient and the vaporizer. This position avoids the potential for delivery of anesthetic concentrations greater than the setting on the vaporizer dial when the vaporizer is positioned between the patient and the ventilator [26]. The Univent works well in the OR, is used by all armed services, and is approved for in-flight use. The Univent can function in synchronized intermittent mandatory ventilation, assist-control, or continuous positive airway pressure mode. Tidal volumes, rate, I:E ratio, FIO₂, and pressure limits can be set. Disconnect, low tidal volume, and high or low peak airway pressure alarms are present. One problem when using the ventilator with the vaporizer is that the drawover is calibrated for spontaneous or assisted ventilations, but when combined with the Impact these calibrations are not accurate so the agent delivered can be 0.5% to 1% lower than expected [25,26]. For this reason, an end tidal agent analyzer, such as the VAMOS (Drager Medical) or Cardiocup 5 (Datex-Ohmeda), is recommended (Fig. 4).

Fig. 4. Narkomed M field anesthesia machine with VAMOS Agent Analyzer. (Courtesy of Bruce Baker, Oceanside, CA.)
There are limited blood products available at the Level 2 facilities. Type O+ and O− packed red blood cells (PRBCs) are readily available. Most resuscitations involve some combination of colloid, crystalloid, and PRBCs. Frequently combat trauma patients require massive blood transfusion, and this invariably leads to a dilutional and consumptive coagulopathy. These cases require fresh whole blood using the “walking blood bank.” Blood donations are taken from a pool of military members, optimally selected and typed before deployment (because dog tags worn by the Marines have up to a 25% rate of having the wrong blood type), who have the same ABO type-specific blood as the casualty. Most sites in Iraq can also type and cross-match the blood in the laboratory. The blood provides valuable clotting factors, platelets, and red blood cells and is usually considered after about 4 to 6 units of PRBCs. By limiting donors to active-duty military members who receive hepatitis B vaccination with verified titers, HIV screening, and urine drug screening, infectious risks should be minimal. Off-label use of recombinant Factor VIIA (Novo Seven) anecdotally aided in the surgeries of several trauma patients and the authors have heard of no reports of significant complications. The surgical company’s laboratory capability can provide type-specific, cross-matched whole blood to the OR within minutes [27].

“Difficult airway” equipment is also limited at Level 2 sites. Initially, the laryngeal mask airway (LMA) was the only nonsurgical rescue option available after failed intubation. Level 2 units were also provided with percutaneous cricothyrotomy kits. Currently lighted stylets, Eschmann intubating stylets, Combitubes, and Intubating LMAs are being used. Fiberoptic bronchoscopes will be available in the future as part of the regular stocked items. Airway trauma has traditionally been noted to be about 1% of total injuries. Facial trauma attributable to penetrating trauma typically is treated with a surgical airway if the patient is in acute distress but in most cases can be intubated by way of direct laryngoscopy. During OIF, the author treated several patients who had anterior airway injuries wherein the laryngeal apparatus was not disrupted and the patients were intubated in a straightforward manner. One patient who had penetrating trauma to the anterior thyroid cartilage presented with dysphonia. The patient was intubated awake with ketamine and midazolam sedation, maintaining spontaneous ventilation with a 6.0 endotracheal tube because of subglottic stenosis of his airway.

Regional anesthesia (neuraxial and peripheral nerve block) along with local anesthesia became an important modality for care in patients who had extremity injuries. At Level 2 facilities the availability of spinal kits, b-bevel insulated needles, and peripheral nerve stimulators could be sought through the logistic supply chain. Approximately 25% of all surgical cases at one Level 2 facility involved regional anesthesia. Most sites have peripheral nerve block capability but no continuous block catheters are available until Level 3. Many patients injured by improvised explosive devices may be
injured in multiple extremities, so general anesthetics are performed for most cases (Fig. 5).

With the current static battlefield environment of OIF, the use of regional anesthesia can be beneficial in providing preoperative analgesia or intraoperative anesthesia as a sole anesthetic or combined with general anesthesia. Regional anesthesia provides excellent postoperative analgesia, decreasing the narcotic use and possibly decreasing the incidence of chronic pain syndromes.

Malignant hyperthermia is a relatively rare condition (1:50,000 adult anesthetics reported in North American population) and these patients have extensive intensive care requirements. Because of this, dantrolene was not initially available at Level 2 sites in expeditionary mode and patients experiencing an episode of malignant hyperthermia were to be treated as expectant. Now every Navy Level 2 facility has access to dantrolene.

POGS are used to supply oxygen at Level 2 facilities. The POGS 33/POGS 10 (Onsite Gas) can deliver 33 and 10 L of oxygen (93%–96%) per minute, respectively. Their performance is limited by altitude. The POGS 10 units can run continuously at 10 L/min oxygen production for taking care of patients or refilling oxygen tanks. Oxygen tanks are refilled using the Rix oxygen booster system to compress them up to 2200 psi. An E cylinder takes approximately 75 minutes to refill in this manner using the POGS 10.

Invasive pressure monitoring and noninvasive blood pressure, oxygen saturation, EKG, and end tidal carbon dioxide monitoring are available, and end tidal agent monitoring is being added. Although somewhat limited in the supplies and diagnostic equipment available, such units can do basic laboratories, including complete blood count and arterial blood gases, basic radiographs, abdominal ultrasound exams, invasive monitoring, and mechanical ventilation of patients [28]. In a stationary battlefield, such as Iraq, there are several small surgical units like this spread over the country, with several larger Level 3 hospitals in more central areas.

![Type of Anesthesia](Fig. 5. Types of anesthesia. (Courtesy of Bruce Baker, Oceanside, CA.)
In one small study comparing the efficacy of such surgical units with a Level 1 trauma center, such as Los Angeles County, patients who had similar injury severity scores (ISS) sorted into moderate (ISS 16–24) or severe (ISS 25+) were evaluated for outcome and were found to have equivalent chances of survival [29].

**En route care**

Medical evacuation is usually by helicopter and may be accompanied by en route care (ERC) nurses for the severely injured. Roughly 20% of patients who receive life-saving care at Level 2 facilities are still stabilizing with such life-threatening problems as hypothermia, hypotension, coagulopathy, and airway needs [16]. These patients are still receiving blood products, are intubated and ventilated, and may have vascular shunts and multiple thoracostomy tubes and drains to care for. They are transported by stretcher under the care of specially trained nurses who must care for their patients working out of a single backpack of fluids, medicines, and equipment, often in dark and hazardous conditions. All of the previous efforts of life-and-limb salvage amount to nothing without the expertise and dedication of these flight-trained medical personnel.

The en-route care system (ERCS) is still relatively new and born from necessity during OIF I. The first nurses were picked from various people in the 1st Medical Battalion and nurses at a fleet hospital. During OIF II (year 2 in Iraq), ERC nurses were actually assigned to each medical unit. No real training existed and not all nurses were critical-care trained, however. Finally, the first training pipeline was designed before OIF III (year 3 in Iraq), in which the Navy Operational Medical Institute and the United States Army School of Aviation Medicine started courses.

The ERCS equipment is a continual work in progress, becoming lighter and more compact, to better fit in the various aircraft models available for transport (ie, UH-60, CH-46, CH-53, MV-22, and so forth) The team itself is changing also. Originally designed to be just one nurse, a corpsman is now part of the two-person team (Fig. 6).

The ERCS is slowly coming to maturity. Nurses fly almost daily in Iraq. They use creativity and initiative to come up with new ways to make their kits more useful. Nurses have done everything from adapting equipment from the Army to using specially marked body bags to keep their patients warm. Although currently a Marine Corps program, the Navy and Army are taking a serious look at the ECRS.

**Level 3**

Level 3 surgical hospitals are designed to be mobile also but take much more time and energy to move. They have six or more ORs and have many
different surgical specialties represented, including general, orthopedics, neurosurgery, otolaryngology, maxillofacial, ophthalmology, and other specialists [1,3,30]. The Narkomed M anesthesia machine is used in each OR. Much more advanced therapeutic and diagnostic equipment is available. In an expeditionary battlefield, but also in the stationary operations in Iraq, patients may transfer through each level (1, 2, and 3) before leaving the country. With central coordination of casualty evacuation, however, flights may take a patient to Level 2 facilities for life-and-limb–sparing operations or straight to Level 3 facilities for more specialized (ie, neurosurgical, facial, ophthalmologic) care. In prior conflicts, wounded soldiers spent many days to weeks recovering from wounds in field hospitals before they were considered stable enough for transport back to major hospitals outside of the operational theater. Now most patients whose injuries do not allow them to return to duty in 7 days are leaving Iraq from the Level 3 centers within 24 to 48 hours.

Advances in pain management

For more than 200 years, morphine was the mainstay of battlefield pain management. The significant role and advantages of morphine in treating pain in previous conflicts is undeniable. Morphine was an effective tool in previous wars because patients were static in the field hospital and their pain could be managed with scheduled doses of morphine provided by hospital nurses. In the present conflict, evacuation of the wounded from Iraq has accelerated with wounded soldiers arriving in a major military hospital (Landstuhl Regional Medical Center, Germany) as soon as 36 to 48 hours after injury. The new goal of field medicine for wounded soldiers is
stabilization of the patient for transport to the next level of care. The difficulties in managing pain in this environment are numerous. Multiple providers, communication difficulties over long distances, and austere patient-monitoring conditions are just a few of the issues that limit the usefulness of traditional, morphine-based pain management protocols. The need for new pain management technologies and strategies was recognized early in the Afghanistan and Iraq conflicts. In addition to surgical procedures, many of the patients leaving these centers have either continuous peripheral nerve block infusion catheters placed or patient-controlled analgesia (PCA) devices with them to make the flight out of Iraq more comfortable [31,32]. This is a relatively new addition to the standards of care that can be given to patients recovering from their wartime wounds, and can improve overall patient care tremendously. Because cooperation between the military medical services was necessary to establish a rapid evacuation system for severely injured patients, multiservice pain management of casualties has required extensive coordination. This problem was illustrated by initial difficulties encountered in using continuous blocks in the evacuation system. The infusion pump selected to transport patients (Stryker PainPumpII, Kalamazoo, MI) (Fig. 7), although acceptable in the Army combat support hospitals, was initially not acceptable for use in flight on Air Force military aircraft.

Fig. 7. Stryker PainPumpII currently approved for flight on United States military aircraft for use with continuous peripheral nerve block catheters. (Courtesy of Chester Buckenmaier, Gambrills, MD.)
because it had not been tested for compatibility with critical flight systems. This early setback established the need for better tri-service communication if advances in pain management were going to be applied successfully for all three services. Subsequently, the Military Advanced Regional Anesthesia and Analgesia (MARAA) organization was established in 2005. The organization works to develop consensus recommendations from the Air Force, Army, and Navy anesthesia services for improvements in anesthesia practice and technology to promote regional anesthesia and analgesia. Through the efforts of MARAA, the infusion pump was approved for flight and a training program was established to train medical personnel throughout the evacuation system in the use of continuous peripheral nerve block technology in soldiers. Today, continuous nerve blocks are a viable alternative for the anesthetic and analgesic management of combat wounded.

Because the percentage of wounded that were receiving blocks was small, owing to training and wounds that were inappropriate, the use of PCA was more likely to benefit wounded soldiers in combat support hospitals or military flights. Providing PCA technology to patients would reduce pain medication response times and also unburden medical personnel from having to manually provide IV morphine injections, conceivably freeing them to attend more severely injured patients on the flight. After a review of available infusion pump technology, the Sorenson, AmbiT PCA infusion pump was accepted as a temporary solution for PCA. These devices are being used in wounded soldiers throughout their evacuation today (Fig. 8).

Fig. 8. Sorenson, AmbiT PCA pump currently approved for flight on United States military aircraft for use in morphine PCA. (Courtesy of Chester Buckenmaier, Gambrills, MD.)
Level 4

After receiving initial surgeries and pain management in military hospitals in Iraq, patients are transported by Air Force medical evacuation planes to a Level 4 hospital out of the continental United States, such as Landstuhl, Germany. The in-flight capabilities of these transports is akin to a mobile ICU, with trained nursing and intensivist care for the multiple patients requiring specialized intensive care. These medical specialists typically have had Critical Care Aeromedical Evacuation Team training and are well versed in taking care of the critically injured patients coming from Iraq. Some patients who are injured in Iraq awaken for the first time in Landstuhl or even back in the United States, remaining intubated and ventilated through multiple surgeries before regaining full consciousness. The patients are further evaluated and depending on urgency, flight availability, and so forth, may have further surgery there or may be sent on to the United States. Usually the continuous block or PCA techniques are continued throughout this stage and back to the stateside hospitals.

Level 5

Currently patients are flown into the Bethesda/Walter Reed Hospital Consortium near Washington, DC, two of several Level 5 hospitals within the continental United States where further evaluation and treatment are rendered. In some cases, the patients are reaching Bethesda as soon as 48 hours after wounding, although the average is 6 to 7 days [30]. Depending on the injuries immediate care is provided or ongoing restorative care is performed over weeks at these tertiary care centers. Soldiers who have stable wounds that do not need acute or subspecialty care are evaluated and released to return to their local hospitals. The completion of their initial care and such follow-up as needed may occur at these smaller centers or through the Veteran’s Affairs system, depending on the patient’s duty status and disability. Routine screening for posttraumatic stress disorder and chronic pain is occurring at each of these sites.

Summary

Expeditionary maneuver warfare and the asymmetric battlefield have forced changes in the traditional methods with which we deliver anesthesia and surgery to the wounded. Although in many ways similar to how we have operated on the wounded for the past half century, new advances in diagnostic and therapeutic modalities and doctrinal shifts have changed the face of the battlefield hospital. Advances in pain management have increased the ability to care for injured patients, while movement of casualties from the battlefield back to facilities in the United States has accelerated
tremendously, allowing for specialized care much sooner than previously. These advances should result in improvements in morbidity and mortality for wounded veterans.

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