Preparing for Large Scale Combat Operations (LSCO): Modeling and Simulation Approaches to Rapidly Improve Medical Training

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ABSTRACT

World War II ended nearly eighty years ago, and since then, the Department of Defense (DoD) has not faced hundreds of thousands of casualties in a single conflict. A large-scale conflict with peer adversaries is likely to overwhelm conventional medical evacuation capabilities, resulting in casualty numbers far exceeding those seen in Iraq or Afghanistan. Current medical training does not adequately prepare for large casualty volumes due to several factors. Air superiority has historically allowed for low casualty rates, and the TC8-800 course sets a minimum training standard, requiring Combat Medics (68W) to assess, treat, stabilize, triage, and evacuate only two trauma casualties. Even if a Combat Medic needed to treat a dozen or more casualties, current medical training technologies lack the interoperability and portability necessary to facilitate mass casualty scenarios, limiting the ability to incorporate advanced triage, patient management, or medical logistics considerations essential for large-scale combat operations (LSCO). This paper argues that medical training must evolve to include LSCO scenarios. It explores the challenges and potential solutions for enabling effective medical response in such conflicts. The paper discusses how current training systems can be adapted to improve interoperability and portability, thereby enhancing flexibility and accommodating a variety of casualty types. Additionally, it examines how robotics and machine learning techniques can improve the speed and accuracy of triage during mass casualty events. Beyond technology-based solutions, the paper also considers policy changes to enhance Role II and Role III capabilities at the point of injury when patient evacuation is not feasible, drawing lessons from World War II.

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INTRODUCTION

Large-scale combat operations (LSCO) are anticipated to produce casualty volumes that will overwhelm conventional medical evacuation capabilities. Unlike recent conflicts such as those in Iraq and Afghanistan, where casualty numbers were relatively manageable and evacuation could often occur within the critical "Golden Hour," future LSCO are expected to be characterized by high-intensity, prolonged engagements against peer adversaries. These adversaries, equipped with advanced weaponry and extensive military resources, will likely inflict casualties at rates unseen in recent decades. The Department of Defense (DoD) must therefore prepare for an increase in casualties far exceeding those experienced in past conflicts.

The sheer scale and intensity of LSCO present unique challenges for military medical operations. Traditional medical evacuation protocols, which rely on swift transportation to well-equipped surgical facilities, may be infeasible due to the scale of the battlefield, the number of casualties, and the likelihood of contested air and ground spaces. Consequently, medical training must evolve to handle these anticipated challenges. This evolution involves not only enhancing the skills of medical personnel but also integrating new technologies and methodologies to manage and treat casualties effectively in situ.

Key areas of focus for this evolved training include comprehensive plans for casualty management, triage, evacuation, and medical logistics (MEDLOG). Effective casualty management and triage are crucial to prioritize and treat the most critically injured personnel swiftly. Efficient evacuation strategies must be developed to transport casualties from the battlefield to medical facilities despite potential logistical obstacles. Additionally, robust MEDLOG systems are essential to ensure the timely supply of medical resources, including blood products and essential medications, to frontline medical units.

The integration of advanced simulation technologies, such as virtual reality (VR), augmented reality (AR), and artificial intelligence (AI), can play a pivotal role in this training evolution. These technologies can create realistic, immersive training environments that replicate the complexities of LSCO, allowing medical personnel to practice under conditions that closely mirror actual combat scenarios. Moreover, the development of innovative medical devices and robotics, capable of performing autonomous or semi-autonomous medical interventions, can enhance the capacity to provide care in challenging environments.

In summary, preparing for the medical challenges of LSCO requires a multifaceted approach that combines advanced training, cutting-edge technology, and strategic planning. By focusing on these areas, the DoD can improve efficiency, increase casualty survival rates, and ensure that military medical operations are equipped to handle the demands of future large-scale conflicts (American College of Surgeons, 2008; Weiner et al., 2016).

INCREASED CASUALTY VOLUMES IN FUTURE LSCO

The U.S. military has long referenced the Golden Hour (American College of Surgeons, 2008). In recent conflicts with multi-domain dominance, the Golden Hour is achievable and greatly reduces mortality. Unfortunately, this dominance is unlikely in future wars. Therefore, the military must look to the past (and to the future) to understand the complexities of conflict with formidable adversaries, and what that means for military medicine and medical training.

Future LSCO are expected to generate significantly higher casualty volumes compared to previous conflicts. Historical data from World War II illustrates the scale of casualties that modern LSCO might resemble. For example, World War II involved many weapons that produced large numbers of casualties, resulting in 963,403 wounded with a nearly 30% lethality rate, while the Global War on Terrorism (GWOT) experienced far lower casualty numbers and lethality rates (Lundy, 2018). In Europe and the Pacific during World War II, some battles resulted in more than 1,000 dead and wounded per day, often spanning over several months (Remondelli et al., 2023). As modern peer adversaries with vast militaries like Russia and China possess advanced artillery, rockets, and precision long-range missiles, casualty estimates in future LSCO could also number in the thousands per day, compared to dozens per day in GWOT (Lundy, 2018; Tien & Beckett, 2022). Recent analyses of killed and wounded in the Russo-Ukraine War indicate over 870 casualties and injuries per day between Russian forces, Ukrainian forces, and civilians, while wargames involving a Chinese annexation of Taiwan estimate 140 dead and wounded per day over a multi-week campaign (Remondelli et al., 2023; Kofman et al., 2017).

The increasing lethality of modern weapons systems will likely result in more severe injuries, compounding the challenge of providing timely and effective medical care. This expectation necessitates a reevaluation of current medical evacuation and treatment protocols – and associated training – to ensure the capability to handle the demands of high-intensity conflict. For example, the logistical constraints and the potential for prolonged engagements will require medical personnel to manage and treat casualties in situ for extended periods, increasing the need for robust, flexible, and comprehensive medical training programs (Menendez, 2022; Gonzalez, 2020). The expectation of Prolonged Casualty Care (PCC) creates unique challenges for medical providers and instructors.

CHALLENGES IN MEDICAL EVACUATION AND CARE

Casualty Management and Triage

Effective casualty management and triage are critical in LSCO. The high-intensity environment requires a system capable of quickly assessing and prioritizing casualties to maximize survival. During the GWOT, a structured system ensured a high survival rate by rapidly moving casualties to surgical facilities within the "Golden Hour" (Schauer & April, 2022). However, this approach may not be feasible in LSCO, where evacuation capabilities could be severely limited. This problem is even greater because there are currently limited military medical personnel available to deploy that possess triage skills; these skills also take time to attain. In a large battle with hundreds, possibly thousands of casualties, the United States must rapidly scale up the number of skilled medical personnel near the front lines and amplify their effectiveness. To achieve this, training and technology will be pivotal.

Advances in robotic-assisted mass-casualty triage, such as those proposed by Chang and Murphy (2007), could play a crucial role in addressing these challenges by utilizing teleoperated robots to triage victims in hazardous environments, non-accessible places, and large-scale incidents. The Simple Triage and Rapid Treatment (START) protocol, commonly used by first responders, is an effective triage system adaptable for use in LSCO with new technologies. START relies on quickly assessing four signs: mobility, respiration, perfusion, and mental state (Chang & Murphy, 2007). By integrating robotic systems capable of assessing these signs remotely, medical personnel could triage large numbers of casualties more efficiently while minimizing exposure to danger.

Medical Logistics (MEDLOG)

MEDLOG involves the efficient supply and distribution of medical resources. The complexity of LSCO necessitates robust logistics to support prolonged operations and high casualty rates. Ensuring the availability of critical supplies, especially blood products, near the front lines is essential to reduce mortality (Riley & Dean, 2018). Innovations in the joint blood supply chain, including resilient logistics and storage solutions, are vital to keep a steady supply during combat (Riley & Dean, 2018). The concept of the "walking blood bank," as discussed by Poropatich and Pinsky (2020), emphasizes the importance of having readily available blood products close to the point of injury, which can significantly impact survival rates in LSCO.

In addition, the integration of autonomous systems for logistics can further enhance the efficiency of MEDLOG operations. For instance, the Defense Advanced Research Projects Agency (DARPA) has developed autonomous drone systems capable of delivering medical supplies and evacuating casualties in hostile environments (Poropatich & Pinsky, 2020). These systems can ensure the timely delivery of critical resources, even in contested or inaccessible areas, thereby supporting sustained medical operations in LSCO.

Constructive simulations must integrate MEDLOG into exercises to better understand how supply chain issues impact warfighter readiness, with impacts felt down the line, following the echelons of care from Role 1 at the point of injury all the way up to Role 4. Accomplishing this involves significant interoperability across existing (and future) simulation and training assets (Menendez, 2022; Gonzalez, 2020).

EVOLUTION OF MEDICAL TRAINING

Realistic Training Scenarios

To prepare for LSCO, medical training must evolve to incorporate realistic rehearsal for triaging, treating, and moving large numbers of patients at the division or company level. This requires a shift from current training models to scenarios that reflect the extended duration and high casualty volumes expected in LSCO (Menendez, 2022). In the current version of the Table VIII skills qualification for Army Combat Medics (68Ws), participants are certified after triaging and rendering care to two patients (Headquarters, Department of the Army, 2021). Infrastructure at the Army's Medical Simulation and Training Centers (MSTCs) enables highly realistic trauma simulations, but it does not accommodate realistic patient volumes expected under LSCO. Advanced human patient simulators offer significant realism, but they are far too expensive to scale at the MSTCs to prepare for dozens of patients at a time. The use of other simulation technologies, such as virtual reality, mixed reality, and haptics, combined with advanced medical manikins, can create immersive training environments that better prepare medical personnel for the complexities of LSCO (Tien & Beckett, 2022).

For example, the implementation of large-scale, integrated training exercises that simulate PCC and high-volume casualty scenarios can provide valuable hands-on experience for medical personnel. Large medical training events, such as Global Medic, give medical providers across the services opportunities to simulate LSCO with greater casualty volumes (Remondelli et al., 2023). These exercises should incorporate a variety of simulated patients, including manikins and live role players, to replicate the diversity of injuries and conditions that may be encountered in LSCO. By practicing under realistic conditions, medical teams can develop the skills and confidence necessary to perform effectively in actual combat situations (Tien & Beckett, 2022). Such training events are also essential opportunities to test and evaluate new training technologies meant to alleviate risks from LSCO. Extensive and persistent coordination between researchers, training centers, and the acquisition community is therefore essential to ensure timely development and fielding (Gonzalez, 2020).

Rethinking Patient Simulators

Current patient simulators are designed for short-duration scenarios, frequently built to satisfy the training requirements imposed by the Golden Hour. In LSCO, medical scenarios can extend well beyond this timeframe, necessitating the development of simulators that can realistically replicate prolonged care situations. This includes incorporating features that simulate complex trauma and long-term care requirements (Schauer & April, 2022). The development of advanced robotic systems for autonomous trauma care, as described in the TRAuma Care In a Rucksack (TRACIR) project, aims to address these needs by providing portable, autonomous critical care solutions (Poropatich & Pinsky, 2020).

The work involved in realistically simulating a trauma patient and their symptoms over the course of 48 to 72 hours, with conditions improving or worsening depending on care rendered, is highly complex and requires advanced physiology engines (Pike & Mazzeo, 2024). Scenarios must undergo time compression, simulating several days within only hours available during a training day; training events spanning multiple days are often infeasible for units (Pike & Mazzeo, 2024). Physiology engines are essential to achieve the time compression of a multi-day scenario to within a single training day, intelligently speeding up and slowing down at key points to allow trainees to focus on treatments. Another significant challenge is that no single manikin platform can support training across all roles of care. Given the unique limitations under a PCC environment, DEVCOM Soldier Center and the Army Applications Laboratory have partnered to research and develop a new, interoperable manikin platform that can facilitate treatment across Role 1 and Role 2 (Schauer & April, 2022).

Additionally, the TRACIR project, funded by the U.S. Army Medical Research and Development Command, seeks to develop a robotic system capable of performing critical care interventions autonomously in the field. By utilizing artificial intelligence and machine learning algorithms, TRACIR can assess and manage trauma patients based on real-time physiological data, ensuring timely and appropriate care even in the absence of immediate human intervention (Poropatich & Pinsky, 2020). Such technologies can greatly enhance the capability of medical teams to provide continuous care in LSCO environments.

APPROACHES TO IMPROVE MEDICAL TRAINING

Institutional Approach: Advanced Training for Combat Medics

One proposed solution is to require 80% of Army combat medics (68Ws) to become Army Combat Paramedics, as suggested by SGM Kathleen Hedges at the Association of Military Surgeons of the United States (AMSUS) annual meeting in 2024. The 68W is the second largest MOS in the Army, numbering in the tens of thousands, compared to far fewer doctors, physician assistants, and nurses (Hedges, 2024). This approach would elevate the baseline medical skills within combat units, ensuring that more medics possess the advanced capabilities necessary for prolonged field care in LSCO scenarios (Hedges, 2024). This institutional change would help bridge the gap between current capabilities and the demands of future combat environments, but it requires consideration and action from Army leadership.

By enhancing the training and certification requirements for combat medics, the DoD can ensure that a greater proportion of medical personnel are equipped to handle the complex medical scenarios that are likely to arise in LSCO. This approach also aligns with the broader goal of integrating military and civilian medical training, ensuring that combat medics can operate effectively in both military and civilian healthcare settings (Tien & Beckett, 2022).

Integrating Military and Civilian Medical Assets

Modeling and Simulation (M&S) can facilitate the integration of military and civilian medical assets to create a comprehensive National Defense Medical System (NDMS). By simulating various LSCO scenarios, military and civilian medical personnel can train together, enhancing coordination and interoperability. This approach can ensure that civilian health sectors are adequately prepared to support military operations, thereby increasing the overall capacity to manage casualties (Tien & Beckett, 2022). The Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) programs encourage research with both military and civilian commercialization opportunities. These programs offer paths for researchers to collaborate with military and civilian medical personnel and instructors to build training systems that allow for wartime scale-up of medical personnel, drawing from larger civilian ranks.

Joint training exercises that simulate large-scale casualty events can provide valuable opportunities for military and civilian medical teams to practice working together. Mass casualty exercises must become more frequent. Such training events are conducted at hospitals, but also by the U.S. and its allies in events like Valiant Shield in the Pacific. By integrating civilian healthcare providers into military training programs, the DoD can ensure that a broad base of skilled medical personnel is available to support LSCO operations. This approach can also facilitate the rapid mobilization of civilian resources in the event of a major conflict, ensuring that military medical facilities are not overwhelmed by the volume of casualties (Tien & Beckett, 2022).

Following COVID-19, the military and civilian medical communities are closer than ever before. In a real emergency during a large-scale war, the government could authorize a medical draft using the Health Care Personnel Delivery System (Remondelli et al., 2023). Current and future training systems and programs must consider this possibility to ensure readiness across the joint force.

Simulation Approach: Utilizing Surrogate Medical Devices for Training

Developing inexpensive surrogate medical devices for use on basic and advanced manikins, as well as live role players, can enhance the realism and effectiveness of medical training (Menendez, 2022). These devices can simulate various medical conditions and injuries, providing trainees with hands-on experience in a controlled, repeatable environment. This approach can significantly improve the readiness and proficiency of medical personnel.

For example, the use of surrogate devices that mimic the physiological responses of real patients can provide valuable training opportunities for medics. These devices can be used to simulate a wide range of medical conditions, from traumatic injuries to chronic illnesses, allowing trainees to practice diagnosing and treating patients under realistic conditions. The U.S. Army Combat Capabilities & Development Command Soldier Center is currently researching and developing a surrogate training tourniquet, which is a first step in developing an array of surrogate instruments from the 68W individual first aid kit (IFAK). Integrating data collection and analysis tools within such surrogates can provide immediate feedback to trainees, helping refine their skills and improve their performance over time (Menendez, 2022).

Technology Approach: Leveraging New Technologies

The DARPA Triage Challenge highlights the potential of new technologies to improve triage speed and accuracy in mass casualty incidents (MCIs). These technologies, which include advanced decision-support systems and AI-driven tools, can assist medics in quickly assessing and prioritizing casualties, thus enhancing the overall efficiency of medical responses in LSCO (Poropatich & Pinsky, 2020).

Advanced technologies such as AI and machine learning can analyze vast amounts of data to identify patterns and trends that may not be immediately apparent to human responders. By integrating these technologies into triage protocols, medical personnel can make more informed decisions, ensuring that resources are allocated effectively and that the most critical patients receive timely care. Additionally, the use of AI-driven tools can reduce the cognitive load on medics, allowing them to focus on providing high-quality care to patients (Poropatich & Pinsky, 2020).

Creative Approach: Integrating Existing Technologies

Integrating existing technologies like virtual reality (VR), inexpensive medical manikins, and live role players can create large-scale simulations with dozens of simulated casualties. These blended simulations can provide a comprehensive training experience that mimics the chaotic and high-pressure environment of LSCO, preparing medical personnel to handle large volumes of casualties effectively (Chang & Murphy, 2007).

For instance, VR technology can be used to create immersive training scenarios that replicate the sights, sounds, and stresses of a real combat environment. Trainees can practice responding to simulated casualties in a virtual battlefield, allowing them to develop their skills in a safe and controlled setting. By combining VR with physical manikins and live role players, training programs can provide a holistic and realistic training experience that prepares medical personnel for the challenges of LSCO (Chang & Murphy, 2007).

POTENTIAL PATHS FORWARD USING MODELING AND SIMULATION (M&S)

AI and ML Decision Support for Triage Training

Artificial intelligence (AI) and machine learning (ML) can revolutionize triage training. These technologies can provide decision support systems that help medics quickly assess and prioritize casualties, thus improving the accuracy and efficiency of triage processes. Additionally, AI and ML can analyze training data to identify areas for improvement and optimize training programs (Poropatich & Pinsky, 2020).

For instance, AI-driven triage systems can analyze real-time data from multiple sources, such as physiological sensors and medical records, to determine the severity of injuries and recommend appropriate treatment protocols. By incorporating these systems into training programs, medics can practice using advanced decision-support tools in realistic scenarios, enhancing their ability to make quick and accurate triage decisions in the field (Poropatich & Pinsky, 2020).

Blended Training Scenarios

Blended training scenarios involving manikins, patient actors, and task trainers can provide a realistic and comprehensive training experience. These scenarios can simulate the high-pressure environment of LSCO, preparing medical personnel to manage large volumes of casualties effectively. The use of surrogate medical devices can further enhance the realism and effectiveness of these simulations (Chang & Murphy, 2007).

For example, training exercises that combine physical manikins with virtual reality simulations can create immersive environments that replicate the chaos and complexity of a battlefield. Trainees can practice responding to multiple casualties with varying degrees of injury, developing their skills in triage, treatment, and evacuation. By providing a diverse range of training scenarios, these blended exercises can ensure that medical personnel are well-prepared to handle the unique challenges of LSCO (Chang & Murphy, 2007).

Federated Models with Data Pass-Through

Federated models that allow data pass-through from the point of injury to definitive care can enhance the coordination and efficiency of medical operations. The open-source Joint Evacuation and Transportation System (JETS) Architecture, for example, facilitates patient handoff and evacuation, ensuring that medical personnel have access to critical patient information at every stage of care. This approach can significantly improve the quality and continuity of medical care in LSCO (Poropatich & Pinsky, 2020).

By integrating data from multiple sources, such as electronic health records, physiological sensors, and communication systems, federated models can provide a comprehensive view of each patient's condition and treatment history. This information can be shared seamlessly across different levels of care, ensuring that medical teams have the information they need to make informed decisions and provide optimal care. Additionally, these models can support the development of standardized protocols and procedures, enhancing the overall effectiveness of medical operations in LSCO (Poropatich & Pinsky, 2020).

CONCLUSION

Preparing for LSCO requires a comprehensive approach to medical training that addresses the challenges of casualty management, evacuation, and medical logistics. By leveraging institutional changes, simulation technologies, and innovative approaches, the DoD can enhance the readiness and effectiveness of medical personnel. Historical lessons and modern technologies can guide the development of training programs that prepare medical teams to handle the complexities of LSCO, ultimately increasing casualty survival rates and improving overall mission success.

The importance of integrating advanced medical technologies, such as AI-driven decision support systems and robotic-assisted triage, cannot be overstated. These technologies will not only enhance the speed and accuracy of medical responses but also allow for more efficient use of limited medical resources in high-casualty scenarios. The adoption of such technologies must be supported by continuous training and simulation exercises that reflect the realities of modern combat environments.

Furthermore, the collaboration between military and civilian medical sectors is crucial for building a robust National Defense Medical System (NDMS). This collaboration can ensure that both sectors are adequately prepared to handle large-scale medical emergencies, thereby enhancing overall national resilience. Programs like SBIR and STTR play a vital role in fostering innovation and ensuring that cutting-edge medical solutions are developed and implemented effectively.

Realistic training scenarios that incorporate a blend of virtual reality, mixed reality, and advanced human patient simulators are essential for preparing medical personnel for the demands of LSCO. These scenarios must be designed to simulate the extended duration and high casualty volumes expected in such conflicts, providing medical teams with the experience and confidence needed to perform effectively under pressure.

The evolution of patient simulators to include features that replicate prolonged care situations is another critical aspect of improving medical training. Advanced physiology engines and interoperable manikin platforms will enable the simulation of complex trauma scenarios, ensuring that medical personnel are well-prepared to manage a wide range of injuries over extended periods.

Ultimately, the DoD's commitment to continuous improvement in medical training and logistics will be key to maintaining a high standard of care in LSCO. By integrating historical lessons, modern technologies, and collaborative approaches, the military can develop a resilient and effective medical training framework that ensures the highest possible survival rates for casualties in future conflicts. This proactive approach to medical readiness will not only save lives but also contribute to the overall success of military operations, reinforcing the DoD's mission to protect and serve the nation.

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