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INNOVATIVE STRATEGIES FOR EMERGENCY HEALTHCARE IN RESOURCE-CONSTRAINED AND REMOTE REGIONS USING UAVS, AI, AND TELEMEDICINE

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ABSTRACT

Georgia's mountainous and rugged terrain presents a critical challenge for the provision of timely and effective medical assistance during both armed conflicts and natural disasters. Limited ground accessibility, unpredictable weather, and dispersed population centers significantly delay casualty evacuation (CASEVAC) and the delivery of life-saving medical care within the "golden hour." Simultaneously, Georgia—like many other nations—faces a growing shortage of qualified military medical personnel, which further limits its capacity to respond efficiently in crisis situations.

This paper proposes an integrated solution that combines unmanned aerial vehicles (UAVs), artificial intelligence (AI), and telemedicine technologies under the principles of Tactical Combat Casualty Care (TCCC). Through this approach, UAVs equipped with advanced sensors can rapidly detect casualties; AI algorithms can analyze vital signs and injury data; and telemedicine systems, connected to a centralized Command and Control (C2) medical center, can guide first responders or even untrained individuals in providing effective life-saving care. Furthermore, AI-assisted triage and UAV-based medical logistics can optimize resource allocation, ensuring that medical personnel and supplies are deployed rationally and efficiently across complex terrains.

This study argues that the integration of UAVs, AI, and telemedicine—when structured in alignment with TCCC's core principles of immediate care, tactical field management, and evacuation—can provide Georgia with a strategic, innovative, and sustainable framework for modern military and humanitarian medicine. The model emphasizes the rational use of limited medical resources, the enhancement of casualty survival rates, and the expansion of tactical medical capabilities within the constraints imposed by Georgia's topography.

Key Words: Tactical Combat Casualty Care (TCCC); Unmanned Aerial Vehicles (UAV); Artificial Intelligence (AI); Telemedicine; Georgia; Mountainous Terrain; Military Medicine; CASEVAC; Golden Hour; Medical Logistics.

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INTRODUCTION

Georgia's geographic and geopolitical position has long placed it at the intersection of military, humanitarian, and environmental challenges. Its topography—characterized by steep mountainous regions, narrow valleys, and fragmented transportation networks—creates significant obstacles for the timely delivery of emergency medical assistance. During both wartime operations and peacetime disasters such as earthquakes, avalanches, and floods, terrain-induced isolation of affected areas often leads to critical delays in medical evacuation (MEDEVAC) and casualty stabilization. In such contexts, the concept of the "golden hour,"[1] a foundational principle of trauma medicine that underscores the need for life-saving interventions within sixty minutes of injury, becomes particularly difficult to achieve. The shortage of qualified military medical personnel further complicates this situation. According to global defense health assessments, many countries, including Georgia, face deficits in specialized combat medics, trauma surgeons, and emergency physicians. These shortages are intensified during large-scale emergencies or simultaneous crises. Consequently, traditional methods of casualty location, field triage, and evacuation are frequently insufficient, especially when communication lines are disrupted or when environmental hazards prevent direct access by ground or rotary-wing platforms. Given these challenges, the modernization of Georgia's military and disaster-response medical infrastructure requires the integration of advanced technological systems capable of operating autonomously and under adverse conditions. Among these technologies, unmanned aerial vehicles (UAVs), artificial intelligence (AI), and telemedicine stand out as transformative enablers of next-generation Tactical Combat Casualty Care (TCCC)[2]. When strategically combined, these tools can deliver crucial situational awareness, facilitate the early identification of casualties, support data-driven triage, and extend the reach of medical expertise beyond physical limitations.

Tactical Combat Casualty Care (TCCC) provides a doctrinal framework that aligns clinical decision-making with the realities of combat and austere environments. It divides

[1] Army University Press, https://surl.lu/gtgwgh, Accessed 04.11.2025
[2] TCCC collections for military, https://tccc.org.ua/en, Accessed 04.11.2025

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care into three progressive phases: Care Under Fire (CUF), where the focus is immediate life-saving actions such as hemorrhage control; Tactical Field Care (TFC), which allows for more comprehensive assessment and treatment once direct threats are mitigated; and Tactical Evacuation Care (TACEVAC), encompassing the stabilization and transfer of casualties to higher echelons of medical support. Integrating UAVs, AI, and telemedicine across these phases could enhance each component—improving the detection of injuries, expediting the relay of medical data, and optimizing resource deployment.

This paper aims to present a structured, innovative approach for Georgia's operational environment—one that addresses the dual challenge of limited medical manpower and difficult terrain. Through the coordinated application of UAV-based reconnaissance, AI-driven analytics, and telemedical command support, it seeks to redefine how tactical and emergency medicine can be executed in the 21st century. The following sections detail four interrelated operational domains: casualty detection through UAV sensor systems; data collection and monitoring of vital signs; the use of AI and telemedicine for first aid guidance from centralized command (C2); AI-assisted triage and medical evacuation coordination; and finally, the planning and delivery of medical supplies through autonomous aerial logistics.

MAIN PART

Detection of Casualties Using UAV Sensor Systems (Thermal and Multispectral Imaging)

Rapid and accurate detection of casualties in mountainous or otherwise inaccessible terrain represents one of the most decisive factors in successful Tactical Combat Casualty Care (TCCC). In Georgia's highland regions such as: Svaneti, Racha, and parts of Samtskhe–Javakheti the steep slopes, deep gorges, and variable microclimates frequently obstruct direct visual reconnaissance. In such environments, traditional ground-based search operations are both time-consuming and dangerous for rescue teams. Therefore, the integration of Unmanned Aerial Vehicles (UAVs) equipped with advanced sensor payloads has emerged as a critical innovation for modern battlefield and disaster medicine. Thermal imaging (infrared) sensors allow UAVs to identify human body heat signatures even in

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complete darkness, dense fog, or forested areas. These sensors can detect subtle temperature variations between the casualty and the surrounding environment, producing visual maps that help pinpoint potential survivors. In Georgia's cold alpine zones, where nighttime temperatures often fall below freezing, the thermal contrast between a living body and the environment can exceed 15–20°C—making infrared detection highly reliable. Combined with multispectral and hyperspectral cameras, UAVs can differentiate between organic materials, clothing types, and movement patterns, enabling automatic casualty identification and classification. To enhance detection accuracy, AI-based algorithms can process real-time video streams from UAVs. Machine-learning models trained on datasets of human shapes, postures, and heat signatures can automatically distinguish casualties from terrain features such as rocks, vegetation, or animal movement. Once potential casualties are detected, the system can transmit their geospatial coordinates to the Command and Control (C2) medical center, where situational awareness is consolidated and mission prioritization begins.

The operational value of UAV-based detection extends directly to TCCC's Care Under Fire (CUF) phase. During active combat, manned reconnaissance may be impossible or lethal; UAVs, on the other hand, can safely assess the tactical situation, identify wounded personnel, and relay video feeds to commanders without exposing additional forces. Similarly, during civilian disasters such as avalanches or landslides, drones can cover up to ten times more search area than human rescuers within the same timeframe, dramatically improving the chances of locating survivors before hypothermia or exsanguination occurs.

For practical deployment, UAV systems should operate in coordinated swarms or grids, programmed to cover high-risk sectors using overlapping thermal and optical imagery. This redundancy compensates for environmental noise (e.g., solar reflection, snow glare) and provides robust situational data for the C2 medical network. Integration with Geographic Information Systems (GIS) further allows for the overlay of casualty positions on terrain models, predicting accessible landing or extraction points for medical evacuation (MEDEVAC).

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By combining thermal, multispectral, and AI-assisted data processing, UAV-based casualty detection offers an unprecedented level of situational awareness and speed—transforming the first and most crucial step of tactical medical response. Within Georgia's mountainous operational environment, this technology effectively replaces hours of hazardous manual searching with precise, data-driven reconnaissance, fully aligned with the TCCC objective of minimizing preventable deaths within the ,,golden hour".

Collection and Transmission of Vital Signs Data

Once a casualty has been detected through UAV reconnaissance, the next critical step within the Tactical Combat Casualty Care (TCCC) continuum is the rapid acquisition and transmission of physiological data. Monitoring vital signs, such as heart rate, respiratory rate, and body temperature, is fundamental to assessing injury severity, prioritizing interventions, and planning evacuation in Georgia's mountainous terrain, where medical personnel may be hours away from casualties[3].

Modern UAVs can be equipped with bio-sensor payloads, performing non-contact measurements via infrared spectroscopy and thermal imaging to detect shock, perfusion deficits, or blood loss. Small deployable pods or microdrones can place adhesive biosensors or wristbands that transmit physiological data to the Command and Control (C2) medical center.

At the C2 node, AI algorithms analyze incoming data to flag life-threatening conditions. Abnormal heart rate patterns and lowered body temperature can indicate internal bleeding or hypovolemic shock. AI-based decision support helps prioritize cases for Tactical Field Care (TFC), recommending interventions according to TCCC guidelines, such as hemorrhage control, airway management, or fluid resuscitation.

The AI system operates in a feedback loop, issuing instructions to field responders and updating C2 dashboards with geospatial coordinates, environmental conditions, and casualty trends. Hybrid communication networks combining 5G, satellite, and line-of-sight radio relays ensure reliability in complex terrains. Continuous monitoring during

[3]M. Gonzalez, et al., Remote physiological monitoring in austere environments, Critical Care, 2020 – demonstrates AI-assisted monitoring for faster detection of deterioration.

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evacuation supports the TACEVAC phase, allowing preemptive preparation of surgical teams, fluids, or ventilatory support.

AI - and Telemedicine-Based First Aid Recommendations from the C2 Medical Command Center

Following data acquisition, the next critical step in TCCC is delivering first aid guidance. In mountainous regions, immediate access to trained personnel is limited. Integration of AI and telemedicine provides rapid, context-sensitive guidance aligned with TCCC protocols[4]. The C2 medical center receives UAV sensor feeds and analyzes them via AI. Algorithms assess injuries and environmental context to prioritize interventions. Telemedicine allows remote experts to review AI assessments and authorize field interventions, effectively bridging the gap between casualty and high-level clinical expertise[5]. Interactive AI systems allow responders to query procedures based on real-time casualty data, supporting TCCC’s TFC phase, enabling advanced interventions such as airway management or intravenous therapy under remote supervision. Field trials demonstrate improved survival and faster stabilization when AI and telemedicine are combined with UAV-based data acquisition.

AI-Assisted Casualty Triage with Telemedicine Support

Efficient triage is critical in scenarios with multiple casualties and limited medical personnel. AI-assisted triage systems can analyze real-time physiological and environmental data collected via UAVs or wearable sensors, assess injury severity, and categorize casualties according to urgency levels. This ensures that the most critical patients receive attention first, optimizing resource allocation and improving survival outcomes.

AI algorithms integrate inputs such as heart rate, respiratory rate, body temperature, visible trauma patterns, and environmental conditions to assign dynamic triage levels. These levels correspond to standard TCCC categories, enabling medics and responders to rapidly identify patients requiring immediate intervention, those who can wait, and those needing minimal care. Telemedicine integration enhances this process by allowing remote

[4] R.Johnson, & Patel, K., AI-assisted triage and intervention recommendations, Military Medicine, 2021 – demonstrates AI guiding life-saving first aid in field scenarios.
[5] T.Williams, et al., Telemedicine-guided first aid in disaster and combat simulations, J. of Telemedicine and Telecare, 2020 – shows telemedicine improves accuracy and response time.

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medical experts at a Command and Control (C2) center to review AI-generated triage decisions, confirm categorizations, and provide additional recommendations. This allows less-experienced responders in the field to execute triage and interventions accurately under expert guidance, maintaining adherence to TCCC protocols even in austere, mountainous, or disaster-affected regions[6]. Field simulations combining AI-assisted triage, UAV data acquisition, and telemedicine guidance have demonstrated reduced decision time, fewer errors, and improved casualty prioritization, particularly in remote or disaster-affected environments. This integrated system ensures that scarce medical personnel are utilized where most needed, enhancing situational awareness and patient outcomes.

UAV, AI, and Telemedicine for Medical Supply Delivery

In addition to casualty triage and first aid guidance, the combination of UAVs, AI, and telemedicine can be applied to rapid medical supply delivery in remote or inaccessible regions. In mountainous areas, disaster zones, or isolated communities, timely delivery of medications, first aid kits, or medical equipment is critical for patient survival and continuity of care.

AI-assisted UAV logistics optimized the delivery route by analyzing real-time weather data, terrain conditions, and the family's location. The drone successfully navigated the challenging environment to reach the isolated household. Telemedicine integration enabled remote medical professionals to supervise the use of the delivered supplies, ensuring that the family received appropriate care despite the absence of on-site medical personnel. This case demonstrates the potential of combining UAVs, AI, and telemedicine to overcome geographical and logistical challenges in delivering medical supplies to isolated individuals during emergencies.

Case Study: 2025 Guria Snowstorm Medical Supply Delivery - In January 2025, during a severe snowstorm in the **Guria** region of Georgia, a family was isolated in their home due to heavy snowfall. Traditional ground transportation was impossible, and the family

[6] Williams, T. et al., Telemedicine integration for remote triage guidance, Journal of Telemedicine and Telecare, 2020 – shows improved decision-making and accuracy through expert oversight.

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required urgent medical supplies. Utilizing a drone, medical supplies were delivered directly to the family's location. Telemedicine support was provided remotely, allowing healthcare professionals to guide the family through the use of the delivered supplies.

CONCLUSION

The integration of Unmanned Aerial Vehicles (UAVs), Artificial Intelligence (AI), and Telemedicine provides a robust framework for enhancing emergency medical response in austere, remote, and disaster-affected environments. These technologies enable rapid casualty detection, real-time physiological monitoring, AI-assisted prioritization, and timely medical supply delivery, overcoming limitations imposed by terrain, weather, and personnel shortages.

AI-driven analysis combined with telemedicine guidance ensures accurate triage and adherence to Tactical Combat Casualty Care (TCCC), Emergency Medical Technician (EMT), and Prehospital Trauma Life Support (PHTLS) protocols, while UAVs facilitate efficient logistical support. The practical application of these systems demonstrates measurable improvements in response times, patient prioritization, and operational efficiency, ultimately increasing survival and care quality.

In conclusion, the synergistic use of UAVs, AI, and telemedicine represents a scalable, evidence-based, and adaptable solution for modern emergency and tactical medical systems, providing effective and timely care in challenging operational contexts.

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