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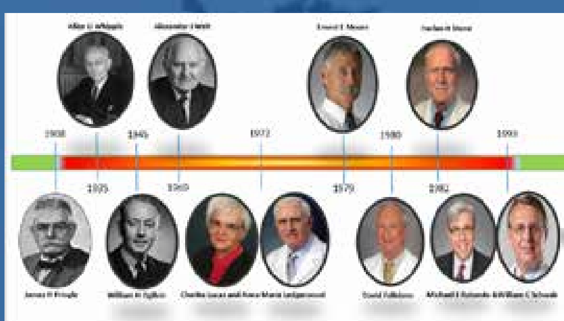
Milestones and Key Figures in the Development of Damage Control Surgery

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Artificial Intelligence in Acute Compartment Syndrome of Lower Limb – A New tool in the War zone

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Abstract
Acute Compartment Syndrome (ACS) of the lower limb is a surgical emergency requiring timely diagnosis and intervention to prevent irreversible tissue damage and limb loss. Current diagnostic methods, reliant on clinical assessment and intra-compartmental pressure monitoring, pose significant challenges due to their subjective nature, potential for delay, and associated risks. Artificial Intelligence (AI) offers transformative potential in addressing these limitations, with the promise of augmenting diagnostic precision, reducing time-to-treatment, and improving outcomes which will be of immense help in war or mass trauma zones.

Keywords
Acute compartment syndrome, Near-infrared spectroscopy, Artificial intelligence, Machine Learning

Acute compartment syndrome (ACS) of the lower limb is a surgical emergency in which there is increased pressure within a closed osteofascial compartment, resulting in impaired local circulation leading to ischemia and eventually necrosis if not treated immediately[1]. ACS is more common in males under 35, and in people who have certain bone fractures, such as a broken tibia due to motorcycle accidents in 69-75% of cases. The average annual incidence of ACS is 0.7 per 100,000 women and 7.3 per 100,000 men[2]. With the increase of morbidity in the young generation due to fasciotomy to relieve ACS, it is now time to bring in artificial intelligence to predict, treat, and manage ACS at the earliest for damage control. Artificial intelligence used in predicting ACS of the lower limb will be an extremely important armamentarium in mass trauma zones like in war/battlefields as triage in the future. While there are some studies and prototypes in this area, comprehensive, peer-reviewed research specifically focusing on the use of AI in ACS management is limited and still emerging as a field. A literature review revealed a scarcity of studies on the use of AI in ACS, highlighting its emerging trend and potential for future research.[3]

Early Detection and Diagnosis

With predictive algorithms, AI can analyze large sets of patient data, including clinical signs, biomarkers, and imaging results, to identify patterns associated with the early stages of ACS. AI-powered wearable sensor devices can monitor tissue pressure, oxygen saturation, or other physiological parameters in real-time, alerting clinicians to potential compartment syndrome before clinical symptoms become severe. AI can aid the treating surgeon by providing decision support tools that recommend the next steps or referrals required based on patient data integration, potentially reducing diagnostic delays that resulted in fatal limb loss in the past[4]. Therefore, an AI model could theoretically balance out immediate transfer vs damage control based on hospital resources and transportation time, and also help in estimating the tourniquet time during transportation to improve the chances of limb salvage[5].

Enhanced Imaging Analysis

AI algorithms, such as those using machine learning, can be trained to analyze MRI, ultrasound, or CT scans to identify subtle changes indicative of increased compartment pressure or compromised blood flow. Automated analysis can expedite the diagnostic process, enabling faster intervention and potentially better outcomes for patients. A neural network model AI study highlighted the critical risk factors for developing deep vein thrombosis, as advanced age, high BMI, and femur fractures, along with elevated direct bilirubin and prothrombin activity. These results suggest that AI can effectively enhance the anticipation of clinical evolution in patients, aiding in early intervention and management strategies[6].

Risk Stratification

AI can help as a predictive model to stratify patients at higher risk for ACS based on preoperative and intraoperative data, guiding more targeted monitoring efforts. By integrating various clinical inputs such as trauma severity, patient demographics, and comorbidities, AI tools can provide comprehensive risk assessment. Algorithms trained to interpret compartment pressure readings and other diagnostic data can reduce false positive rates, ensuring that only patients who truly need surgical intervention receive it. This boosts the clinician's confidence in their decisions and minimizes unnecessary surgeries[7].

Guided Surgical Decision-Making

AI can assist in mapping out the optimal surgical approach if fasciotomy is needed, suggesting incision sites based on potential compartment involvement. Machine learning models can predict potential postoperative complications, helping the surgeon plan more effectively and mitigate risks[8].

Monitoring and Post-Operative Care

Post-operative continuous monitoring with AI-enabled devices can track patient recovery, identifying signs of reperfusion injury or other complications early. AI systems can tailor post-operative care plans based on real-time data analysis, ensuring patient-specific management.

Research and Training

AI can help in clinical research by analyzing large datasets from previous cases to uncover trends and insights that improve the understanding of ACS pathophysiology and treatment. AI-driven simulations can be used for training healthcare providers to recognize and manage ACS, enhancing their diagnostic skills and decision-making capabilities.

Triage in battlefield

In emergency settings, AI tools can help prioritize patients who may be at risk for ACS. This can be particularly useful in trauma centers where timely recognition and response are critical. AI algorithms integrated with electronic health record (EHR) systems can flag high-risk patients based on clinical indicators and historical data, facilitating faster response times and improved patient management. A study found a role of AI in the detection and management of complications associated with lower limb fractures, such as deep vein thrombosis, pulmonary embolism, and acute compartment syndrome which will be of immense help in the future in war zones[4].

Minimally Invasive Monitoring Techniques

AI-assisted analysis of non-invasive monitoring technologies, like near-infrared spectroscopy (NIRS), can assess tissue oxygenation levels. Deep learning models can enhance the interpretation of these readings, offering a non-invasive alternative to direct pressure measurements. Deep learning models can process images to assess tissue perfusion and detect signs of compromised circulation indicative of ACS[9].

Challenges and Considerations

The effectiveness of AI models depends on the quality of the data they are trained on. biased or incomplete data could lead to inaccurate predictions or recommendations. Implementing AI solutions requires seamless integration into existing clinical workflows, as well as training for healthcare providers to interpret and trust AI-generated insights. The use of AI in clinical settings must meet regulatory standards and ethical guidelines to ensure patient safety and privacy.

In a nutshell, AI offers promising avenues to enhance the timely recognition, guide management, and predict treatment outcomes of ACS through advanced data analysis, real-time monitoring, predictive modelling, and improved clinical decision support. AI and deep learning are enhancing the management of acute compartment syndrome of the lower limb by improving early diagnosis, continuous monitoring, clinical decision-making, and personalized treatment.[10] These advances hold the potential to optimize outcomes, reduce treatment delays, and standardize care. However, challenges such as data quality, clinical integration, and ethical concerns must be addressed to fully realize the benefits of these technologies in healthcare. Future integration of AI into portable devices and smartphone-based applications has the potential to democratize access to diagnostic tools, particularly in resource-constrained environments. In conclusion, AI is poised to revolutionize the management of ACS in the lower limb by enabling earlier detection, improving diagnostic accuracy, and facilitating personalized interventions. Continued research and collaboration between clinicians, engineers, and data scientists are essential to unlock the full potential of AI in this critical domain of surgical care.

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- conception and design of the study: KB, UD, NB
- acquisition of data: KB, UD
- analysis and interpretation of data:UD , NB
- drafting the article:KB, UD, NB
- critical revising: KB, UD, NB
- final approval: KB, UD, NB

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