MADM™, Mobile Anesthesia Delivery Module, a solution to filling Capabilities Gaps

Ken Thompson, DNP, CRNA MSN

Lieutenant Colonel (Retired, US Army)
Steven T. Meyer, MSNA, CRNA

Peter Frye, CRNA MSN

Lieutenant Colonel (Retired, US Army)
Randall M. Schaefer, DNP, RN, ACNS-BC, CEN

Clinical Consultants

July 2023

Table of Contents

Executive Summary

As Joint Forces anticipate and plan for future conflicts and world missions, anesthesia providers will need lighter, stronger, and more portable medical equipment to withstand the extreme environments, situations, and missions where care will be provided. Physical locations of opportunity, temperature extremes, power supply availability, medication and medical equipment resupply will impact the effectiveness of anesthesia-provider care.

Within The Army Futures Command Concept for Medical 2022[1] and the Army Medical Modernization Strategy[2], anesthesia and its associated equipment must be considered a distinct capability. Treating combat casualties that require lifesaving surgery at the point of need on the battlefield requires the ongoing development, progression, evolution, and innovation of anesthesia to match the evolving nature of warfare. This will help improve survivability and return warfighters home.

MADM™, Mobile Anesthesia Delivery Module, is an FDA-approved materiel solution that addresses the Capabilities Gaps described in the Initial Capabilities Document (ICD) for Combat Casualty Care (C3) for Future Operations[3] through an inline direct anesthetic vaporizer that is compact and lightweight, allowing for the delivery of anesthesia safely and effectively, far forward on the battlefield.

Medical Modernization

The Army Futures Command Concept for Medical 2028[1] and the Army Medical Modernization Strategy[2] continuously define and codify the requirements for the Army Health System to modernize and maximize Joint Force healthcare in the future operating environment.

Army Futures Command Concept for Medical 2028 Highlights

Provide Medical Support Forward to Enable Semi-Independent Operations

- Align capabilities that directly and routinely impact warfighter survival forward of the Corps.
- Decrease sustainment demand.
- Simplify Class VIII replenishment.
- Employ lighter, smaller, and modernized equipment.
- Optimize Evacuation and Maximize Return to Duty.
- Optimize patient evacuation capacity and capability.
- Employ treatment capabilities to return Soldiers to duty as far forward as possible.

Army Medical Modernization Strategy Highlights

- Medical multi-domain formations will leverage advanced robotics, artificial intelligence, and optionally manned systems, and with humans in the loop, to enable decision-making to inform advanced clinical care and prioritize evacuation.
- Reduce the logistical burdens and footprints required of the 20th-century field hospital capabilities.

Surgical and Anesthesia Capability Gaps

Initial Capabilities Document (ICD) for Combat Casualty Care (C3) for Future Operations[3] identifies the following:

- The Joint Force has limited capability and capacity to provide sustained damage-control surgery and resuscitative care throughout the continuum of care.
- The Joint Force lacks surgical capabilities at the point of injury and in prolonged care.

Anesthesia

"Loss of sensation" using medications to induce numbness or sleep to prevent pain and discomfort during medical procedures and placing an individual in a state of insensibility to pain and other sensation[4]. Specific interventions or drugs induce anesthesia to permit the performance of procedures that may be noxious, painful, or stimulating.

Anesthesia Providers

During trauma, the anesthesia provider is responsible for managing and securing airway, initiating protective mechanical ventilation, obtaining vascular access, resuscitating with blood products, preventing hypothermia and acidosis, correcting coagulopathies, and making sure the tenets of anesthesia are adhered to[3].

Three Principles of Anesthesia

Amnesia, analgesia, and a non-moving patient. A prudent anesthesia provider will ensure unconsciousness, analgesia, decreased cortical stimulation, and muscle relaxation. These principles are often required to successfully complete surgery or other medical procedures.

The Evolution of Battlefield Anesthesia: Where We've Been

As future battlefield operations transition to more complex scenarios with access restrictions and other constraints, optimizing portability and interoperability becomes more important than ever. Anesthesia is typically limited to the Role 2 and Role 3 medical capabilities. As deliberate efforts are made to decrease the time of injury to reach Damage Control Resuscitation (DCR) and Damage Control Surgery (DCS) capabilities, providing anesthesia as far forward on the battlefield is critical to meet this objective. In Afghanistan from 2008-2013, MEDEVAC by air was the predominant type and mode of transport to the Role 2. In 2014, as the operational tempo shifted, CASEVAC became the primary type and method of transportation[5].

The Special Operations Forces (SOF) have responded to this need with organic capabilities to reduce the time to surgery outside of the support of the Role 2 footprint. The Army Golden Hour Offset Surgical Team (GHOST), Air Force Special Operations Surgical Team (SOST), and Marine Corps Forward Resuscitative Surgical Teams (FRSS) all provide expeditionary DCR and DCS to provide Special Operations the ability to have freedom of maneuver in time and space, while reducing medical risk to the force. Operational constraints and limitations are placed upon the medical unit within the SOF footprint for providing surgical care in locations of opportunity, including the open air, tents, house, and non-hospital fixed facilities. Surgical care can occur in any sized vehicle and aircraft platform.

Conventional and Special Operations Commanders mission success depends on the training and preparation of the medical team's ability to perform and function in an environment dictated by their mission requirements. The teams must plan, train, and rehearse on various platforms to identify equipment, supplies, and personnel shortfalls to achieve mission success[6].

Recent operations in Iraq, Afghanistan, Africa, and the Indo-Pacific identified the need for smaller, more mobile surgical and resuscitation teams.

Accompanying the pivot from Counterinsurgency Operations to Large Scale Combat Operations with near-peer forces, the demand for small, mobile surgical teams will increase from a SOF-specific requirement into the conventional forces' toolkit. The Operational Commander will demand that their supporting medical units be agile, mobile, and can continue function with disrupted supply chains and delayed patient evacuation capabilities. As a result, all medical capabilities need to consider the equipment being used. One mission critical consideration is the cumbersome weight and size of oxygen cylinders or stationary oxygen generating systems, and the volatility of anesthetic gases, creating dangerous operational conditions.

Lessons from Operation Enduring Freedom

A small far-forward surgical resuscitation team had to provide damage control surgical support out of a hardened vehicle traveling in the convoy of troops. The significant difficulties of this scenario were deciding what equipment was critical due to space constraints and planning for prolonged care if required. While they managed to provide top-level care, they used much of the vehicle's space when strapping a large oxygen cylinder into the back of it. A prolonged care plan was based on regional techniques and intravenous (IV) anesthetics since they could not take enough anesthetic gas to make an IUPAC Drawover a viable option. Clinical care decisions were driven by the lack of space, weight, and time. Mission risk was elevated with the addition of a large oxygen cylinder strapped into the vehicle with the clinicians and patients. This scenario will likely be repeated on a much larger scale in future operations.

Current Tool Kit

Currently, the U.S. military provides the following anesthesia options for the delivery of far-forward battlefield anesthesia[7,8,9]:

Regional Anesthesia / Peripheral Nerve Block

Administration: Administered using needles, often supported by ultrasound equipment to identify key peripheral nerves.

Typical Use: Primarily used for extremity injuries[10]. Can be used to spplement general anesthesia for pelvic, trunk, abdominal and head injuries.

Considerations: RA and PNB are contraindicated for patients with medication-specific allergies or active infection at the injection site. Patients receiving injuries in austere or far-forward combat conditions are susceptible to septic situations due to the direct cause of the injury. The likelihood of sepsis increases in prolonged care scenarios.

Total intravenous anesthesia (TIVA)

Administration: Uses only IV medications to deliver general anesthesia. Requires working IV, syringe, and syringe pump.

Typical Use: Can be started as far forward as point of injury, through casualty evacuation on any aircraft or vehicle, continued for the entire perioperative period, and stopped well after evacuation and arrival to intensive care.

Considerations: TIVA requires IV access. Obtaining IV access can be difficulty in certain injury patterns, including burns and blast penetrating traumas, and for pediatric patients. TIVA can be initiated without any ancillary equipment for induction and initial maintenance of anesthesia. However, in an unstable trauma patient the limited IV access points may be dedicated to restoring the patient's circulating volume using blood transfusions. Another limitation of TIVA is both a supply of medication and supplies and a power source for the IV pump. TIVA with propofol can also be associated with a precipitous drop in blood pressure in those patients with shock due to hypovolemia. Not fully resuscitated hemorrhagic shock dramatically increases the effects of propofol[11]. Contribution of TIVA anesthetic to hypotension or shock cannot be easily assessed as the level of anesthetic cannot be directly measured, particularly in a trauma patient. Since the preponderance of patients requiring far-forward damage control surgery experience hemorrhagic shock, any interventions that drop a patient's blood pressure can increase morbidity and mortality.

Inhalational Anesthesia

Administration: "Potent inhalation agents" and "volatile anesthetics" are more commonly called "anesthesia gases" and describe medications used by anesthesia providers that are administered via vaporizers to induce and maintain general anesthesia. Sevoflurane and isoflurane are the two most common inhalation agents used in in U.S. tri-service treatment sites. Of all commonly used anesthesia gases, sevoflurane is the choice for the inhalation induction of general anesthesia due to its sweet smell. In addition, Sevoflurane's properties allow for rapid titration of anesthesia depth and a quicker emergence than similar minimal alveolar concentrations /doses of isoflurane, enflurane, and halothane. The use of Isoflurane for induction is possible, but not recommended due to its pungent odor. Isoflurane produces amnesia, sedation, and skeletal muscle relaxation (GABA and NMDA receptors)[12]. Isoflurane is the most potent of the commonly used anesthesia gases and can be delivered with minimal carrier flows. Since isoflurane has similar properties to halothane (an anesthesia gas not commonly used in the US, but still found in many other countries), the two can be used interchangeably if a situation warrants it.

Typical Case: The benefits of using anesthesia gases in austere and combat situations include clinician familiarity, ease of use, and ability to accomplish all goals of anesthesia. The ability to induce general anesthesia without an IV is of utmost importance. Anesthesia gases are administered through an anesthetic vaporizer. A vaporizer provides precise amounts of anesthesia gas while mitigating the effects of temperature and barometric pressure changes on the evaporation process. These devices can utilize room air with an oxygen concentrator to deliver general anesthesia.

Considerations: Typically, these devices are developed for patient care in fixed-facility hospitals or Role 3 locations. They need a reliable power source, logistics resupply and disposal of waste gases, and availability of medical-grade oxygen. Open systems like the IUPAC require large amounts of compressed oxygen and anesthetic gases. Additionally, the weight and cube of each vaporizer can be over 75 kg and comes in multiple hard cases. They require large footprints on vehicles or aircraft to move them from location to location.

MADM™, Mobile Anesthesia Delivery Module, a solution to filling Capability Gaps

Surgical care in the far-forward setting will require materiel solutions to overcome contested logistics and supply chain interruptions, with agility, mobility and self-sufficiency of teams[13]. When improving the capability and capacity to provide sustained damage control surgery and resuscitative care and surgical capabilities as far forward as possible, optimal materiel solutions enable not only the delivery of anesthesia but the ability to ventilate and monitor patients while simultaneously decreasing the DCR and DCS footprint.

The MADM™, Mobile Anesthesia Delivery Module, is a direct injection vaporizer with respiratory gas monitoring that can be used with any ventilator and breathing circuit. Sevoflurane and isoflurane can be delivered and refilled during use. The MADM™ is lightweight (about 7 pounds), portable, and compact. The setup is quick and intuitive. The module includes a monitor indicating respiratory rate, CO_2, and percentage of sevoflurane or isoflurane. An easy-to-read interface signals "No Output," "All OK," and "Warning" functional state indicators. Portability includes the ability to run on 100-240 VAC 50/60 Hz. It also contains hot-swap external batteries with an optional external battery dock. Adding the MADM™ to the anesthesia provider toolkit will allow for the safe delivery of anesthesia gas at a wide range of temperatures up to 10,000 ft in altitude.

The MADM™ also provides additional respiratory gas monitoring, typically not found in deployable anesthesia solutions, including:

- **Agent Selection**
- **Anesthetic Concentration Delivered**
- **End Tidal Anesthetic Concentration**
- **Respiratory Rate**
- **Inspired CO_2 Partial Pressure**
- **End-Tidal CO_2 Partial Pressure**
- **Minute Ventilation (VE)**
- **Minimum Alveolar Concentration (MAC)**

MADM™ and MOVES® SLC™: The benefits of a circle-circuit configuration

When used in concert with the circle-circuit ventilator embedded in the MOVES® SLC™, the MADM™ can reuse an inhalation agent, drastically decreasing consumption. A 2023 case report of MADM™ with MOVES® SLC™ detailed a dramatic decrease in the need for Sevoflurane when completing 20 operating room cases or 40 hours of anesthesia. Only 175 ml of Sevoflurane was required versus an expected use of about 400 - 500 ml with a traditional equipment configuration, demonstrating the power of the MADM™ and MOVES® SLC™ circle circuit configuration in creating efficiency, reducing supply chain and logistics burdens[14]. This capability also decreases the problem of waste anesthesia gas. In addition to decreasing anesthesia gas requirements, MADM™ with MOVES® SLC™ answers the problem of needing large amounts of compressed oxygen that may not be available during prolonged care scenarios or when performing surgery outside of the Role 2 and Role 3.

Using the MADM™ with the micro-integrated life support system MOVES® SLC™, which has a ventilator, oxygen concentrator, and monitoring capabilities, allows for the same functionality of traditional, larger equipment in a much smaller, lighter footprint. The MADM™ and MOVES® SLC™ combination, unlike the bigger fixed anesthesia machines and OR equipment, is small and light enough to be mounted on the side of a regular litter used by most military units for evacuation.

To request a MOVES SLC Capabilites White Paper, please visit
www.thornhillmedical.com/military

Conclusion

Damage Control Resuscitation (DCR) and Damage Control Surgery (DCS) are required capabilities today and during future operations. Providing anesthesia is a critical component of DCS. Anesthesia can be provided under challenging circumstances to increase Warfighter survivability with vaporizers that consider power, weight, cube, and logistical challenges of large-scale combat operations. The MADM™ offers a feasible and sustainable solution to these challenges.

Authors

Ken Thompson went to Arkansas State University on a 4-year ROTC scholarship, and upon graduation, in 1997, was commissioned into the Army as a second lieutenant. He was accepted to the U.S. Army Graduate Program in Anesthesia Nursing in 2001. Only 5 months after graduation, Ken was deployed to the 31st Combat Support Hospital in Baghdad Iraq, where he provided anesthesia for over 500 trauma patients. After this deployment, Ken was selected to the elite Joint Special Operations Command where he deployed 5 more times. Badges and awards include the Bronze Star2, Defense Meritorious Service Medal, the Combat Medic Badge, the Combat Action Badge, the Expert Field Medic Badge, the Air Assault Badge, and the Airborne Badge.

Ken also has an extensive teaching background. He was the Senior Clinical Instructor at a USAGPAN Phase II site. While at JSOC, Ken provided instruction on topics from combat anesthesia to care under fire. Ken also teaches at Western Carolina University, as well as ultrasound guided regional anesthesia for the Wake Forest Nurse Anesthesia Program. He completed his DNP in August of 2020 with the inaugural class at Wake Forest.

Steven Meyer attended the University of Cincinnati on a ROTC scholarship in Nursing. He received his commission as a second lieutenant in 1999 as a Distinguished Military Graduate. In 2001, he graduated from the Army's Critical Care Nursing program and from the US Army Graduate Program in Anesthesia Nursing, USAGPAN, in 2006. He deployed to Iraq and Afghanistan in 2009 as the chief CRNA for the 274th Forward Surgical Team. He then went on to join an elite surgical team with the Joint Special Operation's Command from 2010-2019. During this time, he deployed nine more times and gained extensive combat experience within various fixed facilities and austere environments around the world.

When not deployed or training, he served as a clinical instructor for the USAGPAN at Fort Bragg, NC and instructed numerous special operations medics and medical providers on combat sedation, damage-control resuscitation, airway management and prolonged field care. During his 20-year career, he was awarded three Bronze Stars, Meritorious Service Medal, Joint Service Commendation Medal, Combat Action Badge, Military Freefall Parachutist Badge and Parachutist Badge.

He retired from active duty in 2019 where he continues to provide anesthesia care at his local community hospital.

Author Bio

Peter Frye started his medical career as an EMT in high school and continued it through college working as a Paramedic for advanced critical care transport as he earned his Bachelor of Science in Nursing. He joined the military in 2011 to pursue his anesthesia training at the United States Army Graduate Program of Nursing. He went on to deploy in 2015 with a small surgical team (Split Forward Surgical Team) out of Fort Bliss TX to Afghanistan where he performed over 160 anesthetics, including a MASCAL where he anesthetized over 30 patients in an 18-hour period, in austere conditions.

In 2016 he was chosen to be part of an elite small team surgical unit under the Joint Special Operations Command under which he deployed 5 more times earning 3 bronze stars, a combat action badge and a combat medic badge. He honorably separated from the military in December 2020. Peter currently works as a CRNA in a small community hospital in the Appalachian Mountains.

Randall M. Schaefer (Lieutenant Colonel, USA, Retired), DNP, RN, ACNS-BC, CEN, served for 20 years as an Emergency/Trauma Nurse in operational units and fixed facilities in clinical and staff officer roles. She deployed three times in support of Operation Iraqi Freedom and Operation Inherent Resolve. She earned her 7Y (Capabilities Development) Additional Skill Identifier while serving as a Clinical Consultant at the Capabilities Development Integration Directorate (CDID) at Fort Sam Houston, Texas. She was the lead action officer and lead author for the development and writing of the US Army Health Readiness Center of Excellence "Early Entry Medical Capabilities Concept of Operations". Upon retirement from Active Duty in 2017 until 2021, she worked at the Southwest Texas Regional Advisory Council (STRAC) as the Director of Research overseeing the DOD-funded RemTORN grant. She is the CEO and Clinical Consultant of Schaefer Consulting, LLC. Her area of focus is taking her clinical and operational experiences to help improve patient outcomes and make life a little easier for the clinical staff still at the bedside. Dr. Schaefer received her Bachelor of Science in Nursing from the University of San Francisco, her Master of Science in Nursing from Widener University, and her Doctor of Nursing Practice from the University of Texas Health-San Antonio.

References

1. Army Futures Command. (2022). Army Futures Command Concept for Medical 2028. AFC Pamphlet 71-20-12. https://api.army.mil/e2/c/downloads/2022/04/25/ac4ef855/medical-concept-2028-final-unclas.pdf.

2. US Army Futures Command. (2022). Army Medical Modernization Strategy. https://www.army.mil/e2/downloads/rv7/about 2022_Army_Medical_Modernization_Strategy.pdf

3. Joint Capabilities Board. (2021). Initial Capabilities Document (ICD) for Combat Casualty Care (C3) Support for Future Operations. Retrieved April 27, 2023.

4. American Society of Anesthesiologists. (2023). Anesthesia 101. Retrieved April 27, 2023. https://www.asahq.org/madeforthismoment/anesthesia-101/types-of-anesthesia/.

5. Kotwal, R. S., MC USA, (Ret.), Staudt, A. M., PhD, MPH, Trevino, J.D., MBA, Valdez-Delgado, K.K., BSN, RN, Le, T. D., MD, DrPH, Gurney, J. M., MC USA, Sauer, S. W., MC USA (Ret.), Shackelford, S. A., USAF MC, Stockinger, Z. T., MC USN, Mann-Salinas, E. A., ANC USA (Ret.), A Review of Casualties Transported to Role 2 Medical Treatment Facilities in Afghanistan , Military Medicine, Volume 183, Issue suppl_1, March-April 2018, Pages 134–145, https://academic.oup.com/milmed/article/183/suppl_1/134/4959988

6. Kotzian, J. and Lee, B. (2019). Reducing Risk- Training Surgical teams to Survive. Retrieved April 26th, 2023. https://medium.com/experientia-et-progressus/reducing-risk-training-surgical-teams-to-survive-3447731834da.

7. Baker, B. C., Buckenmaier, C., Narine, N., Compeggie, M. E., Brand, G. J., & Mongan, P. D. (2007). Battlefield anesthesia: advances in patient care and pain management. Anesthesiology clinics, 25(1), 131–x. https://doi.org/10.1016/j.anclin.2006.12.003

8. Jaeger, J. M., Rice, D. C., & Albright-Trainer, B. (2021). Battlefield Medicine: Anesthesia and Critical Care in the Combat Zone. Anesthesiology clinics, 39(2), 321–336. https://doi.org/10.1016/j.anclin.2021.03.002.
9. Barras, P., McMasters, J., Grathwohl, K., & Blackbourne, L. H. (2009). Total intravenous anesthesia on the battlefield. U.S. Army Medical Department journal, 68–72.

10. Folino, T. B., & Mahboobi, S. K. (2023). Regional Anesthetic Blocks. In StatPearls. StatPearls Publishing.

11. Ken B. Johnson, M.D.; Talmage D. Egan, M.D.; Steven E. Kern, Ph.D.; Julia L. White, R.N.; Scott W. McJames, M.S.; Noah Syroid, M.S.; Derek Whiddon, B.S.; Ty Church, B.S. (2003) The Influence of Hemorrhagic Shock on Propofol: A Pharmacokinetic and Pharmacodynamic Analysis Anesthesiology Vol. 99, 409–420. https://doi.org/10.1097/00000542-200308000-00023

12. Hawkley, T. F., Preston, M., & Maani, C. V. (2022). Isoflurane. In StatPearls. StatPearls Publishing.

13. Benham, B.E., Kertes, S.S. (2021). Compatibility of the Drawover Vaporizer with Military Field Ventilators. American Anesthesia Nursing Association. Vol 89, No 2.

14. May 2023. U.S. Army Forward Resuscitative and Surgical Detachment. Humanitarian Mission. MADM & MOVES SLC trial and evaluation.