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Virtual War Medicine - A Key Element of Modern Warfare

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Abstract

The article deals with the impact of wars on the evolution of war medicine. The methodology includes an analysis of current approaches to the integration of new technologies, processes, and artificial intelligence in the treatment of wounded soldiers. In particular, the findings point to the lack of preparedness of medical information systems for intense conflict and highlight the need for rapid change in war medicine processes. Current studies point to the need for a multidisciplinary approach to its modernization, including its virtualization and legislative adaptation.

KEY WORDS: *new military technologies; Ukrainian war; patient; data protection; cyber security; soldier; virtual consilium; health law; cloud services*

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1. Introduction

In the period before the outbreak of the massive conflict in Ukraine (2022), the international concept of war medicine was primarily based on principles and methods that reflected the historical experience of past war conflicts. These approaches emphasized low-intensity combat operations and the dynamics of conflicts, separate isolated actions (see e.g. operations in Afghanistan, Syria, etc.), or the relative dominance of one of the warring parties. However, the current situation in Ukraine shows that these traditional approaches are no longer adequate in the face of new forms of warfare, which include, in particular, the extensive use of various booby traps, artillery, autonomous warfare, by-battle attacks, etc. The massive use of various types of drones and the ability to conduct long-range attacks is bringing new trends in the field of conflict management. The outlined specifics of the modern battlefield greatly complicate the traditional methods of evacuation of wounded soldiers, which forces a rapid rethinking and transformation of war medicine strategies.

In response to these new challenges, a greater focus on virtual warfare medicine and the implementation of related innovative technological solutions that can be effectively integrated into the new sub-processes of modern battlefield warfare medicine is required. The use of virtual consilia, the Internet of Things (IoT), generative machine learning (hereafter referred to as artificial intelligence - AI), and secure data transmission for real-time monitoring of soldiers' health status appears to be crucial for providing effective first aid and follow-up medical care. This implies the need to introduce new standards of healthcare delivery for medical personnel, both in individual military medicine roles and on the battlefield. The hybrid nature of the modern battlefield requires continuous evaluation and updating of strategies, which will allow for a better response to the needs of the wounded and increase the chances of survival.

In this context, an important element is the expansion of education and skills of medical staff not only in the professional sphere of medicine but also in the field of digital technologies and telemedicine. In addition to the necessary technological innovations, legislative and normative adaptation of modern war medicine also seems to be necessary. The security of medical data and its sharing between different levels of military command requires a careful revision of existing laws and rules, with an emphasis on the protection of the personal and medical data of soldiers [78]. All this is within the framework of individual NATO and EU armies, but also in the context of the interconnection of the two groups. This includes not only the adoption of new legal frameworks but also the creation of secure and efficient systems for the management and analysis of soldiers' health data and information in the context of military operations, virtually worldwide.

The paper aims to analyze the process of acquisition, transfer, storage, and evaluation of soldiers' health data in the context of limitations of their rights as patients in the context of virtual war medicine and the decision-making power of their superiors, including the proposal of specific measures and procedures for data transfer applicable in practice.

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2. Ukraine - the experience of the first postmodern high-intensity conflict

More than two years after the official entry of Russian troops into Ukraine, the military conflict against the country continues. Since its beginning, the war has claimed many human lives, greatly depleted material resources, and caused a significant change not only in the European but also in the global security context. Before 24 February 2022, the perception of the possibility of war and its conduct was opposed to today's views. It should be noted that, despite possible interpretations, the Ukrainian conflict is a traditional, conventional war. Russia's aggression is a clear violation of it under international law [27]. The conventional conflict is evidenced by the fact that both countries have declared the mobilization of their citizens. According to the University of Upsalla, this conflict also fulfills the criteria for the designation of war, according to which war is "a conflict or rupture between two states that result in at least 1,000 combat-related deaths in a given calendar year" [60].

However, experience from the Ukrainian battlefield is now providing valuable information for strategic, tactical, and defensive planning for armies around the world that are not directly involved in the fighting. The publicly available or presented data on this conflict is also critical to modern war medicine for all armies, which draws valuable insights from it to adjust their procedures and standards. Although the war could be considered a local conflict carried out exclusively between two states, with fighting conducted by conventional means deliberately only on the territory of Ukraine (from the perspective of democratic states - Ukraine's allies), this conflict undoubtedly has a major international impact, as demonstrated, among other things, by the number of various foreign entities involved in direct or indirect financial assistance to Ukraine[35], but also, for example, through Russia's cyber attacks against Western institutions, both state and non-state. All these external activities carried out outside the conventional battlefield significantly increase the international significance of the conflict [77].

It is important to note that the current conflict is characterized by its enormous scale and extreme intensity, attributes not seen on the European battlefield since the end of the Second World War. The considerable consumption of resources is one of the main features of this war. If, for example, British forces had to maintain the operational tempo assumed by the Ukrainian armed forces in the first six months of the conflict, their ability to counter such a conflict would be exhausted in just a week [84]. In assessing the scope and intensity of this war, it is essential to consider both the military doctrine and force structure involved and the means employed. In particular, the volume of munitions consumed can serve as a key indicator for militaries around the world in relation to the challenges posed by contests between equals in the current era.

The above assertion regarding the scale and intensity is supported by the number of victims of the conflict on both sides. According to Milley's statement, Russia has already seen the loss of more than 100,000 of its troops in January 2023, with similarly serious losses on the Ukrainian side [69]. In March 2024, U.S. Secretary of Defense Lloyd J. Austin III detailed the enormous losses that Russian President Vladimir Putin has inflicted on his own country with his brutal war against Ukraine. In his words, Russia faces losses of at least 315,000 Russian soldiers (killed or wounded) [70]. Information from the New York Times in August points to more than half a million killed or wounded since the invasion began [9]. According to the General Staff of the Armed Forces of Ukraine, as of 1 March 2024, Russian combat losses amount to 414,680 soldiers. During a press conference on 25 February 2024, Ukrainian President Volodymyr Zelensky specified that a total of 180,000 Russians had been killed in Russia's full-scale war against Ukraine. With persons wounded or missing, the figure is as high as 500,000 soldiers [42].

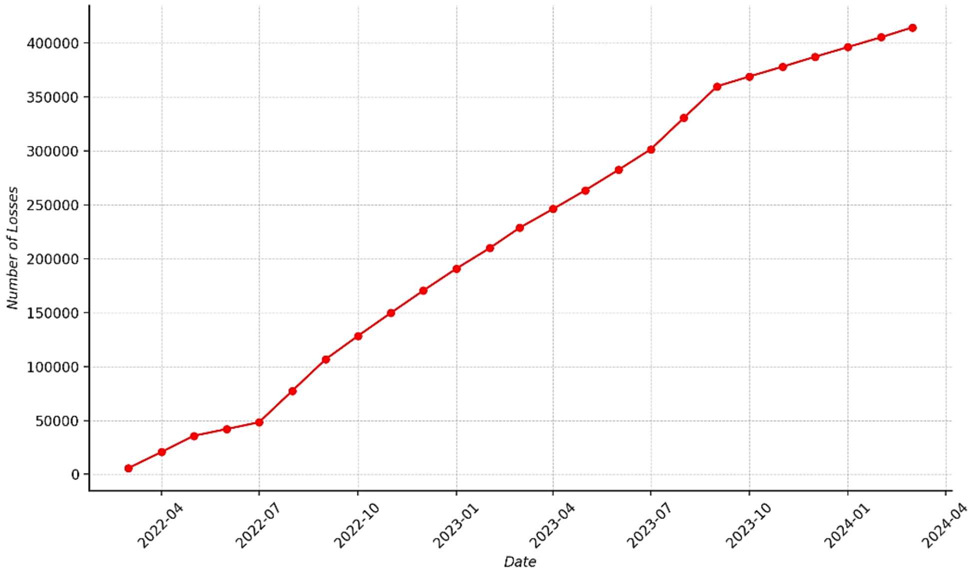

Fig. 1. Russian combat losses since February 24, 2022 [42]

In the early days of the confrontation, it was expected that Ukrainian resilience would not be enough against the superior Russian forces and that the country's defenses would collapse in a matter of days [6]. However, Ukraine has been surprised by its ability to adapt to the situation and confront challenging circumstances, undermining these predictions [2]. It is possible to observe not only Ukraine's tactical agility in the form of quick strikes and solid defense of key positions but also the ability to optimize its offensive maneuvers. The state of the conflict in 2023 embodied a mix of equal and different combat elements, with both sides engaging in a system of conventional and unconventional operations across different spheres of combat [23]. This situation prevails also in 2024, when, however, Ukraine's dependence on financial, material, and especially military assistance from external entities is more noticeable [11], without which it would be impossible to maintain an equal chance of waging conventional war in the style described and would necessarily lead to the abandonment of positions already gained and thus logically again to changes in the style of warfare.

The change like warfare is demonstrated by the inconsistency in the perception and use of military equipment, which is fundamentally reflected in the perception of the value and importance of tanks in this conflict. The initial view of tanks as obsolete instruments of warfare was reassessed in the early stages of the war, as their strategic use and lack of protection by other branches of the armed forces indicated an immediate need to revise their role [39]. With the arrival of spring 2023, there was a shift when Western countries began to supply Ukraine with tanks in particular, which many interpreted as a key moment that could strengthen the Ukrainian offensive [28]. This turn of events highlights that the dynamics of the current conflict are constantly influenced by the evolution of tactical and strategic approaches, with both sides of the conflict adapting their strategies and military structures to better respond to the challenges of the battlefield, as illustrated by the Russian military's significant shift in early 2023 to a divisional organization of their units [4, 16].

Another turning point in the tactics of warfare, which ultimately has significant implications for the principles of the logistics of war medicine, is the massive deployment of artillery and unmanned aerial vehicles on the modern battlefield. The conventional army operates towed artillery, which is transported to firing positions by army vehicles, and self-propelled artillery, which can maneuver itself into designated positions. However, experience from the Ukrainian battlefields declares that future artillery systems must be "constantly moving" without having to account for the time it takes its crew to move from an old to a new firing position [61]. In particular, experiments with extended-range cannon Artillery (ERCA) ammunition show a paradigm shift towards increasing the firing range of artillery, where tested rounds reached targets more than 110 km away [62]. These advanced tests, which included firing rounds from the Paladin howitzer that reportedly exceeded the range of all previous projectiles from this platform, are representative of the military's ambition to modernize and expand the operational capabilities of its artillery [61]. Russian military successes in rapidly targeting adversaries with drones and advanced surveillance technologies represent another significant change in artillery tactics [53]. Integrating drones into artillery operations allows Russian forces to engage targets with surprising speed, often within 180 seconds of detection. This efficiency contrasts with more traditional targeting methods, where the process from identification to engagement can take up to 30 minutes [61]. A significant surprise, then, was Russia's ability to effectively engage and destroy key Western weapons systems that had rarely been hit before, demonstrating the high level of sophistication and coordination within their artillery and intelligence operations [46]. Above all, it was the loss of important systems supplied by Western countries, such as Patriot anti-aircraft missile launchers, which until then had been considered an extremely effective defense system [5]. Similarly, Russia has managed to track down and destroy high-mobility artillery missile systems. All this highlights the challenges facing modern air defense and artillery strategies [76], which are also essential for the protection of rear and medical units, their equipment, facilities, and evacuation routes for the removal of the wounded.

The war in Ukraine reaffirms the old military truth that, even in the age of advanced technology and air power, ground combat is the basis of any conflict. Despite all modern methods of warfare, from precision strikes to the use of drones, the "boots on the ground" fight remains decisive [73]. This reality was also reflected in Ukraine, where neither extensive air and missile strikes at the beginning of the conflict nor advanced air operations during the conflict were able to fundamentally change the course of the fighting in favor of one side [7]. In contrast, efforts to maintain control of key positions through ground forces have shown that in the current conflict, victory depends primarily on the ability to seize and hold territory, which requires the effective deployment of ground forces [7].

Another aspect is adaptation to the ever-changing conditions of the modern battlefield, where traditional (conventional) air superiority no longer necessarily guarantees victory. Although air power plays a key role in reconnaissance, combat zone isolation, electronic warfare, and precision strikes, the ability to effectively employ ground forces to achieve strategic objectives remains essential [47]. It turns out that success lies not in achieving air superiority, but rather in the ability to limit the effects of enemy air power and maximize the potential of ground operations [48, 56]. In this context, the war in Ukraine appears to represent a shift from the traditional emphasis on air dominance to a more complex conception of conflict where the ability to combine different types of troops and tactics to achieve success on the battlefield is key, underscored by the massive casualties on both sides and the tactical innovations conducted in response to these challenges [47]. This evolution highlights that in modern conflicts, despite the growing importance of technology and innovation, ground combat and the strategic use of large numbers of ground forces remain critical success factors. However, such a mode of warfare inevitably brings with it enormous requirements for the provision of medical care to soldiers, with an emphasis on reducing casualties.

3. Modern warfare medicine - reasons for the path to virtualization

Already Napoleon Bonaparte was aware that when commanders move field hospitals to the front line of troops, they are declaring their intention to accept losses and also their intention to fight. In January 2022, the international community noted, largely in publicly available source material, that field hospitals were appearing along Ukraine's northern, eastern, and southeastern borders. There were, among other things, blood draws of university students, Russian military medical exercises, and tests of their medical evacuation chains back to St. Petersburg. These signals of Russian intentions already warned of impending war [51]. Unfortunately, it was only in the wartime environment of Ukraine that a significant shift in the concept and implementation of war medicine occurred, which was due to the exceptionally high number of wounded and the specific conditions of the battlefield, including the extensive deployment of artillery and the associated difficulties in evacuating the wounded. Deficiencies in the preparation and training of soldiers in the area of first aid, combined with the intensive use of artillery making it impossible to safely evacuate the wounded from the front line, resulted in significant casualties [81]. All of this has increased pressure on medical units, their equipment, and the implementation of new procedures, especially efforts to fully digitize the army's medical processes and the quality training of combat medics [85].

Changes in the conduct of war, as described in the previous section of this article, therefore require the adaptation of new war medicine strategies to effectively meet new challenges. In particular, the ability to respond to a broader spectrum of threats and the ability to provide rapid and effective care are key [65]. Rapid drone targeting and advanced technology mean that warfighting medicine must not only be mobile and flexible but also equipped to counter sophisticated attacks that can unexpectedly change the dynamics on the battlefield [7].

In July 2022, the Royal United Services Institute Journal published an article entitled "You are the weakest link: the limits of Britain's defense medical capabilities" [84]. This article stated that the war in Ukraine has highlighted the shortcomings and stagnation in the development of military medical capabilities for combat that have accrued during the 30-year peacetime period following the Cold War. Lessons learned from the war express the urgent need to restructure Allied wartime medical services [29], which is closely related to the implementation of operations to deter Russian aggression and prevent war [57]. With this knowledge, we have the space to address gaps in NATO's collective medical capabilities and can take appropriate corrective actions that would be shared directly with the NATO military medical community [19].

The need to revise the principles of war medicine is necessarily reinforced, among other things, by Russia's repeated violations of international humanitarian law and legal norms regulating armed conflicts. Traditionally, it was assumed that the adherence to the principles of the Geneva Conventions and the recognition of the Red Cross symbol protected field hospitals in international conflicts. However, recent conflicts, including those involving Russia, have shown that these assumptions may not always be met. Specifically, Amnesty International in 2016 highlighted the systematic and deliberate attacks by Russian and Syrian government forces on medical facilities in northern Aleppo as a strategy to facilitate the advance of ground forces [1]. As a result of these prolonged conflicts, medics have been forced to take refuge underground or in unmarked buildings to provide care to the wounded [45].

In Ukraine, it is now becoming clear that the international consensus and existing legal norms do not provide sufficient physical or virtual protection for medical units from an aggressor that recognizes neither the laws of armed conflict nor humanitarian principles [15]. In January 2023, Neil Bush, head of the UK delegation to the Organisation for Security and Co-operation in Europe, highlighted the growing evidence of war crimes against medical facilities committed by Russian forces in Ukraine, including attacks on areas under their control [24]. These continuous strikes on Ukrainian cities and civilian medical infrastructure have a lasting humanitarian impact not only on the population but also on wounded soldiers and their treatment options. Already in the first weeks of the invasion, many medical facilities were targeted, often with devastating consequences [65]. These findings, together with Ukraine's experience before the beginning of the conflict, when although the war was constantly mentioned in the media and communication with the public, Ukrainian hospitals were not prepared for the invasion on a systemic level [18], led to the extension of the application of the principles of war medicine also to civilian medical facilities, which in the event of a conflict will necessarily become part of the military medical infrastructure.

A possible sub-measure in such a context is a reassessment of operational procedures by the military health service, including the introduction of tactics of camouflage, deception, and distraction. This includes the use of underground structures, such as underground car parks or emergency hospital wards, to safely provide care to wounded soldiers [49]. In addition, it may be necessary to implement enhanced air and cyber defense measures for medical facilities located in critical areas to ensure their protection from hostile activities [49]. An example of this is the need to respond to hostile UAVs tracking marked medical vehicles to the extraction site (Role 2), often with artillery subsequently targeting the area to destroy or damage the area and the occupants [41].

It is not only about the physical security of military medical facilities in all roles but also about virtual security. In addition, the vulnerability of military medical facilities is their electromagnetic interference (EMI) signature [82], which extends beyond command-and-control locations to medical buildings, acting as a navigational beacon for enemy fire. According to Samuel L. Fricks, who served in Ukraine as a member of the U.S. Department of Defense's surveillance team, anything that is stable on the ground for more than seven minutes can be targeted by the enemy [41]. Thus, visual tracking is not needed for detection. The described situation is one of the basic causes of both high casualties and the need for mass evacuations and medical care for wounded soldiers in the field.

In response to these factors, war medicine must constantly adapt and transform to meet the demands of modern conflict. Simulations and analyses by some militaries suggest that in high-intensity conflicts such as the one in Ukraine, the role of war medicine becomes a key factor that can determine the outcome of the conflict [81]. The increasing use of artillery, air defense, and long-range strike capabilities limits the options for rapid medical evacuation, a challenge not encountered in previous lower-intensity conflicts [79].

These developments require innovative approaches, including the use of new technologies for on-scene diagnosis and treatment, improved rapid evacuation systems, and enhanced first-aid training for all soldiers [68]. Increasing the chances of survival of wounded soldiers on the modern battlefield will thus require not only traditional medical skills but also the ability to adapt quickly to the ever-changing conditions and challenges that modern conflicts bring. Integrating these elements into concepts of war medicine could mean the difference between life and death for many of those serving on the front lines [48]. The diversity of warfare brings a complex mosaic of tactics and strategies that reflects both the evolution of modern warfare and the continued importance of traditional combat methods [47], which goes hand in hand with the development of modern warfare medicine and its necessary virtualization.

4. Modern war medicine - front line

With conflict, the challenges of war medicine are transferred to the front lines, where wounded soldiers, due to the factors described above, are at risk of delayed evacuation due to intense and constant bombing. Traditional first aid and evacuation methods are tested to extremes, often forcing medical teams to adapt to difficult conditions on the ground. Although contemporary warfare contains elements of post-modern conflict, such as cryptographic communications and the use of private military companies that sometimes operate autonomously [32], conventional tactics such as persistent frontline warfare, massed artillery [83]. and extensive field fortifications must not be overlooked [23]. This complex course of war reflects not only technological advances but also the determination and ingenuity of both armies involved, which are constantly adapting and developing new methods to achieve strategic superiority [84]. In direct connection with this, emphasis is placed on changes in the concept of war medicine and especially first aid for the wounded on the battlefield, who cannot be evacuated "immediately".

The reaction of the allied armies watching the Ukrainian conflict consists, among other things, of the implementation of so-called war games, which allow simulation of the real possibilities of providing medical services to wounded soldiers and their further provision. In the context of the Ukrainian conflict, these simulations show dramatic casualties - up to 21,000 wounded soldiers during the first seven days of fighting [62]. These figures illustrate the demands of modern warfare and highlight the importance of effective and prompt medical care for wounded soldiers. Given the difficulty of evacuating the wounded during the so-called golden hour, a critical period when prompt and proper medical intervention can mean the difference between life and death, it appears that traditional approaches are no longer sufficient [62]. Failure to adequately move patients to higher levels of care affects the quality of care and mortality of trauma patients [25]. The transfer of wounded soldiers to a medical facility at the front during the golden hour is unlikely given the current constraints of the conflict. Evacuation times combined with overstretched and/or destroyed medical facilities significantly affect the mortality of trauma patients [25]. The use of aerial evacuation would significantly reduce the evacuation time but is currently not feasible due to the hazardous airspace in the combat zone [55]. Evidence from battlefield studies strongly suggests that many deaths and serious injuries are related to massive bleeding immediately after injury and that most preventable deaths can be achieved by controlling blood loss [34]. Intensive efforts to address the problems associated with massive blood loss are evidenced by the U.S. Army's Tactical Combat Casualty Care (TCCC) training and management programs for all members of the armed forces, which have been widely implemented or are reflected in similar programs in many other countries, including Ukraine [30]. Michael Talley also pointed out the need to review the organization and especially the training of military and medical personnel to prepare them for the challenges of high-intensity conflicts [62].

Another key factor revealed within the Russian military is that inadequate first-aid training has resulted in a high number of deaths and injuries. According to a report published by the Ria Novosti website, up to 50% of the deaths of Russian soldiers in Ukraine can be attributed to poor first aid due to inadequate training [52]. This problem is compounded by the fact that most Russian soldiers remain without adequate training, leading to high casualties. In contrast, Ukrainian forces, which have effectively trained their personnel in the area, show a significantly higher survival rate of their wounded, thanks in part to cooperation with Western instructors [8]. These data and revelations point to the critical importance of adequate training, first aid, and rapid medical intervention in modern warfare, particularly on the line of engagement. They also point to the need to rethink and innovate approaches to war medicine so that as much medical assistance as possible can be provided on the ground without the possibility of moving the injured person.

The U.S. military is responding to the challenges described above by developing new technologies and methods that expand the capabilities of medical care on the battlefield. Innovations include but are not limited to, synthetic blood, antigen therapy to improve compatibility in transfusions, the use of augmented reality, artificial intelligence, robotics, and 3D printing. These technologies aim to give military units' greater autonomy in caring for the wounded until evacuation is possible [80]. The combination of the described innovations and procedures necessarily requires, due to the impossibility of evacuation or the presence of qualified medical personnel directly on the battlefield, remote access to medicine and its useful extension from physical to virtual form.

5. Military health data transfer options

Military environments and crises such as wars and conflicts have historically acted as catalysts for the development of modern technologies. This trend is also evident in the case of the current conflict in Ukraine, where the military, given the aforementioned facts, is faced with an urgent need to innovate and adapt technologies in war medicine to effectively respond to the challenges of treating injuries in combat settings. History shows that militaries have long used telemedicine to overcome geographical and logistical barriers, enabling them to provide critical medical care in the most extreme conditions. The earliest use of radio telemedicine documented by the military has its roots in Australia at the Military and Veterans Health Centre in Brisbane, where in 1917, Perth physician J.J. Holland telegraphed a postmaster at Halls Creek, 2,900 kilometers away, how to treat a seriously injured stockman [36]. A significant step in the development of telemedicine in general was NASA's 1989 initiative to create the US-Soviet Space Bridge following the earthquake in Armenia, which caused extensive damage to medical infrastructure and loss of life [3]. This telebridge enabled the transmission of image documentation and the provision of consultative assistance to patients, which subsequently helped in the Russian city of Ufa after a tragic railway accident. The telemedicine link provided transmission of image documentation from the affected areas and subsequent consultation by U.S. military doctors [64]

In the military context, the possibility of data transmission is also related to the field of telepsychiatry and telerehabilitation, especially on bases, ships, and field hospitals, but also on the battlefield [80]. A significant benefit of telemedicine is its ability to provide rehabilitation support to wounded soldiers and civilians in war zones, as demonstrated in the United States, where telerehabilitation has developed primarily in military medicine [3]. This approach, in the context of today's times, illustrates the key role of telemedicine in the rapid and efficient delivery of medical care in extreme situations, and its use in the military and response to the war in Ukraine offers the promise of improved treatment outcomes and saving more lives.

The basis for the implementation of military telemedicine directly in Ukraine is the development of a coordinated national medical evacuation system and trauma registry, which would improve both evacuation time and especially clinical communication [37]. The development and use of such systems will enable critical improvements in the trauma system of Ukraine and will serve as the information backbone for process improvement of all systems within the entire system. A trauma registry is the foundation of a responsive and dynamic trauma system, which is lacking in Ukraine, that collects information related to trauma events, injuries, care, and outcomes across the continuum of trauma care. The data collected allows for systematic analysis leading to continuous quality improvement, resource allocation, and change in the practice of war medicine in general [54]. Ukraine is currently developing modified electronic systems and tools related to the complete computerization of its health care system concerning the ongoing armed conflict. It explores what approaches, policies, standards of care and guidelines are necessary to strengthen the trauma care system in addition to the trauma registry. Since the beginning of the war, the Ministry of Health has been concerned with setting up health care using global standards of disaster medicine, however, they decided to develop their trauma system to meet their needs and constraints [71, 72].

The Ukrainian experience with the development of electronic systems is an extremely valuable source of knowledge for the actual development of systems of other NATO armies enabling the transmission of data, not only on the health status of soldiers on the battlefield. It is imperative that NATO's Military Health Section, as well as those of the individual armies, begin to implement systems that enable the collection and analysis of physiological data directly from soldiers' bodies, for example, using IoT (i.e. biosensors and sensors) to monitor environmental parameters. This data should then be transmitted and stored in the databases of ambulatory or hospital information systems of military medical facilities through protocols that ideally use predefined interoperable standards.

The personalized evaluation of the health status of individual soldiers based on this data will not only enable more accurate and faster diagnosis of wounded soldiers but also prediction of the development of their health status and timely initiation of effective therapy, including subsequent rehabilitation. The implementation of such an integrated, adaptable system, which would also function in a decentralized manner and be accessible both at the individual soldier level and at the command level, represents a key step towards ensuring better care for the wounded in wartime conditions, including optimization of their evacuation.

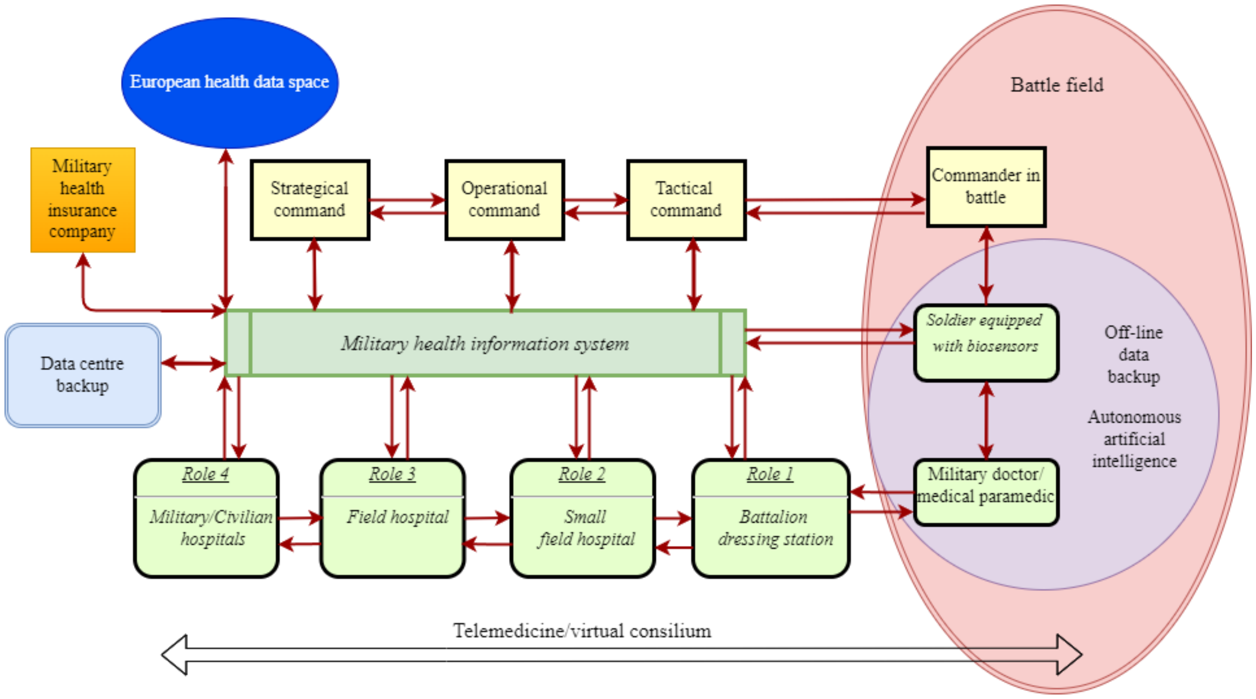

Fig. 2. The model for the transfer and use of military medical data.

This strategy, supported by digitalization and telemedicine, would not only be able to significantly expand the capabilities of war medicine but also increase the chances of soldiers' survival by enabling timely and targeted medical interventions based on real-time analysis of medical data without the need for immediate transport to a medical facility (field hospital). A possible solution is illustrated in the following diagram (see Fig. 2). The diagram in Fig. 2 depicts a sub-module, designed by the article's authors, that transfers and manages data (both content and metadata) about soldiers' health status from their deployment locations (e.g., battlefields, foreign missions) to various levels of the selected army's military medical service roles. This sub-module is integrated into a broader military health information system. This system will facilitate the collection, capture, analysis, and efficient transfer of vital health data for soldiers to medical officers and commanders at all levels within a critical time frame. The model also enables the creation of a secure virtual environment for the transmission of all types of required data, including the implementation of virtual consilia or the provision of health services through telemedicine.

At the individual command levels, the data obtained from the soldiers' sensors can be used for further evaluation and decision-making on their deployment or provision of medical assistance. The whole concept creates a holistic ecosystem, the central node of which is the military health information system, which collects, processes, and distributes soldiers' health data. This system communicates with various levels of command, military, and non-military health service providers, enabling the provision of rapid data access and real-time decision-making. However, should the military medical system experience an outage, it is still possible to store the data and transmit it to specific roles. The advantage of using a centralized system is the immediate distribution of data to authorized individuals and its independence from this central element.

The security protocols for data transmission must incorporate robust encryption standards and firewall protection to prevent unauthorized access or data breaches during both peacetime and armed conflicts. Such a solution must necessarily include security protocols for authorization, authentication, and identification of authorized persons and their authorization levels, ensuring that only authorized users or entities that can process and transmit data can have access and verification. From a cybersecurity perspective, the short-term operating horizon of the computer system is ideal, however, for more permanent use, it will be necessary, on the part of the Member States concerned, to build up an information technology infrastructure and establish appropriate legislation governing both the security and standards of its operation and the protection of personal data directly affected by the system.

A significant consideration is the potential use of existing non-military communication and encryption tools, such as civilian mobile applications [44]. The potential use of these tools has been confirmed by their use in Ukraine, where they have been used for pre-hospital care, remote patient monitoring, and also to improve standardized forms [37]. A fundamental prerequisite for the use of existing technologies and systems of the civilian sector for virtual military medicine is their use only if the digital signal used by them does not represent a potential target for attack [20, 74]. Another necessary measure for the implementation of these systems will be, for example, the suppression of the transfer of geolocation and contact data to other than authorized entities. This step has already been taken, for example, in Ukraine for all electronic health records [56]. Taking measures to remove the geographical and contact details of doctors, soldiers, and all other users of the system is essential to ensure optimal cyber security. An important lesson from the fighting in Ukraine is the implementation of the aforementioned telemedicine, which is used among civilians for primary care, but its role in trauma care has been severely limited due to language barriers, insufficient technological infrastructure, and, in particular, persistent concerns about ensuring cyber security [26, 38].

To ensure the transfer of data and information across different platforms and units, the alliance militaries need to establish and maintain interoperability standards. These standards will in the future, similar to the civilian sector, allow for the integration of systems from different vendors and ensure that data can be effectively shared and used by all relevant parties, both within the military sector and in the civilian health sector, if required.

The presented model assumes the use of a partially virtualized and cloud environment that can offer a high level of diversification and data availability. Such a solution appears to be suitable for military cloud platforms designed specifically for resilience against cyber threats and with the ability to operate in a variety of environments - from stable data centers to mobile and deployed operational units that require high levels of redundancy and rapid adaptability to changing conditions. However, as already mentioned, the transfer of data and information is not dependent on the cloud environment and allows for alternative ways of transferring data and information.

The diagram presented in Fig. 3 are also created by the authors, it illustrates the process of transferring medical data from the battlefield to the various levels of the military medical service. In the first step, the health data of the wounded soldier is collected by biosensors; it can be supplemented by first aid or autonomous first aid information using artificial intelligence. If online transmission is possible, the data is immediately sent to the military health information system, regardless of distance. If online transmission is not possible, the data is stored offline and transmitted over a short distance of up to 2 km to a military doctor who is on or near the battlefield where it can be evaluated and processed for further use. En route to the military doctor, the data can be further transmitted to the military medical service system, which is divided into several roles. Role 1 is the battalion dispensary, which can be located up to 10 km from the battlefield. Role 2 is a small field hospital that can be located up to 30 km from the battlefield. Role 3 is a full-field hospital that can be located up to 50 km away. Role 4 represents a military or civilian hospital where the data is finally integrated into the broader military health information system. In the military medical service system, data is coordinated and analyzed at the tactical, operational, and strategic command levels, allowing for informed decision-making regarding treatment and evacuation options for wounded soldiers. The medical information system serves as the basis for data collection, storage, and analysis, enabling telemedicine consultations and the provision of virtual medical care.

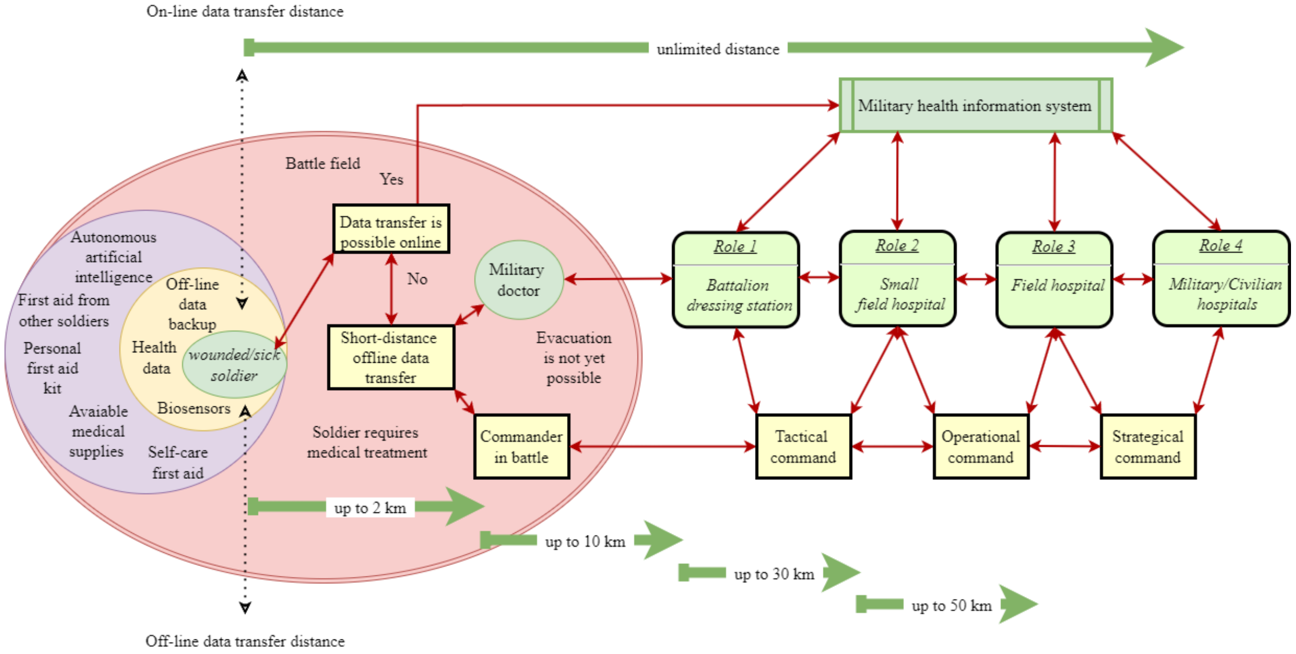

Fig. 3. The model (diagram) illustrating data transfer allowing for both cloud and semi-offline data.

From the experience of the Ukrainian battlefield, it can be assumed that it will not be possible to maintain this system relatively permanently online on the battlefield. It can be sad that Fig. 3 illustrates a sophisticated system for the transmission and use of military health data that is designed to withstand the challenges an army may face in combat conditions. It must be designed to remain functional under adverse conditions in high-intensity conflicts where immediate evacuation of the wounded is not possible. It includes an off-line/semi-off-line data collection and storage solution that will allow for continuous monitoring of soldiers' health status and that will provide backup and recovery of data when needed until it can be securely shared and connected to the Army network again. Related to the above is the possibility of linking artificial intelligence technologies that would be able to assist in providing medical services to a wounded soldier autonomously on the battlefield without network connectivity for some time [75]. The assumption is that artificial intelligence will be able to guide the soldiers performing the treatment through predefined steps, which will be variably evaluated based on the changing situation (see the use of generative AI data), to stabilize the injured person as much as possible, leading to a stable health state until possible transport. Generative AI could be used as a means to consult or assist military medics on the battlefield in their activities. According to the authors of the article, the combination of deepening unit medical training, AI, and telemedicine described earlier in the article can significantly increase the percentage chance of survival for wounded soldiers. The use of simulations, virtual consilia, and remotely controlled medical technology could make it possible to perform surgical procedures and provide necessary emergency medical care even in inaccessible or isolated battlefield environments.

The proposed system takes into account the requirements of both the civilian and military spheres - it maintains strict security standards while providing the flexibility and integration needed for civilian treatment facilities, facilitating the transition and continuation of care for military patients in the civilian health system, for example in the context of rehabilitation or when civilian medical facilities need to be used for military purposes.

6. Cloud as a possible interoperable platform

Significant developments in the acceptance of cloud-based solutions for the storage and transmission of medical data have already been made by some EU Member States. Here, in the context of the ever-evolving field of war medicine, the rapid and secure collection, processing, and distribution of data plays a key role. The study 'Cloud Intelligence for Decision Support and Analysis' (CLAUDIA), funded by the European Defence Agency (EDA), has revealed major benefits of cloud computing that can be applied to the described virtual military medicine model. Cloud technologies, which include computing capacity, data storage, and software tools hosted externally, offer both strategic and tactical advantages. The SWAN platform, developed by the CLAUDIA project, demonstrates the ability of clouds to support tactical and strategic military decision-making not only for military medicine, but especially for improved situational awareness and reduced response times in a variety of operational environments, through virtualization that enables the creation of virtual versions of servers, storage, and networks [10]. The EDA therefore plays a crucial role in the development of EU Member States' defence capabilities and the field of war medicine supports initiatives such as cloud computing that facilitate cross-border collaboration and the use of shared resources, which is invaluable in situations where it may not be possible to ensure the timely evacuation of the wounded. The use of telemedicine and virtual consilia in this setting is essential, enabling a high level of quality medical care regardless of physical distance from specialized medical facilities [58].

European Health Data Space (EHDS) [21]. also offers opportunities for the creation of a dedicated virtual space for the secure storage of sensitive data of EU Member States' militaries. This space, respecting the principles defined by Regulation

(EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation) and by Directive (EU) 2022/2555 of the European Parliament and of the Council of 14 December 2022 on measures for a high common level of cybersecurity across the Union, amending Regulation (EU) No 910/2014 and Directive (EU) 2018/1972, and repealing Directive (EU) 2016/1148 (NIS 2 Directive), represents an ecosystem specifically designed for the health domain, consisting of rules, common norms and infrastructures. Its primary goal is to empower individuals by giving them better control over their health data while ensuring a high level of data protection and privacy [22]. This structure could be specifically tailored to create an isolated and secure segment for military use, where only authorized individuals with military encryption keys have access, ensuring that operations in sensitive and dangerous environments remain protected.

The importance of EHDS to military health information systems is further enhanced by the integration of technologies that enable the secure exchange, reuse, and analysis of health data not only for healthcare delivery but also for research and innovation [22]. This approach supports the creation of a single market for electronic health records and related technologies, enabling effective cooperation and interoperability between military and civilian health systems of different Member States. The use of EHDS would also enable faster and more informed healthcare decision-making based on specific medical evidence, which is key to improving preparedness and crisis response. In addition, the creation of a dedicated military segment within the EHDS would ensure that even at the highest threat level, soldiers' health data is protected from cyber threats, which is in line with the cybersecurity requirements of the NIS 2 Directive.

7. Legal protection of soldiers' personal data

Apart from the physical and virtual security of the transmitted data and the ongoing processes, the issue of legal regulation of their processing also plays an important role, especially in the protection of soldiers' personal data, which includes sensitive personal data, such as information on the health status of soldiers and their biometric data. In light of current and future military operations conducted by both the EU and NATO, soldiers' personal data and their biometric information have become a key component of information superiority and operational effectiveness [40]. While there are strict rules for data protection in the EU civilian sector, a similarly strict framework is lacking for EU military missions. This represents a legal vacuum, especially about fundamental rights and data protection, which are protected in the EU by both primary and secondary law [33].

Biometric technologies are a usable element of the military health information system and are gradually becoming an essential tool in military intelligence and security, with the key benefit being the ability to strip enemies of the advantage of anonymity, which in turn can be a major weakness in the event of a data leak. This technology has already been implemented in NATO-led operations and, to a lesser extent, in EU missions [31]. Given the significant benefits of this technology in a military environment, efforts to make it more widely used in these missions can be expected. Another important aspect is the fact that, unlike NATO, the EU as an international organization has developed an extensive framework for data protection, including biometrics, which raises expectations regarding legal safeguards for the use of biometric systems in EU military missions, in particular as regards the sharing of biometric data [12]. This is particularly relevant for EU Member States that are also NATO members and may be bound by EU data protection law when participating in NATO operations [50]. This raises a very interesting legal question regarding the potential creation of a single NATO army and the sharing of soldiers' personal data between the different armies.

As regards the protection of personal data in the context of EU military missions, Article 39 of the Treaty on European Union (TEU) is the basis for specific rules on the protection of personal data in the framework of the Common Foreign and Security Policy (CFSP). Although the EU Council has not yet adopted a decision establishing a specific data protection regime for the CFSP, a certain level of protection can be achieved by applying existing EU data protection legislation. This is the GDPR, which is the most significant piece of data protection legislation and Directive (EU) 2016/680 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons about the processing of personal data by competent authorities for the prevention, investigation, detection or prosecution of criminal offenses or the execution of criminal penalties, and on the free movement of such data, and repealing Council Framework Decision 2008/977/JHA, which is lex specialis about the GDPR as regards the protection of natural persons in connection with the processing of personal data for law enforcement purposes. This EU legal framework also applies to the processing and sharing of biometric data in the context of CFSP-led missions. The use of biometric technology in EU military operations and missions is becoming increasingly important given its potential to reveal the identity of enemies and remove their advantage of anonymity. An example is the relatively recent EUNAVFOR MED IRINI operation, aimed at enforcing the UN arms embargo on Libya, which can collect and store personal data, including biometric data, to identify persons involved in the transport of prohibited items [13].

The EU's specific legal framework on data protection, covering health information and biometric data, raises the pressure to adopt high legal safeguards when processing and sharing data in the context of EU military missions. This also has implications for EU Member States that are also NATO members, as they may be bound by EU data protection law when participating in NATO operations [67]. The application of EU health data protection legislation to the sharing of biometric data in the context of EU military missions has an important role to play. The focus is on the impact of EU framework law on the processing and sharing of health data and biometric data, which includes cases where Member States implement EU legislation in their armed forces [14]. This approach will need to be brought into line with NATO requirements in the development of military health information systems and clear rules for sharing personal data between armies will need to be defined. The acceptance of the use of biometrics and the setting of rules for the protection of personal data within the national regulation of Member States shape the approval of their military use abroad. Moreover, how a Member State allows its military to process personal data shapes the processes by which technical interoperability is achieved between other militaries. For example, legal caveats for data retention - if applicable - must be part of the technical interoperability that accompanies exchanged health and biometric data throughout its lifecycle from cradle to grave [17]. Since the US can be considered a pioneer in the military use of biometrics and the specific processing of sensitive personal data, its legal safeguards and generally higher level of societal acceptance of the adoption and use of new technologies is strongly reflected in the current military-technical interoperability standards for the health information systems of the various NATO armies [14].

Another issue discussed is the impact of biometric systems on interoperability between different missions and the need to develop comprehensive data protection rules by Article 39 of the EU Treaty to effectively share personal data collected in the framework of CFSP missions with other elementary security regimes, such as NATO or the UN [50]. Within the EU, Article 39 TEU, in conjunction with Article 16 TEU, is key for the processing of personal data in the context of the Common Security and Defence Policy. Although primary EU law contains strong fundamental commitments to data protection, effective protection in practice depends on the details and implementation of secondary law that specifically addresses the unique circumstances of military missions and operations. Secondary legislation such as the GDPR, while not primarily designed for military missions, can serve as a primary guide and analogy for creating the missing framework [43]. It is therefore necessary for the EU member armies, which are also part of NATO, to use this approach as the basic legal framework for the development of military health information systems designed for the accuracy and processing of health data.

An essential element is the need for clearly defined and transparent processes for the sharing and processing of personal data, with the explicit consent of the persons concerned or based on other legitimate legal grounds. These measures must be underpinned by robust safeguards that protect against misuse and provide access to soldiers' personal data and data. Any transfer of personal data must be underpinned by adequate security standards, including in the case of data transfers between different international organizations or states. The issue of creating and adopting such standards will certainly be a very complicated one, but it is nevertheless necessary.

In light of the lack of a specific legal framework for the cyber protection of shared data in foreign military missions, the creation and adherence to detailed agreements that establish protocols for processing, sharing, and protecting data is essential. Such agreements could serve as a temporary substitute for the lack of legislation, although they are only a temporary solution, as unresolved legal issues can severely limit the effectiveness and interoperability of military operations. Advances in technology and lessons learned also play an important role in this area, where virtual medicine and the use of cloud technologies are pushing the boundaries of what is possible, yet always with an emphasis on security and individual soldier data protection.

8. Conclusions

The war in Ukraine and similar conflicts have exposed key shortcomings and the need to modernize war medicine. Developments show that current methods of healthcare may not be sufficient for a rapid and effective response in high-intensity conflicts. The urgent need for a fundamental transformation in the approach to war medicine lies in adapting to the rapidly changing nature of modern warfare. An essential element of this transformation is the integration of new technologies, such as artificial intelligence and advanced biomedical technologies, which can fundamentally improve diagnosis and treatment on the battlefield. The development of telemedicine services and virtual consilia will enable military doctors to provide fast and effective medical care, even in situations where the physical presence of a doctor is not possible or is only possible with hindsight. Importantly, such technologies enable faster and more secure processing and sharing of medical data, which is critical for real-time decision-making by commanders.

Another critical aspect is the need to develop and implement new educational programs and training modules that focus on the specifics of war medicine. Training of medical personnel must include scenarios that simulate realistic and intense conflict situations so that doctors and nurses are prepared to face the challenging conditions that modern conflicts present, with particular emphasis on first aid.

Last but not least, it is essential to stress the importance of the legal framework, which must be adapted to reflect the new opportunities and challenges associated with the use of modern technologies in war medicine. The protection of personal and particularly sensitive health data appears to be a priority to ensure that soldiers' health information is processed and shared by the highest standards of security and ethics, both within NATO and the EU.

The paper introduces a groundbreaking concept in military health data transfer that has the potential to transform the way armies address current war medicine challenges. The proposed model combines advanced technologies such as biosensors and artificial intelligence with a robust data system that ensures effective communication and coordination between all levels of the military health service. It demonstrates how continuity of care can be maintained in the face of disruption or complete network failure through off-line and semi-off-line capabilities and autonomous artificial intelligence. This integration has the potential to increase the chances of survival and the effectiveness of treatment for soldiers on the battlefield by enabling the immediate collection and analysis of real-time medical data, bringing significant improvements in the speed and accuracy of medical interventions. Our findings and proposals also provide new insights into the possibilities of information sharing within civilian and military medical systems, particularly in the context of the European Health Data Space. This interconnection provides a unique opportunity to significantly improve data transfer practices, enabling a faster and more effective response to the challenges of war. The proposed model can be seen as a basis for the development of systems that are resilient, adaptable, and capable of operating even in the most severe combat conditions. By using the described proposals and model it is possible to improve the care of the wounded not only on the battlefield but also in the process of their further treatment and rehabilitation. All this, together with the modernization of war medicine and its virtualization, contributes to a deeper understanding of the key role of telemedicine and innovative technologies in war conditions and their impact on saving lives, including improving the quality of care provided not only on the battlefield. This is the only way to ensure that military healthcare can respond effectively to the challenges of current and future warfare, increasing the likelihood of survival and minimizing the loss of life of members of the armed forces.

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