Chapter 21

ARTIFICIAL INTELLIGENCE TECHNOLOGIES IN THE HEALTHCARE DURING THE WAR

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INTRODUCTION

To improve healthcare systems during the war and effectively save soldiers' lives, several key changes should be considered based on learnings from recent and historical military conflicts. One of the most important tasks facing the country's health care system in the context of the beginning of a military invasion upgrading emergency response capabilities is critical. This includes training medical workers in trauma care, ensuring that sufficient emergency supplies are delivered to the medical facilities as well as to the frontline, and ensuring that these facilities are equipped to handle a surge of casualties. Another important measure is adapting any available healthcare facilities. In war zones, traditional hospital settings may not always be accessible. Adapting existing structures into makeshift medical centers, like converting basements and bomb shelters into operational facilities, can provide critical care under fire. It's also essential to protect these facilities from attacks and ensure they have autonomous supplies of water and power. "Doctors and medical personnel in Ukraine found themselves in incredibly difficult conditions after the invader suddenly began aggressive military operations against the country. The war had every chance of completely destroy the health system, but instead it pushed the government and local specialists to find effective solutions, thanks to which medicine in the country not only survived, but also continued to develop. In some critical situations doctors have to work in the field, replacing sterile operating rooms with basements and bomb shelters. In some cities, the medical staff does not leave the hospital around the clock, which has become their second home"[1].

Implementation these strategies requires coordination with military and humanitarian organizations to ensure that healthcare interventions are timely and effective, even under challenging conditions. Artificial intelligence (AI)

[1] Oleksii Korzh The impact of the war on the healthcare system in Ukraine, BMJ Global Health, August 9 2022, URL: https://blogs.bmj.com/bmjgh/2022/08/09/the-impact-of-the-war-on-the-healthcare-system-in-ukraine/

can provide truly valuable assistance at all stages of ensuring the proper medical care of a military service members during a time of war in a country.

To enhance medical services during the evacuation of wounded soldiers from the battlefield, several critical measures should be implemented. Early medical intervention and timely evacuation are crucial. Studies show significant survival benefits when evacuation occurs within the first hour after injury.

1. Tourniquets use at the battlefield

Despite its use from Alexander the Great's war with Persia to current conflicts in the Middle East, the tourniquet has been considered both a lifesaver and invention of the Devil. This poor reputation developed through several conflicts, from the US Civil War to Vietnam. Concerns and unfortunate dogmas from these conflicts persisted, and tourniquets were not recommended in civilian practice. Despite this, tourniquets returned to military use in the 1990s via US Special Forces, who aggressively advocated their use. In a retrospective case-control study, Beekley et al. reported that 57% of deaths may have been prevented by earlier tourniquet use in a Baghdad hospital. Equally importantly, no adverse outcomes, including subsequent amputation, were attributable to tourniquet use. A prospective study, also in Baghdad, reviewed 2828 casualties. The survival rates were higher for those who had pre-hospital use of tourniquets compared to those with hospital use (89% vs 78%), higher with use before shock onset versus after shock onset (96% vs 4%), and higher with tourniquet use versus without tourniquet use (87% vs 0%)[2]. The use of tourniquets for controlling hemorrhage has been shown to significantly reduce mortality and in the war in Ukraine. Tourniquets have proven highly effective in saving lives on the battlefield by controlling severe bleeding from extremity injuries. Their use is now a critical component of both military and civilian trauma care. Studies have shown that tourniquet application has significantly reduced mortality rates in military conflicts and civilian mass casualty events where using tourniquets played a key role in saving lives. Despite their benefits, the use of tourniquets also comes with challenges. Incorrect application can lead to additional injuries, such as nerve damage or tissue death. There is also the risk of increased bleeding if a tourniquet is improperly tightened or loosened. Additionally, there are logistical issues in training both medical and non-medical personnel on the correct use of tourniquets, ensuring widespread and effective usage. These developments reflect a growing understanding of the critical role tourniquets play in hemorrhage control, underscoring the importance of ongoing research and training to maximize their lifesaving potential on the battlefield during the

[2] Amisar Shai, Radomski Rohem Tourniquet, United States Patent, Pub No.: US2007/0191881, A1, 08.2007

war. One of the very important problems that invalidating too many wounded fighters on a first stage of evacuation is the luck of self-regulating and AI-driven tourniquets. Innovations in tourniquet technology include the development of more user-friendly designs that ensure easier and more reliable application. New materials and mechanical improvements are being integrated to reduce the risk of injury when tourniquets are applied. Moreover, educational programs and simulations are increasingly used to train both civilians and professionals in proper tourniquet use, enhancing their effectiveness in emergency situations. There are too many amputations after incorrect use of tourniquets. The reason for this is that the tourniquet may be applied too tightly, or not loosened after a certain time and tightened again, which should be done when using the tourniquet for long time during evacuation. AI powered and self-regulating tourniquets can be good solution for saving life our soldiers at the battlefield. Most advancements in tourniquet technology focus on mechanical improvements, pressure regulation, and materials that increase safety and efficacy without integrating AI capabilities. One of the models of self-regulating tourniquets is described in US-patent[3]. This self-regulating tourniquet accurately regulates the pressure applied to a wound, simple to use, may be self-applied and fully portable so is to be suitable for use in the field. A self-regulating tourniquet by using liquified gas as the source of the pressure. When the device is activated, the liquefied gas flow into the inflatable bladder and produce pressure inherent to its chemical composition. This physical phenomenon and temperature are regulating the pressure applied to a limb. The proximity of the balloon to the limb is regulating the temperature the gas is subjected to and stabilizing the pressure on the limb at the designated pressure.

The absence of AI-driven tourniquets highlights an opportunity in medical technology where AI could potentially be applied in the future to enhance medical devices, particularly in terms of automating pressure control or integrating with health monitoring systems to improve emergency responses.

2. AI in evacuation of wounded soldiers from the battlefield

Organizing the evacuation of wounded soldiers from battlefields is a complex operation that involves careful planning and coordination across multiple military and medical units. The steps and considerations involved in this process are complicated and need to be done as soon as possible after beginning the military actions. AI *triage.* The first step at the site of injury is triage, which involves assessing the severity of soldiers' injuries to prioritize urgent medical needs. Triage ensures that those who need immediate life-saving intervention receive attention first. Triage is a critical component in the

[3] D. Maher Innovations from the Battlefield: Tourniquets. In History Issue, JMVH, Volume 28 No. 4 URL: https://doi-ds.org/doilink/05.2021-95761283/

evacuation of wounded soldiers from battlefields, ensuring that medical care is administered efficiently and effectively according to the urgency of soldiers' injuries. This is a AI-driven process of sorting and prioritizing patients based on the severity of their injuries and in battlefield conditions, triage aims to maximize the number of survivors by quickly identifying who needs immediate medical attention and who can wait.

Typically, triage categorizes injuries into several levels: Immediate (T1): Life-threatening injuries that require immediate intervention to save life or limb. Delayed (T2): Serious injuries but not immediately life-threatening; treatment can be delayed. Minimal (T3): Minor injuries that need less urgent treatment. Expectant (T4): Injuries so severe that survival is unlikely even with treatment; comfort measures may be provided[4].

To prioritize patients to provide them with proper services and to optimally use the resources and facilities of the medical centers during accidents, the use of triage systems, which are one of the key principles of accident management, seems essential. The use of tags or markers to denote the severity of injuries can help streamline this process. The main steps of triage process are: 1) Assessment. Upon arrival at the scene, trained personnel assess the wounded using quick, systematic methods. This might involve checking vital signs, level of consciousness, and the extent of injuries. 2) Tagging. Each casualty is tagged with a color-coded label that indicates their triage category. This visual system helps in quick identification and prioritization during evacuation. 3) Re-assessment. Conditions can evolve rapidly, necessitating frequent re-evaluations of the wounded to update their triage category as needed[5]. Using AI in triage during the evacuation of wounded soldiers from battlefields is an emerging area that can potentially enhance the speed and accuracy of medical assessments under combat conditions. Integration of AI in battlefield triage can be used to develop decision support systems that assist medics in quickly assessing the severity of injuries. These systems can analyze data from various sources, such as vital signs, visual assessments, and verbal reports, to recommend triage categories. Wearable devices equipped with sensors can monitor vital signs continuously, feeding data into AI algorithms that detect changes signaling deterioration or improvement in a patient's condition. This real-time data helps in dynamically updating triage decisions of interest. Immediate medical treatment is provided at the point of injury or at a nearby field medical station. This includes stabilizing the wounded, administering first aid, and preparing them for

[4] Jafar Bazyar, Mehrdad Farrokhi, and Hamidreza Khankeh Triage Systems in Mass Casualty Incidents and Disasters: A Review Study with A Worldwide Approach, Open Access Maced J Med Sci. 2019 Feb 15; 7(3): 482–494. doi: 10.3889/oamjms.2019.119

[5] William J Sacco, D Michael Navin, Robert K Waddell et al. A New Resource-Constrained Triage Method Applied to Victims of Penetrating Injury, Journal of Trauma and Acute Care Surgery 2007, 63(2):316 DOI:10.1097/TA.0b013e31806bf212

evacuation. Medical personnel must be equipped with the necessary supplies and training to handle a variety of combat injuries. Establishing effective communication systems are crucial. This involves coordination between the medical team on the ground, evacuation units, and the facilities prepared to receive the wounded. Radios, satellite communications, and even drones might be used for real-time information exchange. AI-powered image recognition can analyze photographs or live images of wounds and compare them against a database of injury images to quickly suggest the severity and type of injury, helping to prioritize cases without immediate human input. Triage algorithms such as START (Simple Triage and Rapid Treatment) or MARCH (Massive bleeding, Airway, Respiration, Circulation, Head/hypothermia), which provide guidelines on assessing and categorizing injuries[6]. The MARCH algorithm is laid out differently from Advanced Trauma Life Support (ATLS) which used Airway, Breathing, and Circulation (ABC's) as the order of treatment. MARCH stands for Massive Hemorrhage, Airway, Respiration, Circulation, Hypothermia/Head injury. This order prioritizes bleeding control as the first step since morbidity and mortality linked to massive hemorrhage can happen in some cases twice as fast compared to airway and breathing complications[7].

Communication devices play a vital role in coordinating the evacuation of wounded soldiers from battlefields. These devices must be reliable, secure, and adaptable to various environmental conditions to ensure effective management of medical evacuations. Crucial for relaying information about the wounded to medical facilities and coordinating evacuation efforts. Radio systems are the backbone of battlefield communication, especially in environments where other forms of connectivity may be unreliable or unavailable. They facilitate real-time voice communication between medics, evacuation teams, and command centers. Military radios are typically robust against interference and can operate in environments with high electronic interference. They are typically equipped with encryption to prevent eavesdropping and ensure secure communication. Another advantage is durability because it designed to withstand rough handling and extreme conditions. In remote or challenging terrains where terrestrial networks are absent, satellite communications (SATCOM) are crucial. SATCOM devices allow global coverage and they can communicate across vast distances, including remote battlefield locations. Good data capabilities because beyond voice, they support data transmission, essential for sending images or medical

[6] Rick Kye Gan, Helal Uddin, Ann Zee Gan, Ying Ying Yew ChatGPT's performance before and after teaching in mass casualty incident triage, Scientific Reports volume 13, Article number: 20350 (2023) URL: https://www.nature.com/articles/s41598-023-46986-0

[7] The M.A.R.C.H Algorithm – Massive Hemorrhage, TacMed Marketing March 03, 2022, Tacmed solutions, URL: https://tacmedsolutions.com/blogs/product-training/the-m-a-r-c-h-algorithm-massive-hemorrhage

data. And they have high reliability because less dependent on local infrastructure, which may be compromised in conflict zones. As part of the Space Force's complex strategy to ensure warfighters on the battlefield can stay securely connected in the face of ever-improving adversary electronic warfare systems, Space Systems Command wants to begin rapid development of a new satellite.

Fig. 1. The Advanced Extremely High Frequency System (AEHF) satellites for encrypted military communications. (US Space Force photo) communications (SATCOM) constellation in fiscal 2025 with hopes of starting initial operations on orbit in 2028[8]

AI-powered drones. Drones can be used for surveillance, communication, delivery and evacuation especially to and from inaccessible areas using AI technologies.

Medical evacuation can be done with different types of drones and light helicopters like Bell 47 (H-13G). It is conceivable that in medium term, a transparent drone ambulance flying at ground level could reduce the anxiety of the transported patient. For the time being, only desperate situations will justify unaccompanied AI-powered medical evacuation by cargo drone over a combat zone. Drones can be used for direct evacuation of wounded soldiers from the battlefield. Ukraine has already used large cargo drones capable of carrying 180 kg (400 lb) loads up to 70 km (43 miles!), to evacuate wounded

[8] Space Force wants $248M to kickstart new jam-proof SATCOM constellation THERESA HITCHENS on March 13, 2024, URL: https://breakingdefense.com/2024/03/space-force-wants-248m-to-kickstart-new-jam-proof-satcom-constellation/

personnel. This makes Ukraine the first country in the world to conduct this sort of automated MEDEVAC[9] [10].

Fig. 2. The Skyfront Perimeter 8 hybrid drone

Other types of heavy lifting drones like Drone Perimeter 8 UAV can be used for delivering equipment, blood, plasma, medications etc. The Skyfront Perimeter 8 hybrid drone flew 205 miles, achieving a flight time of 13 hours and 4 minutes. For carrying large payloads for long distances in a wide range of operating conditions. 13 hours with auxiliary tank. Drone operating temperature icon -10°C to 50°C. Customizable for any mission. Drone payload capacity 10 kg. Made in the United States[11]. Smaller drones (DJI Mavic 2 Enterprise Advances and others) can help in evacuation of wounded with real-time data from sensors, surveillance cameras, up-to-date information about ongoing conflicts, road conditions, and changing threats identifying safe paths and allowing evacuation teams to make informed decisions. This drone is compact and universal, with high-resolution thermal imaging and visual cameras with 32x digital zoom and can work in difficult weather and combat conditions. Portable drone with high ascent and descent speeds, excellent maneuverability and connectivity[12].

Medical AI-powered robot-drones on a way to the battlefields. A second generation of medical drones is already on the drawing board: these will be flying robots, interacting with patients, first aid or rescue teams. With no contact with the patient, and equipped with all the attributes of a medical teleconsultation (steerable camera with zoom, microphone and loudspeaker),

[9] Ukraine Evacuating Wounded Soldiers With Large Drones in a Battlefield First Wes O'Donnell·Aug 8, 2023 URL: https://wesodonnell.medium.com/ukraine-evacuating-wounded-soldiers-with-large-drones-in-a-battlefield-first-556433ab8e87

[10] The Dronization of Combat Medical Support Worldwide Military medicine.com, 2023, URL: https://military-medicine.com/article/4254-the-dronization-of-combat-medical-support.html

[11] The Skyfront Perimeter 8 hybrid drone. URL: https://skyfront.com/?gad_source=1&gclid=Cj0KCQjwlZixBhCoARIsAIC745A9Wb918mx2roceXJA7lIhlJbSgHOrdyxmompCJpgG4g2ZlGmoAWLcaAoFQEALw_wcB

[12] Drone DJI Mavic 2 Enterprise Advances, URL: https//airunit.com.ua/dron-dji-mavic-2-enterprise-advanced/

silent enough to allow a good quality close dialogue with casualties and battle-buddies in all possible languages (instant translation by AI), they will be able to assess the state of consciousness, make a visual assessment of lesions and collect infra-red data on body temperature. Soon, thanks to technologies currently under development, it will be able to measure heart and respiratory rates, as well as hemoglobin oxygen saturation, without contact[13]. Combined with biometric sensors worn by combatants, it will be able to collect more medical data, such as the cardiac electrical activity, and refine the parameters measured remotely[14]. This robotic drone will be able to assess and monitor the clinical condition of a casualty, either on its own assisted with medical artificial intelligence or with the help of remote medical personnel, and to advise or steer a rescue team already on site. A drone of this kind will revolutionize field care for battle injuries. This second generation of medical AI-powered robot-drones will be equipped with articulated arms. Initially, they will be able to carry out their own environmental sampling (water, soil, plants, small corpses, etc.) or even biological sampling, with a drop of blood taken by a needle from a casualty who will be hopefully consenting or at least unconscious. These samples will be brought as fast as possible to the most appropriate laboratory, and in a few years time, the drop of blood will probably be analyzed by the robot-drone itself: it will then only transmit the results to the medical team[15].

Predictive analytics for evacuation of wounded soldiers play very important role. The choice of transportation depends on the terrain, the urgency of medical needs, and the distance to the nearest medical facility. Drones and helicopters are commonly used for their speed and ability to land close to the front lines. Ambulances and, in less accessible areas, even animals or foot soldiers may be employed. Evacuation routes must be planned to minimize time and exposure to danger. These routes need to be regularly reassessed for safety due to the changing dynamics of battle. Convoy protection and route clearing from mines or debris might be necessary.

Using AI in predictive analytics for the evacuation of wounded soldiers involves leveraging machine learning models and advanced algorithms to anticipate and optimize various aspects of medical evacuation and treatment. AI can process vast amounts of data from different sources to provide actionable insights that enhance the effectiveness and efficiency of evacuation operations. AI can be integrated in predictive analytics for this purpose. AI models can analyze data from past incidents, including types of injuries

[13] Haleem A, Javaid M, Singh RP, Suman R, Rab S. Biosensors applications in medical field: A brief review. Sens Int. 2021;2:100100.

[14] DVIDS. US Troops test experimental 'Wearables Pilot Program' technology at Exercise Talisman Sabre 2023. URL: https://www.dvidshub.net/news/449695/us-troops-test-experimental-wearables-pilot-program-technology-exercise-talisman-sabre-2023

[15] Mohd Daud SMS, Mohd Yusof MYP, Heo CC, Khoo LS, Chainchel Singh MK, Mahmood MS, et al. Applications of drone in disaster management: A scoping review. Sci Justice. 2022 Jan;62(1):30–42.

sustained under different combat conditions, to predict the types and severities of injuries likely to occur in future engagements. This information can be crucial for pre-staging the appropriate medical supplies and personnel. AI can optimize the allocation of resources such as medics, vehicles, and equipment. By predicting the number and severity of injuries, AI can help ensure that resources are not only well-distributed but also that they can be dynamically reassigned in real-time as battlefield conditions change. AI algorithms can analyze geographic data, current conflict zones, weather conditions, and other environmental factors to determine the safest and fastest evacuation routes. These models can adapt to changing conditions to suggest alternative routes if the initial paths become compromised[16].

AI can also predict the likely medical outcomes for wounded soldiers based on their injuries and the initial treatments received. This helps in making informed decisions about which medical facilities soldiers should be evacuated to, depending on the level of care they are likely to need. Using historical data and current operational inputs, AI can forecast the demand at various medical facilities, helping manage their capacity effectively. This ensures that facilities are prepared for incoming casualties without being overwhelmed, which can improve survival and recovery rates. AI excels in processing and analyzing real-time data. In the context of battlefield evacuations, it can continuously update its predictions based on new data from the field, such as the rate of casualties or changes in the tactical environment, thereby refining its recommendations on-the-fly. AI can be used to simulate various evacuation scenarios based on predictive analytics, providing valuable training insights for medical and military personnel. These simulations can help in developing more effective strategies and in training personnel to handle complex situations[17]. The psychological impact on both the wounded soldiers and the personnel involved in their evacuation and care is significant. Providing mental health support is a critical. Regular training and simulation drills for all personnel involved in medical evacuation (MEDEVAC) processes are essential. These helps ensure that everyone knows their role and can perform it under pressure. Organizing an efficient and effective evacuation operation is critical to saving lives and improving outcomes for wounded soldiers. This operation relies heavily on coordination, speed, and adaptability to the often rapidly changing conditions on the ground.

Implementing AI in predictive analytics for evacuating wounded soldiers represents a significant advancement in military medical logistics and

[16] E. B. Kolesnikov, V. V. Kryzhevsky The use of artificial intelligence at the stages of evacuation, diagnosis and treatment of wounded soldiers in the war in Ukraine, Kharkiv Surgical School, № 4-5 (121-122) 2023, p. 80-83. DOI: 10.37699/2308-7005.4-5.2023.11

[17] Phillip R. Jenkins, Brian J. Lunday, Matthew J. Robbins Artificial Intelligence for Medical Evacuation in Great-Power Conflict, Air Force Institute of Technology, September 2020, URL: https://www.researchgate.net/publication/349255211_Artificial_Intelligence_for_Medical_Evacuation_in_Great-Power_Conflict

decision-making, promising to improve outcomes by making evacuations faster, more efficient, and better tailored to the specific needs of each situation.

3. AI in diagnostics and treatment of wounded soldiers

AI in diagnostics process. The use of artificial intelligence (AI) in the diagnosis and treatment of wounded soldiers on the battlefield and in military medical facilities represents a significant advancement in military medicine. AI technologies can improve the speed, accuracy, and efficiency of medical diagnostics and personalized treatment processes in wounded soldiers.

AI algorithms are increasingly used to analyze diagnostic images like X-rays, CT scans, and MRIs. These tools can identify injuries such as fractures, internal bleeding, and other trauma-related abnormalities faster and often with greater accuracy than human radiologists AI algorithms can analyze vast amounts of medical images and identify patterns that may be challenging for radiologists to detect. The use of AI algorithms in medical imaging can improve diagnostic accuracy, speed up the interpretation process, and reduce errors. AI algorithms can detect abnormalities in medical images that may have gone unnoticed by a radiologist. AI can also help with the quantification and analysis of medical images, such as measuring the size of a tumor, detecting changes in the structure of the brain, or evaluating blood flow patterns[18] [19]. The use of AI in the interpretation of orthopedic X-rays has shown great potential to improve the accuracy and efficiency of fracture diagnosis. AI algorithms rely on large datasets of annotated images to learn how to accurately classify and diagnose abnormalities. One way to improve AI interpretation of X-rays is to increase the size and quality of the datasets used for training, and to incorporate more advanced machine learning techniques, such as deep reinforcement learning, into the algorithms. Another approach is to integrate AI algorithms with other imaging modalities, such as computed tomography (CT) scans, and magnetic resonance imaging (MRI), to provide a more comprehensive and accurate diagnosis of complex injuries and complications in wounded patients[20].

AI can be used in other areas of diagnostic process. In addition to medical imaging, AI algorithms can also improve diagnostics in other areas of medicine. For example, AI algorithms can analyze electronic health records (EHRs) to identify patterns in patient data, such as symptoms, medical history, and test results. AI can also help with the interpretation of laboratory test results, such as blood tests, urine tests, and genetic tests. AI algorithms can

[18] Mohamed Elbanan, Hersh Sagreiya Artificial Intelligence in Trauma Imaging, Trauma Computed Tomographypp,Yale-New Haven Health February 2024, p. 313-331. DOI:10.1007/978-3-031-45746-3_14

[19] Armand Ruiz AI for Diagnostics and Medical Imaging, nocode.ai Newsletter, May 1, 2023, URL: https://www.nocode.ai/ai-for-diagnostics-and-medical-imaging/

[20] Sanskrati Sharma Artificial intelligence for fracture diagnosis in orthopedic X-rays: current developments and future potential, SICOT J. 2023; 9: 21, doi: 10.1051/sicotj/2023018. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10324466/

analyze these results and provide insights into specific medical conditions, such as infections, cancers, and genetic disorders. AI can also help with the interpretation of medical scans, such as electrocardiograms (ECGs), which can detect irregular heartbeats and other heart conditions.

By analyzing this data about characteristic, AI can help physicians make more accurate diagnoses, predict the risk of developing specific complications and diseases, and recommend personalized treatment plans. AI algorithms by processing extensive patient data, including genetic information, medical records, and lifestyle factors, can create personalized treatment plans. Personalized healthcare, also known as precision medicine, focuses on tailoring medical decisions, interventions, and treatments to individual patients. It involves integrating patient data, including genetic information, biomarkers, clinical data, and lifestyle factors, to provide targeted and customized care. By understanding the unique characteristics of each patient, healthcare providers can make more accurate diagnoses, develop personalized treatment plans, and predict disease progression with greater precision. Precision medicine, also known as personalized medicine, aims to tailor treatments based on individual characteristics and genetic profiles. By analyzing an individual's genetic makeup, biomarkers, and other relevant data, healthcare providers can identify specific treatment strategies that are more likely to be effective for a particular patient. This approach minimizes trial and error and increases the chances of successful outcomes[21]. AI can also help with the interpretation of laboratory test results, such as blood tests, urine tests, and genetic tests. AI algorithms can analyze these results and provide insights into specific medical conditions, such as infections, cancers, and genetic disorders. AI can also help with the interpretation of medical scans, such as electrocardiograms (ECGs), which can detect irregular heartbeats and other heart conditions. The role of artificial intelligence in personalized healthcare for wounded soldiers during wartime is becoming increasingly pivotal. AI technologies can tailor medical interventions to the specific needs of each soldier, enhancing treatment effectiveness and potentially improving recovery outcomes. AI can analyze a soldier's medical history, genetic information, and specific circumstances of injury to create personalized treatment plans. By considering factors unique to each soldier, such as previous health records, allergies, and genetic predispositions to certain conditions, AI can recommend tailored treatment strategies that may lead to better outcomes. AI models can predict the course of recovery and potential complications, adapting rehabilitation programs to meet the changing needs of wounded soldiers. By analyzing progress in real-time, AI can suggest adjustments of post-treatment care to optimize recovery trajectories. AI-enabled devices can continuously monitor the health status of wounded soldiers, even after they have returned to duty or are in recovery away from

[21] The Role of AI in Personalized Healthcare, Gaper, 2024, URL: https://gaper.io/role-of-ai-in-personalized-healthcare/

primary care facilities. This ongoing monitoring helps in early detection of issues that may arise during the recovery process, allowing for prompt interventions. The use of wearable technology in monitoring vital signs and physiological data in real-time offers a clear application for AI, enabling personalized alerts and interventions based on data trends.

Using machine learning techniques, AI models can identify patterns and correlations between different types of injuries and treatment outcomes. For example, they can learn from past cases where certain types of injuries led to specific complications and use this information to predict risks for new cases. AI uses statistical techniques and machine learning algorithms to make predictions about future events. In the context of wounded soldiers, AI can predict how long a soldier might take to recover based on the severity and nature of their injuries. Also, it can identify soldiers who are at high risk of developing infections, organ failures, or other medical complications and estimate how well a soldier will respond to various treatments, allowing for adjustments to be made early in the care process. AI also plays a crucial role in identifying and managing the psychological impacts of combat and injury. Through the analysis of speech patterns, behavior monitoring, and self-reported symptoms, AI can help in diagnosing and treating conditions like depression, and anxiety, often tailoring therapeutic interventions to the individual's specific needs. AI-driven platforms have been used to deliver personalized mental health support and cognitive behavioral therapies, showing promise in military contexts[22]. For military medicine, lessons learned from previous conflicts mean innovation in wound care and trauma management will be some of the most heavily invested areas. Indeed, researchers are already applying predictive analytics and artificial intelligence to advance surgical triaging on the battlefield.

Wearable health monitoring devices play a crucial role in wartime scenarios, particularly in enhancing the medical care of soldiers. These devices continuously track health metrics and provide real-time data, which can be critical in both immediate battlefield conditions and long-term health management. With AI integration in wearable devices or monitoring equipment, real-time data about a soldier's vital signs can be analyzed instantaneously. AI can detect subtle changes that may indicate the onset of complications before they become apparent clinically, prompting immediate medical interventions. Wearable devices can monitor vital signs such as heart rate, blood pressure, body temperature, and oxygen saturation. This real-time monitoring is invaluable on the battlefield where immediate medical response can be the difference between life and death. Such devices ensure that any significant changes in a soldier's health are promptly detected and addressed. To improve military fighters' security, advanced devices are equipped with the soldiers to view their status of the health and as well as the live location of

[22] Lauren E. Walker, 1 Jessica Watrous, 2 Eduard Poltavskiy et al. Longitudinal mental health outcomes of combat-injured service members, Brain Behav. 2021 May; 11(5): e02088, doi: 10.1002/brb3.2088

the soldier and a lot more to provide the safety to them in all aspects by giving the smart wearable's using WSN (Wireless Sensor Network) technology. Smart wearable like a smart vest, smart helmet, and the smart strap is equipped with BSN (Body Sensor Network) to determine the various psychological parameters and mental state of the solider. These smart wearable devices are capable of monitoring the health of soldier and ability to track the live location in real-time, by this if a soldier gets injured in the battlefield within no time the information transmitted to the control unit using LoRaWAN (Long Range Wide Area Networking) and to the nearby soldiers using Zigbee module by forming a Mobile Ad-hoc Network (MANET), so that the control unit can take any necessary actions for saving the life of the soldier. Soldiers have to face different climatic environments, need to face different emergencies all day 24/7. With various advancements in technology, wearable sensors have developed for monitoring various health parameters of the soldier. The soldiers may face difficulty in border surveillance all day or in the night and there may not be proper communication between other soldiers and to the control unit during various emergency scenarios. For the safety purpose biomedical sensors and modules are attached to the soldier's body which are lightweight, such types of components are used to build these devices SMART STRAP, SMART VEST and SMART HELMET for live monitoring the soldier.

Fig. 3. SMART Tactical combat ballistic bulletproof HELMET PGD ARCH

SMART HELMET helps the solider in preventing from any head injuries during the war. AI smart helmet can replace the traditional helmet and it has few functionalities like measuring brain glucose levels, drowsiness detection, night vision lens, thermal camera, proximity sensor, motion sensor, EYE blink detector, and fatigue detection and stress level management can be done by

analyzing the brain activity using EEG senso (Fig. 3). SMART VEST consists of sensors like ECG for observing the heart rate fluctuations, an adjustable thermostat sensor for calculating the surrounding temperature and adjusting the body temperature according to the surrounding temperature, and this smart vest is capable of identifying the bullet injury place on the body of a soldier (Fig. 4).

Fig. 4. SMART WEST Body armor Warmor Gen. 3

Body armor Warmor Gen. 3 with class 6 plates is a modern armor protection element designed for reliable protection of a person in dangerous situations. Made of high-quality materials, it provides maximum comfort and reliability during various tasks. SMART STRAP consists of sensors such as temperature sensor for observing the body temperature, figure print sensor for authentication that becomes a unique identity for the soldier, heart rate sensor for calculating the pulse rate of the soldier, OLED display for showing data which is observed by the sensors, Zigbee module is used to establish the communication between soldier to soldier and LoRAWAN is for soldiers to control unit and few more, with all these sensors a soldier unit is made. This system is divided into 2 parts 1) Soldier unit. 2) Control/Base unit. Control unit that has the LoRa module equipped with the strap for receiving the entire soldier's sensor data and transmitting the data to could. Soldier unit attached to the soldier, the data that is collected such as health parameters and live location from the solider unit is updated to the cloud every 5 s so that the control unit can know the live status of a soldier. In critical situations, the soldier unit communicates with other soldier units and also to the control unit for help. In this manner life of the soldier can be saved in emergencies and immediate rescue operations can be performed in protecting the solider by analyzing the data in the base unit. Overall, wearable AI-assisted health monitoring devices are transforming the way military medical care is

provided, offering significant benefits in terms of real-time data, enhanced response capabilities, and long-term health management[23].

The use AI technology in treatment of wounded soldiers. The use of artificial intelligence technology in the treatment of wounded soldiers is a rapidly evolving field, leveraging cutting-edge developments to enhance medical care in both emergency and ongoing treatment scenarios. AI can provide support across various stages of medical intervention, from initial injury on the battlefield to long-term rehabilitation. In military hospitals, surgical treatment of wounded soldiers involves a range of methods tailored to address trauma and injuries commonly encountered in combat. These methods are designed to stabilize patients, treat injuries effectively, and then begin the rehabilitation process. Using AI technology speeds up the diagnostic process, enabling quicker and more accurate treatment decisions by providing recommendations based on the analysis of large datasets. This includes selecting the most effective medications, predicting allergic reactions, necessary types of surgical procedures and foreseeing potential complications. The surgical treatment of wounded soldiers involves a range of methods tailored to address trauma and injuries commonly encountered in combat. These methods are designed to stabilize patients, treat injuries effectively, and begin the rehabilitation process. Initially *damage control surgery (DCS*) method focuses on stabilizing the most life-threatening injuries first, often in a staged approach. The initial surgery aims to control bleeding and prevent contamination rather than complete all repairs in one operation. Subsequent surgeries are performed once the patient's condition stabilizes. The purpose of DCS is quickly address critical injuries to increase survival chances before proceeding with more complex repairs.

Severe burns, often seen in combat due to explosions and fires, require specialized surgical treatment. This includes debridement (removal of dead tissue), skin grafting, and possibly reconstructive surgery. A new approach for burn wound assessment is being led by Dallas, Texas-based company SpectralMD, who are using AI and machine learning techniques to develop an imaging tool, the DeepView system, that can accurately predict the severity of burn injuries. One of the most critical decisions when treating burn victims is assessing how deep the burn is and whether surgery is required. The technology under development is being adapted for use in military settings and emergency rooms to quickly and clearly assess if patients need treatment from a burn specialist or non-burn specialist. Using multi-spectral imaging, the system integrates AI algorithms and optical technology that can distinguish between healthy and damaged tissues. The imaging technology

[23] Sandeep Kodam, Nadimpally Bharathgoud, Balaji Ramachandran A review on smart wearable devices for soldier safety during battlefield using WSN technology, Journal Materials Today, Volume 33, Part 7, 2020, Pages 4578-4585. URL: https://doi.org/10.1016/j.matpr.2020.08.191

extracts clinical data, processes the image, and displays a comparison of the original image next to an image with a highlighted area of the non-healing portions of the wound. According to SpectralMD, the image acquisition takes 0.2 seconds, and the output takes approximately 20 to 25 seconds, helping to avoid unnecessary surgeries or a reduction in military forces[24]. The innovative telemetry monitoring system (FlexiGuard system) composed of appropriate sensors based on previous researches and tests is recommended for use in military practice. AI facilitates telemedicine applications by enabling remote diagnosis and treatment recommendations through the analysis of medical data transmitted from the battlefield to specialists in another location[25]. Artificial intelligence holds significant potential to enhance the surgical treatment and rehabilitation of wounded soldiers during wartime by providing advanced diagnostics, precision in surgical procedures, and personalized rehabilitation plans. AI systems can identify the best pathways for minimizing damage during surgeries or suggest the optimal placement of implants. By creating 3D models of the patient's anatomy, AI enables surgeons to visualize and strategize complex procedures beforehand. AI can be used for intraoperative decision support.

AI can offer real-time data analysis during surgery, providing guidance based on the unfolding situation. This could include monitoring vital signs to predict unstable conditions before they occur or suggesting adjustments based on surgical progress.

In robotic-assisted surgery robots controlled by AI can perform or assist in surgical procedures, providing greater precision and control than human hands alone. These robotic systems (DaVinci) can carry out repetitive or highly intricate tasks with consistency and accuracy. (Fig. 5) For example, in orthopedic surgery, robots can help precisely cut bones and place implants, while in neurosurgery, they can perform delicate maneuvers around critical structures.

[24] Catherine Longworth, The wounds of war: AI leads arms race for burn assessment. July 17, 2023 URL: https://www.medicaldevice-network.com/features/the-wounds-of-war-ai-leads-arms-race-for-burn-assessment/

[25] Patrik Kutilek, Petr Volf, Slavka Viteckova et al. Wearable Systems for Monitoring the Health Condition of Soldiers. 2017 International Conference on Military Technologies. DOI:10.1109/MILTECHS.2017.7988856
URL:https://www.researchgate.net/publication/317785682_Wearable_Systems_for_Monitoring_the_Health_Condition_of_Soldiers_Review_and_Application

Fig. 5. The DaVinci surgical robot (Atlantic Health System)[26]

The Da Vinci is a surgical robot designed for minimally invasive procedures. It has four arms equipped with surgical instruments and cameras that a physician controls remotely from a console. The Da Vinci robotic system, a pioneering technology in robotic-assisted surgery, significantly enhances surgical precision and flexibility. Artificial intelligence can further augment the capabilities of such systems, leading to even more advanced applications in surgery. AI can be integrated with the Da Vinci robotic system to improve surgical outcomes. AI can analyze a wide range of medical imaging data to assist in the planning stages of surgery. By using machine learning algorithms, AI can help determine the most effective surgical approach, identify potential risks, and create a detailed plan that the Da Vinci system can follow. This can include mapping out precise paths for surgical instruments to avoid critical structures and maximize surgical safety and effectiveness. During surgery, AI can provide real-time analytics based on visual and sensory data collected by the Da Vinci system. AI can enhance the surgeon's view by highlighting or enhancing specific tissues, identifying critical structures, or providing augmented reality overlays that show hidden anatomy such as blood vessels or nerves. AI can suggest adjustments to the surgical plan based on real-time feedback, such as changes in tissue characteristics or the presence of unexpected anatomical variations. Certain repetitive or extremely precise tasks can be semi-automated using AI, allowing the surgeon to focus on the most critical aspects of the surgery. For example, AI could handle suturing, precisely placing stitches based on the optimal spacing and depth computed for tissue healing, or automatically adjusting lighting and camera angles for optimal visibility. AI can predict potential complications during surgery by analyzing ongoing procedural data and comparing it with historical data. This predictive capability enables preemptive actions to mitigate risks. For instance, if AI detects patterns

[26] Robotic Guide. Your Guide to the World of Robotics Intuitive Surgical, 1999, USA, URL: https://robotsguide.com/robots/davinci

associated with high risk of bleeding, it can alert the surgeon to take precautionary measures immediately.

AI can offer intraoperative decision support with real-time data analysis during surgery, providing guidance based on the unfolding situation. This could include monitoring vital signs to predict unstable conditions before they occur or suggesting adjustments based on surgical progress. AI models can analyze blood loss and vital signs to alert the surgical team of potential complications. AI can be used to create sophisticated surgical simulations based on actual surgical cases, allowing surgeons to practice on virtual replicas of their upcoming surgeries. This can help in honing skills and preparing for complex procedures, reducing the likelihood of complications during actual surgery. After surgery, AI can analyze the data gathered during the procedure to evaluate the success of the surgery and identify areas for improvement. This continuous learning approach helps refine surgical techniques and improve outcomes over time. *Performing robotic surgery remotely*, where a surgeon operates on a patient from a long distance using the Da Vinci robotic system and AI technology, is a concept often referred to as telesurgery. This technique combines robotic surgery and telecommunication technologies to allow surgeons to perform procedures without being physically present in the operating room. The Da Vinci robotic system needs to be set up in the hospital where the patient is located. This system includes robotic arms equipped with surgical instruments and a camera that provides a high-definition, 3D views of the surgical site. A robust, high-speed, and secure internet connection is crucial for telesurgery. This connection must support real-time, high-bandwidth data transmission with minimal latency to allow the surgeon to control the robotic system effectively and receive instant visual and sensory feedback. he surgeon operates from a remote console, which may be located miles away or even in a different country. This console replicates the control interface of the Da Vinci system, allowing the surgeon to manipulate the robotic arms and instruments as if they were physically present in the operating room. To ensure patient safety, robust safety protocols and backup systems must be in place. This includes manual override capabilities at the local site, emergency stop functions, and the presence of a qualified surgical team in the operating room to intervene if technical issues arise or in case of an emergency. The enhancement of human dexterity resulting from the use of a robot and performance of high-precision tasks from a distance may have other advantages that extend beyond surgery. Indeed, this achievement symbolizes and realizes an important technological revolution. Whether up-to-date, telecommunication technologies have allowed the sharing of information, voice, and images, here we show for the first time that complex gestures can be performed with high precision and in real time over long distances. Applications of teleperformance of precise tasks might be multiple

and might well apply to distant manipulations of hazardous materials such as nuclear or biologic devices[27].

Integrating AI with the Da Vinci robotic system represents a significant step forward in surgical technology, offering the potential to enhance surgical precision, improve patient outcomes, and revolutionize the way surgeries are planned and executed. As AI technology advances, its integration into robotic surgery systems like Da Vinci is likely to become more prevalent and sophisticated. While the concept of telesurgery has been successfully demonstrated, widespread adoption is still limited by technological, regulatory, and logistical challenges. However, ongoing advancements in network technology like 5G and improvements in AI and robotics are gradually overcoming these barriers, making remote surgery a feasible option for the future.

Preparing young surgeons to work in wartime conditions requires a focused training approach, emphasizing the types of surgical operations most commonly encountered on the battlefield[28]. Wounded soldiers often sustain specific types of injuries that differ significantly from those seen in typical civilian trauma. Here's an outline of the surgical operations young surgeons should be proficient in, along with training considerations for these conditions. Damage control surgery (DCS) is crucial for managing critically injured patients in wartime. It focuses on stopping bleeding, preventing contamination, and stabilizing the patient rather than definitive repair of all injuries. Surgeons must be trained to quickly assess the situation and prioritize life-saving interventions over less critical treatments. Orthopedic surgery knowledge and skills must be learned and training courses accomplished. Many battlefield injuries involve fractures and blast injuries to bones. Training should include: a) Techniques for external fixation, a rapid method for stabilizing fractures. b) Internal fixation skills for more definitive management once the patient is stabilized. c) Amputation techniques, when limb salvage is not feasible. Training in Vascular Surgery is essential because surgeons need skills to repair damaged blood vessels to prevent life-threatening hemorrhage and limb loss. This includes surgical techniques for both temporary shunting and definitive repair. Skills in handling soft tissue to ensure adequate coverage of vascular repairs. Soft tissue management handling soft tissue injuries, including muscle and skin lacerations. Skills in debridement to prevent infection are crucial. Techniques for complex wound closures or the use of skin grafts and flaps. Pairing young surgeons with experienced military surgeons for mentorship and hands-on training during deployments. Understanding the ethical considerations of battlefield medicine, such as triage decisions under resource constraints. Basic

[27] Jacques Marescaux, Joel Leroy, Francesco Rubino et al. Transcontinental Robot-Assisted Remote Telesurgery: Feasibility and Potential Applications, Ann Surg. 2002 Apr; 235(4): 487–492. DOI: 10.1097/00000658-200204000-00005

[28] How doctors work in wartime fighting for every life, Jun 08, 2022 URL: https://aam.com.ua/en/2022/06/08/how-doctors-work-in-wartime-fighting-for-every-life/

knowledge of military tactics and the operational environment to better understand injury mechanisms and safety protocols.

Training young surgeons for war conditions is about preparing them to handle severe, multifaceted trauma cases with limited resources and in high-stress situations. It requires a balance of technical skills, quick thinking, and emotional resilience to provide the best care possible under challenging conditions.

CONCLUSIONS

Implementation AI strategies during the war requires coordination with military and humanitarian organizations to ensure that healthcare interventions are timely and effective, even under challenging conditions. Artificial intelligence (AI) can provide truly valuable assistance at all stages of ensuring the proper medical care of a military service members beginning with evacuation from the battlefield, diagnostics, surgical treatments and rehabilitation in postoperative period. The first step at the site of injury is triage, which involves assessing the severity of soldiers' injuries to prioritize urgent medical needs. Triage ensures that those who need immediate life-saving intervention receive attention first. Triage is a critical component in the evacuation of wounded soldiers from battlefields, ensuring that medical care is administered efficiently and effectively according to the urgency of soldiers' injuries.

Implementing AI technologies during wartime requires careful consideration of ethical, security, and reliability aspects. AI systems need to be robust against cyber threats, which can be heightened in conflict settings. Moreover, ensuring that these technologies do not exacerbate inequalities or become targets themselves is critical. Machine learning models can predict the development of complications after complex surgical military injuries and their outcomes based on patient data. This can lead to more effective treatments with fewer side effects. AI models can predict how wounded patients will respond to various medications, allowing for more personalized and effective treatment plans. AI-driven robots may assist surgeons to increase precision in operations on wounded patients. These robots can perform complex surgical tasks with high precision, reducing human error and improving patient outcomes. Robotic assistance in surgery often leads to smaller incisions, less blood loss, and quicker recovery times. AI-powered virtual assistants can provide 24/7 health monitoring and basic healthcare support. AI automates many administrative tasks in healthcare facilities on the battlefields, such as scheduling, wounded patient data management. This reduces the workload on human staff, increases efficiency, and decreases the likelihood of errors. Very important part of the training of young surgeons – getting appropriate knowledge and skills to be ready to save lives of the wounded soldiers. Overall, the potential of AI to support and enhance healthcare in wartime is significant, offering hope for improved medical care in some of the most challenging war time conditions.

SUMMARY

One of the critical tasks facing the country's health care system in the context of the beginning of a military invasion is upgrading emergency response capabilities. This includes training medical workers in trauma care, ensuring that sufficient emergency supplies are delivered to the medical facilities as well as to the frontline, and ensuring that these facilities are equipped to handle a surge of casualties. Another important measure is adapting any available healthcare facilities. In war zones, traditional hospital settings may not always be accessible. Adapting existing structures into makeshift medical centers, like converting basements and bomb shelters into operational facilities, can provide critical care under fire. The first step at the site of injury is triage, which involves assessing the severity of soldiers' injuries to prioritize urgent medical needs. Triage ensures that those who need immediate life-saving intervention receive attention first. Triage is a critical component in the evacuation of wounded soldiers from battlefields, ensuring that medical care is administered efficiently and effectively according to the urgency of soldiers' injuries.AI powered and self-regulating tourniquets can be good solution for saving life our soldiers at the battlefield. The absence of AI-driven tourniquets highlights an opportunity in medical technology where AI could potentially be applied in the future to enhance medical devices, particularly in terms of automating pressure control or integrating with health monitoring systems to improve emergency responses. The use of artificial intelligence (AI) in the diagnosis and treatment of wounded soldiers on the battlefield and in military medical facilities represents a significant advancement in military medicine. AI technologies can improve the speed, accuracy, and efficiency of medical diagnostics and personalized treatment processes in wounded soldiers. With AI integration in wearable devices or monitoring equipment, real-time data about a soldier's vital signs can be analyzed instantaneously. AI can detect subtle changes that may indicate the onset of complications before they become apparent clinically, prompting immediate medical interventions. Wearable devices can monitor vital signs such as heart rate, blood pressure, body temperature, and oxygen saturation. This real-time monitoring is invaluable on the battlefield where immediate medical response can be the difference between life and death. Surgical robots controlled by AI can perform or assist in surgical procedures, providing greater precision and control than human hands alone. Training young surgeons for war conditions is about preparing them to handle severe, multifaceted trauma cases with limited resources and in high-stress situations. It requires a balance of technical skills, quick thinking, and emotional resilience to provide the best care possible under war time challenging conditions.

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