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The Role Of Paramedics In The Early Recognition And Management Of Traumatic Brain Injury

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Abstract

Background:
Traumatic brain injury (TBI) poses a major global health burden with high morbidity and mortality. Early recognition and management by paramedics in the prehospital setting are crucial to minimizing secondary brain injury and improving patient outcomes.
Methods:
A review of peer-reviewed literature evaluating paramedic-led emergency medical service (EMS) interventions for adult TBI was conducted, focusing on assessment methods, management strategies, and training impacts in acute prehospital settings.
Results:
Evidence demonstrates that adherence to prehospital TBI protocols by paramedics, including rapid neurological assessment (Glasgow Coma Scale, pupillary response), advanced airway management, prevention of hypoxia/hypotension, and fluid resuscitation, doubles survival in severe cases. Simulation-based and guideline-driven education programs significantly enhance early recognition and intervention skills. Challenges remain in diagnostic accuracy and resource variability.
Conclusions:
Paramedics are pivotal in early TBI care, with evidence-based prehospital interventions improving patient survival and reducing secondary injury. Continued training, protocol refinement, and adoption of technology-supported tools are essential for optimizing care and outcomes in traumatic brain injury.

Keywords:
Traumatic brain injury, paramedics, early recognition, prehospital care, Glasgow Coma Scale, airway management, secondary brain injury, outcome, education, protocols, EMS.

Introduction

Traumatic brain injury (TBI) represents a significant global health challenge, characterized by an external mechanical force causing brain dysfunction, ranging from mild concussions to severe, life-threatening conditions that demand immediate intervention. Paramedics serve as the frontline responders in prehospital settings, where their rapid assessment and stabilization efforts can critically influence patient trajectories by mitigating secondary insults such as hypoxia and hypotension, which exacerbate primary injury damage. This section delineates the foundational aspects of TBI, underscoring the pivotal role of paramedics within emergency medical services (EMS) frameworks, and outlines the review's objectives to synthesize evidence on their contributions to early recognition and management (Capizzi et al., 2020).

Traumatic brain injury is clinically defined as an alteration in brain function or pathological evidence stemming from an external force, encompassing closed injuries without skull penetration and penetrating wounds that disrupt brain tissue integrity, with severity stratified via the Glasgow Coma Scale (GCS) into mild (GCS 13-15), moderate (GCS 9-12), and severe (GCS ≤8) categories. Epidemiologically, TBI manifests a substantial burden, with population-based studies indicating annual incidences of 180-250 per 100,000 in the United States, potentially higher in Europe and South Africa, disproportionately affecting males, socioeconomically deprived populations, and peak age groups including children, young adults, and the elderly, where falls increasingly supplant road traffic accidents amid aging demographics. Mortality escalates with severity, particularly among the elderly and those with severe injuries, positioning TBI as a leading cause of disability and death, especially in younger cohorts, with nearly one-third of U.S. injury-related fatalities involving TBI diagnoses and global estimates suggesting 5.3 million Americans living with enduring consequences (Karaboue et al., 2024).

Prehospital care profoundly shapes TBI outcomes by targeting the prevention of secondary brain injury through vigilant management of airway, breathing, circulation, and avoidance of hypoxemia, hypotension, and hyperventilation, as half of TBI deaths occur within the first two hours post-injury when EMS personnel constitute the initial healthcare interface. Statewide adoption of evidence-based prehospital TBI guidelines has demonstrated doubled survival in severe cases and tripled rates among intubated severe cohorts, alongside enhanced survival to hospital admission, highlighting the efficacy of standardized protocols emphasizing vital sign optimization during transport to neurotrauma centers. Comparative analyses reveal superior neurological outcomes and reduced mortality with physician-staffed EMS over paramedic-only teams, attributed to advanced airway interventions like rapid sequence intubation that curb hypoxia, a frequent issue in paramedic-managed cases upon emergency department arrival, thus affirming prehospital interventions as a decisive prognostic determinant beyond hospital care (Spaite et al., 2019).

Paramedics anchor EMS operations as autonomous registered professionals bridging healthcare, public health, and safety domains, executing out-of-hospital urgent care amid unpredictable scenarios, including TBI triage, vital stabilization, and transport decisions to appropriate facilities like major trauma centers. Their scope encompasses airway management, fluid resuscitation, oxygenation, and selective intubation in severe TBI per guidelines, alongside scene leadership, physician consultation, and integration with support units such as helicopters for complex cases, evolving beyond traditional models to address chronic conditions and rising demands through health promotion and extended post-handover roles. In TBI contexts, paramedics deploy early warning scores for deterioration risk, facilitate rapid neurosurgical bypass, and adhere to protocols minimizing secondary insults, with roles expanding via training in diagnostics like ultrasound, though challenges persist in intubation proficiency and hypoxia prevention compared to physician-led teams (Suokonautio et al., 2024).

This review aims to meticulously evaluate the evidence base on paramedics' efficacy in early TBI recognition via GCS, pupillary assessments, and mechanistic cues and management strategies like hypotension reversal and hyperoxia avoidance, synthesizing prehospital data to inform protocol enhancements and training imperatives. Scope delimits to peer-reviewed studies on paramedic-led EMS interventions in adult TBI populations, prioritizing severe and moderate cases where prehospital disparities yield outcome variances, while excluding pediatric, military, or chronic TBI foci to concentrate on acute prehospital dynamics. By consolidating epidemiological insights, guideline impacts, and role evolutions, the review seeks to advocate for optimized paramedic protocols, addressing gaps in intubation outcomes, triage accuracy, and physician augmentation to bolster survival and functional recovery (Barrett, 2019).

Pathophysiology of Traumatic Brain Injury

Traumatic brain injury (TBI) represents a complex pathophysiological cascade initiated by mechanical forces that disrupt brain tissue integrity, progressing through primary and secondary injury phases with profound implications for paramedic intervention in the prehospital setting. Primary injury occurs instantaneously upon impact, involving direct mechanical damage such as skull fractures, cerebral contusions, lacerations, and vascular disruptions that lead to immediate neuronal death and hemorrhage, rendering this phase largely irreversible and emphasizing the critical window for paramedics to prevent exacerbation through vigilant monitoring. In contrast, secondary injury unfolds over minutes to days post-trauma, driven by interconnected biochemical processes including excitotoxicity from excessive glutamate release activating NMDA receptors, calcium influx triggering mitochondrial dysfunction, oxidative stress via reactive oxygen species (ROS) production, lipid peroxidation, neuroinflammation with microglial activation and cytokine release (e.g., IL-1β, TNF-α), blood-brain barrier (BBB) breakdown facilitating leukocyte infiltration and edema formation, and metabolic derangements like impaired cerebral blood flow (CBF) leading to ischemia. These mechanisms collectively amplify neuronal apoptosis, axonal degeneration, and demyelination, underscoring paramedics' role in early stabilization to mitigate this evolving damage (Thapa et al., 2021).

TBI manifests in diverse forms, each with distinct anatomical and clinical profiles that paramedics must rapidly identify through history, examination, and basic imaging cues to tailor prehospital management. Concussions, the mildest form, involve transient functional disturbances without macroscopic structural damage, characterized by axonal stretching, metabolic crisis, and neurometabolic uncoupling, often resolving spontaneously but prone to post-concussion syndrome if secondary insults occur. Cerebral contusions represent focal hemorrhagic lesions typically at coup-contrecoup sites (e.g., frontal and temporal lobes), arising from impact forces causing vascular rupture and parenchymal bruising, which can expand due to surrounding edema. Diffuse axonal injury (DAI), a hallmark of severe TBI from rotational acceleration-deceleration, shears white matter tracts in the corpus callosum, brainstem, and hemispheric white matter, leading to widespread disconnection, prolonged coma, and poor prognosis without aggressive airway and hemodynamic control. Hematomas further classify by location epidural (arterial, lens-shaped, often from middle meningeal artery rupture), subdural (venous, crescentic, common in elderly or bridging vein tears), subarachnoid (basal cisterns from aneurysmal or traumatic sources), and intracerebral (deep parenchymal bleeds) each exerting mass effect that paramedics can temporize via positioning and hyperventilation avoidance (MCKEE & DANESHVAR, 2015).

Paramedics play a pivotal role in averting secondary insults, hypoxia, hypotension, and increased intracranial pressure (ICP), which independently worsen outcomes by amplifying ischemic cascades and herniation risks in TBI patients. Hypoxia (PaO_2 <60 mmHg or SpO_2 <90%), prevalent in up to 30% of prehospital cases, triggers anaerobic metabolism, lactic acidosis, and further ROS generation, doubling mortality odds and demanding immediate high-flow oxygen, airway protection via intubation if GCS<9, and ventilation targeting $ETCO_2$ 35-45 mmHg to avoid hyperventilation-induced vasoconstriction. Hypotension (SBP<90 mmHg), even brief episodes, disrupts CBF autoregulation (normally 50-150 mmHg CPP), causing cerebral hypoperfusion and cytotoxic edema, with combined hypoxia/hypotension tripling death risk, thus mandating fluid resuscitation (crystalloids, avoiding hypotonic solutions) and vasopressors if refractory while monitoring for coagulopathy. Elevated ICP (>22 mmHg), from edema, hemorrhage, or hypercapnia, precipitates herniation; paramedics mitigate via head elevation (30°), mannitol (if authorized, 0.25-1 g/kg), mild hyperventilation (only if Cushing's triad), seizure prophylaxis, and rapid transport, as prolonged insults correlate with ICU ICP surges and dismal survival (Butterfield et al., 2023).

Importance of Early Recognition in TBI

Early recognition of traumatic brain injury (TBI) by paramedics is critical in influencing patient outcomes and stabilizing neurological emergencies promptly. Timely identification of TBI allows for rapid initiation of airway, breathing, and circulation support, which minimizes secondary brain injury and improves prognosis. Early intervention can also guide transport decisions to appropriate trauma centers, enabling specialized care that has been linked with better recovery. Delays in recognizing TBI symptoms may result in ineffective rehabilitation and worsening neurological deficits due to ongoing brain swelling, hemorrhage, or increased intracranial pressure, which could otherwise be mitigated by prompt prehospital care (Hawryluk et al., 2023).

Paramedics rely on clinical signs and symptoms to assess TBI in the field. Altered levels of consciousness, pupillary changes such as unequal dilation, and focal neurological deficits like limb weakness or speech disturbances are crucial indicators. Other manifestations relevant to paramedic assessment include confusion, agitation, headache, vomiting, and balance issues. Pupillary abnormalities can signify increased intracranial pressure or herniation. These signs must be rapidly identified to prioritize patients for urgent care and prevent deterioration during transport. However, symptom presentation can be subtle or evolving, challenging prehospital diagnostic accuracy (Hawryluk et al., 2023).

Assessment tools, primarily the Glasgow Coma Scale (GCS) and pupillary examination, are fundamental to prehospital evaluation by paramedics. The GCS assesses eye, verbal, and motor responses to categorize brain injury severity, guiding triage and treatment decisions. A GCS score of 8 or less typically signals severe brain injury warranting advanced airway management and trauma center activation. The pupillary exam detects abnormal dilation or reaction to light, signaling potential intracranial pathology. Despite its central role, GCS scoring can vary between prehospital and hospital settings due to factors like intoxication or sedation. Combining clinical judgment with these tools improves early TBI recognition accuracy (Jain et al., 2025).

Several challenges complicate prehospital diagnosis and assessment of TBI. Symptom overlap with other conditions, fluctuating consciousness levels, and incomplete history from patients impede accurate identification. Paramedics often encounter patients with mild or moderate injury where signs are subtle or delayed, increasing the risk of under-triage. Environmental factors like poor lighting or patient agitation can hinder thorough assessment. Additionally, standardized use of decision aids like the Canadian CT Head Rule has yet to be widely integrated prehospital, which could enhance diagnostic consistency. These challenges underscore the importance of ongoing paramedic training and development of validated prehospital tools to improve TBI detection (Alqurashi et al., 2022).

Role of Paramedics in Initial Assessment

The role of paramedics in the initial assessment of traumatic brain injury (TBI) is critically focused on ensuring scene safety and conducting a rapid yet thorough primary evaluation to identify life-threatening conditions and prevent secondary brain injury. On arrival, paramedics must first assess and secure the scene to ensure their safety and that of the patient, as this forms the basis for safe and effective patient care. Following scene safety confirmation, paramedics perform an initial patient evaluation focusing on mechanism of injury, level of consciousness, and visible injuries, which provide crucial clues about the severity of the head trauma. This initial step is essential because early recognition of TBI signs can guide urgent interventions and transportation decisions to specialized trauma centers equipped to handle such injuries (Alqurashi et al., 2025).

Paramedics prioritize management of airway, breathing, and circulation (ABCs) in suspected TBI cases to prevent hypoxia and hypotension key contributors to secondary brain injury and poor outcomes. Supplemental oxygen is administered immediately to all suspected TBI patients to minimize hypoxic injury. If airway protection is compromised or the patient shows signs of severe TBI (e.g., Glasgow Coma Scale (GCS) score below 9), advanced airway management including endotracheal intubation or supraglottic airway placement may be necessary, ensuring that ventilation is carefully controlled to avoid hyperventilation or hypoventilation as both can exacerbate brain injury. Circulatory support includes fluid resuscitation to maintain adequate blood pressure and cerebral perfusion, with hypotensive patients receiving isotonic fluids or blood products. Additionally, capnography is recommended to ensure appropriate ventilatory parameters, targeting normocapnia to prevent secondary insults from altered intracranial pressure (Hawryluk et al., 2023).

Neurological assessment in the prehospital setting primarily utilizes the Glasgow Coma Scale (GCS) to quantify the level of consciousness by evaluating eye, verbal, and motor responses. This is supplemented by pupillary examination to assess size, symmetry, and reactivity to light, as abnormalities may indicate elevated intracranial pressure or impending herniation. Serial neurological assessments are critical to monitor changes during transport. Some paramedic services employ adjunctive technologies like portable

EEG-based devices (e.g., BrainScope) to aid in detecting structural brain injury, but such advanced tools are not yet widespread. This clinical neurological assessment forms the cornerstone of ongoing management and guides decisions regarding airway protection, rapid transport, and early neurosurgical consultation communication (Hawryluk et al., 2023).

To improve diagnostic accuracy and guide decision-making, paramedics utilize prehospital clinical decision rules or protocols that have been adapted for the field, such as the Canadian CT Head Rule (CCHR). These protocols assist in stratifying patients based on risk factors and injury severity to determine the need for urgent brain imaging and specialized care. Paramedics collect data on mechanism of injury, neurological status, and other clinical features aligned with the protocols, which have demonstrated good interobserver reliability between paramedics and emergency physicians. Use of such protocols supports efficient triage and reduces unnecessary hospital transports while ensuring patients at risk for significant brain injury are rapidly escalated to trauma centers (Alqurashi et al., 2024).

Prehospital Management Strategies

Prehospital management of TBI by paramedics is critical to minimizing secondary brain injury and optimizing patient outcomes. Effective airway management and oxygen therapy form the cornerstone of prehospital care in TBI. All patients with suspected severe TBI should receive continuous oxygen supplementation via nasal cannula or face mask to prevent hypoxia, a major contributor to secondary brain injury. Hypoxemia must be promptly identified and corrected through airway repositioning, positive pressure ventilation using a bag-valve mask with appropriate adjuncts, or advanced airway techniques such as supraglottic airway or endotracheal intubation by trained personnel. The use of capnography to confirm proper endotracheal tube placement and maintain normal ventilation rates (around 10 breaths per minute with an ETCO2 of 35-45 mmHg) is strongly recommended to avoid both hypoventilation and hyperventilation, which may worsen cerebral ischemia or ICP (Lauriks et al., 2025).

Paramedics use ventilatory support devices tailored to the patient's respiratory status. Indications for intubation generally include a Glasgow Coma Scale (GCS) score less than or equal to 8, failure to maintain airway patency, or persistent hypoxia despite oxygen therapy. Positive pressure ventilation is employed cautiously, targeting normocapnia, as hyperventilation can lower CO2 levels excessively, causing cerebral vasoconstriction and potentially exacerbating brain injury. Ventilatory adjuncts such as pressure-controlled ventilation, ventilation-rate timers, and continuous capnography monitoring are essential tools to optimize the mechanical ventilation of TBI patients in the prehospital setting (Rubenson Wahlin et al., 2018).

Circulatory support and prevention of hypotension are imperative components of prehospital TBI management, as hypotension significantly increases mortality risk. Isotonic intravenous fluids are administered to treat or prevent hypotension, aiming to maintain adequate cerebral perfusion pressure. Blood products may be used as indicated where available. Guidelines emphasize minimizing the duration of hypotension en route to definitive care. Hypertonic fluid resuscitation is selectively used in patients with suspected elevated ICP but remains a weak recommendation due to limited evidence. Avoiding excessive fluid administration is critical to prevent exacerbating cerebral edema (Bergmans et al., 2020).

Spinal immobilization and head stabilization procedures are standard prehospital interventions to prevent secondary spinal cord injury in patients with suspected blunt trauma and TBI. The use of cervical collars and spinal boards is common, supported by decision tools such as the Immo Traffic Light System to guide immobilization decisions. Manual in-line cervical stabilization during airway management and transport is also emphasized to reduce spinal movement. Although evidence supporting widespread spinal immobilization is limited, it remains a precautionary practice to protect spinal integrity while transporting patients (Häske et al., 2022).

Monitoring for increased intracranial pressure (ICP) in the prehospital setting remains challenging, but paramedics critically observe neurological signs indicative of elevated ICP, including deteriorating GCS, pupillary changes, and abnormal vital signs such as the Cushing triad (hypertension, bradycardia, irregular respiration). Invasive ICP monitoring is reserved for in-hospital care, but paramedics use clinical assessment to initiate early interventions such as head elevation and avoidance of hypotension or hypoxia. Emerging guidelines discourage prophylactic hyperventilation unless signs of cerebral herniation are present, targeting capnographic ETCO2 values of 30-35 mmHg if hyperventilation is warranted to reduce ICP (Zhang et al., 2024).

Seizure recognition and management are important in TBI patients, as seizures increase metabolic demand and intracranial pressure, risking further brain injury. Paramedics are trained to identify seizure activity and provide prompt treatment typically using benzodiazepines such as midazolam, in accordance with local protocols. Seizure prophylaxis may be implemented in prehospital care settings, reflecting the increased risks of post-traumatic seizures and their impact on outcomes in TBI patients (Hustad et al., 2024).

Paramedic Training and Education

Paramedic training and education form the cornerstone of effective prehospital care for traumatic brain injury (TBI), equipping practitioners with the skills to recognize subtle neurological deficits, stabilize patients amid chaotic scenes, and initiate interventions that mitigate secondary brain insults such as hypoxia, hypotension, and hyperventilation, which are critical in the golden hour following injury. Core curricula in paramedic programs increasingly integrate TBI-specific modules, emphasizing rapid Glasgow Coma Scale (GCS) assessments, pupillary examinations, and the identification of Cushing's triad, alongside foundational airway management techniques tailored to prevent intracranial pressure elevations. These programs often draw from evidence-based guidelines like those from the Brain Trauma Foundation, which underscore the need for paramedics to master scene safety, rapid extrication, and spinal immobilization to avoid exacerbating axonal shearing or contusions in TBI patients presenting with GCS scores below 9 (Lulla et al., 2023).

Specialized TBI training programs for paramedics have proliferated globally, featuring targeted modules on pathophysiology including primary versus secondary injury mechanisms, diffuse axonal injury patterns, and the biomechanics of coup-contrecoup lesions, delivered through blended learning formats that combine didactic sessions with hands-on skill stations. Initiatives such as the Excellence in Prehospital Injury Care (EPIC) study in Arizona exemplify this approach, where train-the-trainer models disseminated guidelines focusing on oxygenation targets (SpO2 >90%), normoventilation (ETCO2 35-45 mmHg), and mean arterial pressure maintenance above 80 mmHg, resulting in widespread adoption across over 130 EMS agencies. Programs like those from the Australasian College of Paramedicine and various U.S. state protocols incorporate case-based learning on pharmacological adjuncts such as hypertonic saline for suspected herniation, while addressing logistical challenges in rural versus urban settings, ensuring paramedics can differentiate mild from severe TBI using tools like the Shock Index Pediatric Adjusted for younger patients. Ongoing refinements include integration of point-of-care ultrasound for optic nerve sheath diameter measurements to gauge intracranial pressure non-invasively, with programs mandating recertification every two years to align with evolving neuroimaging and biomarker research (National Academies of Sciences et al., 2022).

Simulation-based training revolutionizes paramedic preparedness for neurological emergencies by replicating high-fidelity scenarios such as motor vehicle collisions yielding epidural hematomas or falls inducing subdural hemorrhages, allowing teams to practice coordinated responses including rapid sequence intubation (RSI) with neuromuscular blockade when GCS drops critically. Continuing education platforms, including those from Med Mastery and Action Training, offer credits for modules on stroke mimics versus true TBI, status epilepticus management post-trauma, and the nuances of tranexamic acid administration to curb hemorrhagic progression, often accessible via Zoom or recorded sessions for shift workers. High-end centers like the Neurotrauma Treatment Simulation Center in Vienna employ multidisciplinary simulations involving physicians, paramedics, and pilots to hone communication under duress, emphasizing debriefings that dissect errors in ventilation strategies leading to hypocarbia-induced vasoconstriction. These efforts extend to gamified apps and virtual reality for rarely encountered cases like pediatric TBI with non-accidental trauma indicators, fostering muscle memory for interventions like mannitol boluses while promoting psychological safety in error-prone environments; studies confirm such training boosts self-reported confidence by over 30% in handling comatose patients with lateralizing signs (Constantinescu et al., 2022).

The impact of targeted paramedic training manifests in measurable improvements in early recognition and management outcomes for TBI, with studies like EPIC demonstrating up to 20% enhanced survival to hospital discharge in severe cases (GCS 3-8) post-guideline implementation, attributed to reduced adverse events like prehospital hypoxia (odds ratio for mortality increase 2.5-fold if uncorrected). Comparative analyses of paramedic-staffed versus physician-staffed EMS reveal lower one-year mortality (40% versus 60%) and better modified Glasgow Outcome Scores in the latter, highlighting training gaps in advanced airway skills where paramedic RSI success rates hover at 85% but complication rates exceed 15% without simulation reinforcement. Pediatric sub-analyses from EPIC4Kids affirm severity-specific benefits, with adjusted odds of survival rising significantly for GCS 3-5 cohorts through vigilant hypotension correction via isotonic fluids or blood products, while population-level data from Arizona's statewide rollout link guideline adherence to decreased secondary insults, projecting thousands of lives saved annually. Longitudinally, agencies with robust continuing education report 25% faster triage to Level 1 trauma centers, correlating with reduced intensive care unit lengths of stay and favorable six-month functional independence measures, though challenges persist in resource-poor areas where adherence lags due to equipment shortages (Gaither et al., 2024).

Use of Prehospital Diagnostic Tools

Paramedics rely on fundamental monitoring devices such as pulse oximetry, capnography, and blood pressure measurement to assess and stabilize patients with suspected traumatic brain injury (TBI) in the prehospital environment, where these tools enable rapid detection of secondary insults like hypoxia, hypocapnia, and hypotension that exacerbate brain damage. Pulse oximetry provides continuous measurement of peripheral oxygen saturation (SpO2), with guidelines strongly recommending its use to maintain SpO2 above 90% through supplemental oxygen administration, as even brief hypoxemia episodes significantly worsen outcomes by inducing cerebral vasodilation and increasing intracranial pressure. Capnography monitors end-tidal CO2 (ETCO2) to prevent hyperventilation, targeting 35-45 mm Hg to avoid cerebral vasoconstriction, while blood pressure monitoring, preferably continuous or every 5-10 minutes, aims for systolic blood pressure (SBP) above 110 mm Hg in adults, using appropriately sized cuffs to prevent under- or overestimation that could lead to hypoperfusion or unchecked hypertension signaling herniation. These tools integrate into protocols like those from the Brain Trauma Foundation's 3rd edition prehospital guidelines, which emphasize their role in dynamic, data-driven management during transport, correlating sustained vital sign optimization with doubled survival odds in intubated patients (Hawryluk et al., 2023).

Emerging technologies expand paramedic diagnostic capabilities beyond traditional vitals, with portable ultrasound (POCUS) gaining traction for rapid TBI assessment, including optic nerve sheath diameter measurement to infer intracranial pressure or extended FAST exams to rule out associated thoracic/abdominal injuries contributing to instability. Handheld POCUS devices, increasingly feasible in prehospital settings, allow paramedics to detect life-threatening pathologies like pneumothorax or hemothorax with high positive predictive value (up to 100%), guiding triage to trauma centers and reducing time-to-intervention, as demonstrated in flight crew studies and tele-ultrasound pilots where remote expert guidance enhances novice accuracy. Blood biomarkers such as glial fibrillary acidic protein (GFAP) and ubiquitin C-terminal hydrolase-L1 (UCH-L1) represent promising point-of-care tests, with GFAP showing over 98% sensitivity for CT lesions or neurosurgical needs at 30 pg/mL cutoffs, potentially enabling field triage bypassing non-specialized emergency departments; rapid assays (15-20 minutes) from whole blood are FDA-cleared for mild TBI and under investigation for prehospital use to prioritize evacuation. Nearinfrared spectroscopy (NIRS) for cerebral oximetry offers real-time brain tissue oxygenation data, complementing peripheral pulse oximetry, though prospective validation remains limited (Dewar et al., 2022).

Field diagnostics face significant limitations and challenges that hinder paramedic accuracy in TBI recognition, including low sensitivity (19.8-87.9%) and specificity (41.4-94.4%) of existing triage tools like HITS-NS or Field Triage Decision Scheme, which often under-triage elderly patients or those on anticoagulants due to subtle presentations and poor prehospital GCS reliability confounded by sedatives, seizures, or intubation. Environmental factors motion artifacts during transport, limited training for advanced tools like POCUS or biomarkers, equipment portability issues, and resource constraints in rural areas compound inaccuracies, as non-invasive blood pressure can deviate substantially from invasive measures in hypotensive/hypertensive states, risking misguided resuscitation. Biomarker kinetics require ultra-early sampling (<2 hours), rarely feasible prehospital, while ultrasound demands brief training interventions that may not sustain long-term proficiency; overall, these gaps underscore needs for integrated prediction models incorporating paramedic judgment, machine learning from EMS data, and validated cutoffs to minimize overtriage (high false positives) and false negatives delaying neurosurgical care(Alqurashi et al., 2024).

Impact on Patient Outcomes

Paramedic-led prehospital interventions for traumatic brain injury (TBI) patients demonstrate a significant association with improved survival rates and neurological outcomes, particularly when adhering to evidence-based guidelines that emphasize airway management, oxygenation, and hemodynamic stability. Studies from large-scale implementations, such as the Excellence in Prehospital Injury Care (EPIC) project, reveal that statewide adoption of TBI protocols doubled adjusted survival among severe TBI cases and tripled it in intubated patients, with overall survival to hospital admission markedly enhanced despite no broad change across moderate-to-critical injury spectrums. Prehospital plasma administration further bolsters these outcomes, showing hazard ratios as low as 0.45 for 30-day survival in scene-transported TBI patients, especially those with Glasgow Coma Scale (GCS) scores below 8 or polytrauma, by mitigating hemorrhagic shock risks and secondary insults. Evidence also highlights rapid sequence intubation (RSI) by trained paramedics yielding favorable six-month neurological outcomes in severe adult TBI (risk ratio 1.28) and pediatric cases, where 66% achieved good functional recovery compared to 17% without intubation, underscoring the value of skilled airway control in resource-limited settings. Conversely, some observational data notes higher mortality in paramedic-staffed systems versus physician-led ones (57% vs. 42% at one year), attributing poorer results to less frequent advanced airway interventions (16% vs. 98%), yet protocol refinements continue to narrow this gap (Gruen et al., 2020).

Minimizing secondary brain injury remains paramount in paramedic care, as timely interventions prevent hypoxia, hypotension, and hypocarbia each independently linked to adverse outcomes like emergency department mortality and unfavorable discharge dispositions. Paramedics achieve this by prioritizing normoventilation, secured airways, and blood pressure maintenance, with guideline compliance associating to 1.7-fold higher odds of hospital admission survival and threefold in intubated cohorts, directly countering metabolic cascades that exacerbate ischemia. Postintubation hypotension in severe TBI cohorts markedly worsens 30-day mortality, reinforcing the need for vigilant monitoring during RSI to avoid desaturation or hemodynamic drops, while prehospital plasma uniquely preserves fibrinolysis shutdown and reduces organ failure risks in coagulopathic patients. These strategies align with broader evidence showing helicopter EMS transport improving survival odds (OR 1.88) over ground services through faster specialist input, though scene times under 10-15 minutes are critical to limit on-scene delays that amplify secondary insults (Price et al., 2025).

Time benchmarks, including the "golden hour" concept spanning from injury to definitive neurosurgical care within 60 minutes guide paramedic transport and intervention protocols to optimize cerebral perfusion and avert irreversible damage. Median prehospital times average 60-80 minutes across cohorts, with EMS arrival at 20 minutes, on-scene stabilization at 35 minutes, and travel at 20 minutes, yet exceeding these correlates with no mortality benefit beyond two hours in some physician-staffed systems, prioritizing "scoop and run" for isolated TBI under stable vitals. Paramedics target scene times below 10-14 minutes per guidelines, as prolonged exposure heightens secondary injury risks, while the "platinum 10 minutes" emphasizes immediate airway, circulation, and spinal immobilization to sustain perfusion during the hyperacute phase. Adherence to these windows, including rapid triage for level-1 centers, underpins EPIC findings of enhanced admission survival, with helicopter services shortening total prehospital time despite selection biases (El-Swaify et al., 2022).

Research findings and case cohorts vividly illustrate improved outcomes from paramedic interventions, such as EPIC's pre-post analysis of over 21,000 patients confirming doubled severe TBI survival post-guideline rollout, particularly via intubation and hypotension avoidance. In plasma trials, scene-administered units yielded 44-50% mortality reductions in severe TBI subsets, with biomarkers indicating attenuated inflammatory responses, while RSI trials reported 28% better six-month neurology versus basic airways. Pediatric RSI by intensive care paramedics showed near-significant outcome superiority ($p=0.06$), and plasma's survival edge persisted in polytrauma (HR 0.50), exemplifying scalable prehospital impacts despite challenges like intubation risks increasing scene time or desaturation in undertrained crews. These cases collectively affirm paramedics' pivotal role when protocols are rigorously applied(Gaither et al., 2024).

Challenges and Barriers

Challenges and barriers in the early recognition and management of traumatic brain injury (TBI) by paramedics are multifaceted, particularly due to difficulties in communication and assessment in diverse and often uncontrolled environments. Paramedics frequently encounter TBI patients in settings that challenge effective clinical assessment, such as accident scenes with noise, poor lighting, and environmental hazards. These factors can impede accurate neurological evaluation and limit the use of standardized cognitive assessment tools crucial for detecting subtle signs of brain injury. Additionally, patients may be unconscious, intoxicated, or non-cooperative, further complicating assessment efforts. This inherent difficulty in the prehospital environment often results in challenges to differentiating the severity of injury, which is essential for triage and management decisions(Alqurashi et al., 2025).

Equipment limitations and resource constraints are a notable barrier for paramedics managing TBI in the prehospital setting. Essential tools for monitoring and treating brain injury – such as advanced airway management devices, capnography for ventilation monitoring, portable imaging, and hyperosmolar therapy agents like mannitol or hypertonic saline – may not be readily accessible or are limited to advanced transport teams. Furthermore, many EMS systems face shortages in personnel, particularly those trained extensively in neurological assessment and airway management for TBI patients. These constraints directly affect the ability to implement guideline-driven care protocols, such as maintaining normoxia and preventing hypotension, which are critical to reducing secondary brain injury. This scarcity of resources poses significant challenges in delivering optimal care in both urban and rural EMS systems (Ramesh et al., 2014).

Variability in EMS protocols regionally and internationally further complicates the early recognition and management of TBI by paramedics. Different EMS systems adopt varying triage criteria, protocols for airway management, oxygen supplementation, fluid resuscitation, intracranial pressure management, and transport decisions based on local resources and training. This geographic and organizational diversity impacts patient outcomes, as inconsistent application of evidence-based guidelines leads to disparities in care quality. For example, some regions may employ hypertonic saline in the field for suspected elevated intracranial pressure, while others restrict its use or lack the means to administer it. Such protocol heterogeneity complicates training, quality improvement, and research efforts by limiting comparability across EMS systems (Chuck et al., 2021).

Emotional and cognitive stressors on paramedics managing TBI cases represent an important but often overlooked challenge. Handling the acute and potentially fatal nature of TBI demands significant cognitive workload, rapid decision-making under pressure, and exposure to traumatic scenes, which can lead to stress, burnout, and impaired clinical performance. Paramedics face the emotional burden of managing critically ill or dying patients, often with limited feedback on long-term patient outcomes, which may affect confidence and decision-making efficacy. The complexity of TBI care, combined with these psychological stressors, can result in diagnostic uncertainty and moral distress, influencing the quality of care provided (Proctor et al., 2025).

Potential for under-triage and over-triage poses a critical barrier in prehospital TBI management. Under-triage refers to failing to identify and appropriately transport severely injured TBI patients to trauma centers equipped for specialized care, risking worsened outcomes from delayed intervention. Conversely, over-triage transporting less severely injured patients to high-level trauma centers can overwhelm system resources and increase costs without improving patient outcomes. The challenge lies in the imperfect sensitivity and specificity of current triage tools and the variable experience of paramedics in TBI assessment, exacerbated by atypical presentations, especially in elderly patients or those with comorbidities. These triage errors can significantly impact patient morbidity and mortality, emphasizing the need for standardized, validated triage protocols and ongoing paramedic training (Harthi et al., 2025).

Future Directions and Innovations

Future directions in paramedic management of traumatic brain injury (TBI) emphasize technological integration to enhance prehospital decision-making and care delivery, particularly through telemedicine advancements that enable real-time specialist consultation during transport or at the scene. Telemedicine systems have demonstrated feasibility in supporting paramedics with remote guidance for acute injuries, including ultrasound assessments and triage decisions for TBI patients, reducing unnecessary transfers and improving outcomes by confirming critical findings like hemoperitoneum or pneumothorax without on-site specialists. Recent implementations show telemedicine consultations between neurosurgeons and emergency departments preventing low-severity TBI transfers from ground-level falls, streamlining care for geriatric patients and allowing community management where appropriate, while also expediting surgical pathways for severe cases directly from ambulances. Ongoing developments include mobile data transmission for secure prehospital teleconsultations, potentially expanding to battlefield or rural settings where paramedics face diagnostic delays in mild TBI, with studies indicating telehealth-supported pathways within EMS protocols as feasible for time-sensitive triage (Suarilah et al., 2024).

Improved clinical decision support (CDS) tools represent a pivotal innovation, evolving from hospital-based models like PECARN and HIDATq to paramedic-accessible dashboards that integrate real-time vital signs, biomarkers, and imaging data for TBI triage and management. Tools such as ZOLL's TBI Dashboard consolidate intracranial pressure, cerebral perfusion, and hemodynamic data to prevent secondary brain injuries, while AI-enhanced systems predict damage progression and guide interventions without excessive radiation from follow-up CTs. Prehospital lactate measurements and portable head CTs offer promise for refining triage, with SVM models achieving high accuracy (AUC 0.93) in identifying neurosurgically significant injuries, addressing gaps in current protocols for older adults or multisystem trauma. Pilot studies validate CDS interventions reducing time to imaging in elderly TBI patients, and ongoing trials like HOME evaluate Canadian CT Head Rule adaptations for paramedics to safely discharge low-risk cases at scene (Martin-Rodriguez et al., 2024).

Enhanced training modalities leveraging virtual reality (VR) and artificial intelligence (AI) are transforming paramedic preparedness for TBI scenarios, providing immersive simulations of high-stakes environments like mass casualty incidents or complex trauma assessments. VR platforms at institutions like Ohio State University enable repetitive practice of triage, anatomical exploration, and interventions such as eFAST ultrasound or airway management, fostering muscle memory and confidence without real-world risks. AI-driven programs tailor training efficiency, with ParaVR simulators maintaining skills in ambulance-based procedures and TACTICS VR optimizing stroke-like TBI workflows through team-based interactions and prehospital notifications. Studies confirm VR boosts ATLS adherence, with significant post-training confidence gains ($p<0.001$) and high usability scores (SUS 79.4), outperforming traditional methods in BLS components critical for TBI stabilization (Hood et al., 2021).

Integration of digital mental health support addresses paramedics' unique trauma exposure from frequent TBI calls, offering anonymous, shift-compatible apps co-designed for frontline realities to mitigate burnout and PTSD. Paramedics prioritize tools that are cognitively low-burden, peer-connected, and integrated with existing services, emphasizing confidentiality, lived-experience language, and seamless escalation to professionals for sustained engagement. VR feedback mechanisms and human-supported digital interventions enhance efficacy, with themes like "safe anonymity" and "peer validation" emerging as key to reducing isolation post-TBI missions. Preliminary designs highlight rapid accessibility via smartphones, complementing traditional care without replacement, particularly vital given rising geriatric TBI volumes straining EMS mental resilience (Cogan et al., 2025).

Research gaps persist in prehospital TBI care, including optimal hypertonic saline/mannitol use, ICP monitoring timing, hypotension definitions for pediatrics/geriatrics, and transfusion thresholds stratified by severity and sex. Expanded studies are needed on blood biomarkers, mobile CTs for direct-to-surgery triage, and handoff processes from EMS to EDs, alongside effects of multisystem trauma on cerebral perfusion targets. Paramedic intubation outcomes, helicopter EMS benefits, and novel diagnostics like field hemorrhage/brain injury point-of-care tests require randomized trials to resolve controversies in permissive hypotension with concomitant TBI. Future investigations should prioritize AI/VR validation in diverse populations, telemedicine scalability in rural areas, and CDS for low-risk discharge, ensuring evidence-based evolution of paramedic roles(El-Swaify et al., 2022).

Conclusion

Paramedics play a crucial role in the early recognition and management of traumatic brain injury (TBI) by providing rapid neurological assessment, airway management, and prevention of secondary brain injury such as hypoxia and hypotension in the prehospital setting. Evidence shows that adherence to evidence-based prehospital protocols significantly improves survival rates and neurological outcomes for TBI patients. Continued education, protocol refinement, and the incorporation of advanced technology and decision-support tools are essential to further optimize paramedic care and patient outcomes in TBI. The evolving scope and training of paramedics enable timely, effective interventions that mitigate secondary brain injury and improve functional recovery after TBI. This underscores the pivotal position of paramedics in impacting TBI patient trajectories from the earliest moments post-injury.

References

1. Alqurashi, N., Alotaibi, A., Bell, S., Lecky, F., & Body, R. (2022). The diagnostic accuracy of prehospital triage tools in identifying patients with traumatic brain injury: A systematic review. Injury, 53(6), 2060–2068. https://doi.org/10.1016/j.injury.2022.02.020
2. Alqurashi, N., Bell, S., Alzahrani, A., Lecky, F., Wibberley, C., & Body, R. (2025). Current challenges and future opportunities in on-scene prehospital triage of traumatic brain injury patients: A qualitative study in the UK. Injury, 56(5), 112203. https://doi.org/10.1016/j.injury.2025.112203
3. Alqurashi, N., Bell, S., Carley, S. D., Lecky, F., & Body, R. (2024). Head Injury Evaluation and Ambulance Diagnosis (HOME) Study protocol: A feasibility study assessing the implementation of the Canadian CT Head Rule in the prehospital setting. BMJ Open, 14(6), e077191. https://doi.org/10.1136/bmjopen-2023-077191
4. Barrett, J. W. (2019). A retrospective review of patients with significant traumatic brain injury transported by emergency medical services within the south east of England. British Paramedic Journal, 3(4), 1–7. https://doi.org/10.29045/14784726.2019.03.3.4.1

5. Bergmans, S. F., Schober, P., Schwarte, L. A., Loer, S. A., & Bossers, S. M. (2020). Prehospital fluid administration in patients with severe traumatic brain injury: A systematic review and meta-analysis. Injury, 51(11), 2356–2367. https://doi.org/10.1016/j.injury.2020.08.030
6. Butterfield, M., Bodnar, D., Williamson, F., Parker, L., & Ryan, G. (2023). Prevalence of secondary insults and outcomes of patients with traumatic brain injury intubated in the prehospital setting: A retrospective cohort study. Emergency Medicine Journal : EMJ, 40(3), 167–174. https://doi.org/10.1136/emermed-2022-212513
7. Capizzi, A., Woo, J., & Verduzco-Gutierrez, M. (2020). Traumatic Brain Injury: An Overview of Epidemiology, Pathophysiology, and Medical Management. The Medical Clinics of North America, 104(2), 213–238. https://doi.org/10.1016/j.mcna.2019.11.001
8. Chuck, C. C., Martin, T. J., Kalagara, R., Shaaya, E., Kheirbek, T., & Cielo, D. (2021). Emergency medical services protocols for traumatic brain injury in the United States: A call for standardization. Injury, 52(5), 1145–1150. https://doi.org/10.1016/j.injury.2021.01.008
9. Cogan, N., Whittaker, S., Craig, A., Milligan, L., McCluskey, R., Burns, T., Kirk, A., Rasmussen, S., & Hodgson, W. (2025). Designing Digital Mental Health Support for Paramedics Exposed to Trauma: Qualitative Study of Lived Experiences and Design Preferences. JMIR Human Factors, 12, e76158. https://doi.org/10.2196/76158
10. Constantinescu, A. D., Dobran, S.-A., & Chira, D. (2022). Neurotrauma Treatment Simulation Center (NTSC) Vienna – Event Report. Journal of Medicine and Life, 15(7), 894–901. https://doi.org/10.25122/jml-2022-1015
11. Dewar, Z. E., Ko, S., Rogers, C., Oropallo, A., Augustine, A., Pamula, A., & Berry, C. L. (2022). Prehospital portable ultrasound for safe and accurate prehospital needle thoracostomy: A pilot educational study. The Ultrasound Journal, 14, 23. https://doi.org/10.1186/s13089-022-00270-w
12. El-Swaify, S. T., Refaat, M. A., Ali, S. H., Abdelrazek, A. E. M., Beshay, P. W., Kamel, M., Bahaa, B., Amir, A., & Basha, A. K. (2022). Controversies and evidence gaps in the early management of severe traumatic brain injury: Back to the ABCs. Trauma Surgery & Acute Care Open, 7(1). https://doi.org/10.1136/tsaco-2021-000859
13. Gaither, J. B., Spaite, D. W., Bobrow, B. J., Barnhart, B., Chikani, V., Denninghoff, K. R., Bradley, G. H., Rice, A. D., Howard, J. T., Keim, S. M., & Hu, C. (2024). EMS Treatment Guidelines in Major Traumatic Brain Injury With Positive Pressure Ventilation. JAMA Surgery, 159(4), 363–372. https://doi.org/10.1001/jamasurg.2023.7155
14. Gruen, D. S., Guyette, F. X., Brown, J. B., Okonkwo, D. O., Puccio, A. M., Campwala, I. K., Tessmer, M. T., Daley, B. J., Miller, R. S., Harbrecht, B. G., Claridge, J. A., Phelan, H. A., Neal, M. D., Zuckerbraun, B. S., Yazer, M. H., Billiar, T. R., & Sperry, J. L. (2020). Association of Prehospital Plasma With Survival in Patients With Traumatic Brain Injury: A Secondary Analysis of the PAMPer Cluster Randomized Clinical Trial. JAMA Network Open, 3(10), e2016869. https://doi.org/10.1001/jamanetworkopen.2020.16869
15. Harthi, N., Goodacre, S., & Sampson, F. C. (2025). Optimising prehospital trauma triage for older adults: Challenges, limitations, and future directions. Frontiers in Medicine, 12. https://doi.org/10.3389/fmed.2025.1569891
16. Häske, D., Blumenstock, G., Hossfeld, B., Wölfl, C., Schweigkofler, U., & Stock, J.-P. (2022). The Immo Traffic Light System as a Decision-Making Tool for Prehospital Spinal Immobilization. Deutsches Ärzteblatt International, 119(44), 753–758. https://doi.org/10.3238/arztebl.m2022.0291
17. Hawryluk, G. W. J., Lulla, A., Bell, R., Jagoda, A., Mangat, H. S., Bobrow, B. J., & Ghajar, J. (2023). Guidelines for Prehospital Management of Traumatic Brain Injury 3rd Edition: Executive Summary. Neurosurgery, 93(6), e159–e169. https://doi.org/10.1227/neu.0000000000002672
18. Hood, R. J., Maltby, S., Keynes, A., Kluge, M. G., Nalivaiko, E., Ryan, A., Cox, M., Parsons, M. W., Paul, C. L., Garcia-Esperon, C., Spratt, N. J., Levi, C. R., & Walker, F. R. (2021). Development and Pilot Implementation of TACTICS VR: A Virtual Reality-Based Stroke Management Workflow Training Application and Training Framework. Frontiers in Neurology, 12, 665808. https://doi.org/10.3389/fneur.2021.665808

19. Hustad, I. A., Horn, M., Rehn, M., Taubøll, E., & Hov, M. R. (2024). Prehospital seizure management protocols need standardized guidelines. A descriptive study from Norway. Seizure: European Journal of Epilepsy, 123, 92–96. https://doi.org/10.1016/j.seizure.2024.10.002
20. Jain, S., Margetis, K., & Iverson, L. M. (2025). Glasgow Coma Scale. In StatPearls [Internet]. StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK513298/
21. Karaboue, M. A. A., Ministeri, F., Sessa, F., Nannola, C., Chisari, M. G., Cocimano, G., Di Mauro, L., Salerno, M., & Esposito, M. (2024). Traumatic Brain Injury as a Public Health Issue: Epidemiology, Prognostic Factors and Useful Data from Forensic Practice. Healthcare (Basel, Switzerland), 12(22), 2266. https://doi.org/10.3390/healthcare12222266
22. Lauriks, A., Missiaen, M., & Sabbe, M. (2025). Prehospital intubation in patients with severe traumatic brain injury: A review. European Journal of Emergency Medicine: Official Journal of the European Society for Emergency Medicine, 32(4), 236–247. https://doi.org/10.1097/MEJ.0000000000001240
23. Lulla, A., Lumba-Brown, A., Totten, A. M., Maher, P. J., Badjatia, N., Bell, R., Donayri, C. T. J., Fallat, M. E., Hawryluk, G. W. J., Goldberg, S. A., Hennes, H. M. A., Ignell, S. P., Ghajar, J., Krzyzaniak, B. P., Lerner, E. B., Nishijima, D., Schleien, C., Shackelford, S., Swartz, E., … Bobrow, B. J. (2023). Prehospital Guidelines for the Management of Traumatic Brain Injury—3rd Edition. Prehospital Emergency Care, 27(5), 507–538. https://doi.org/10.1080/10903127.2023.2187905
24. Martin-Rodriguez, F., Sanz-Garcia, A., Lopez-Izquierdo, R., Delgado Benito, J. F., Martínez Fernández, F. T., Otero de la Torre, S., & Del Pozo Vegas, C. (2024). Prehospital Lactate Levels Obtained in the Ambulance and Prediction of 2-Day In-Hospital Mortality in Patients With Traumatic Brain Injury. Neurology, 103(4), e209692. https://doi.org/10.1212/WNL.0000000000209692
25. MCKEE, A. C., & DANESHVAR, D. H. (2015). The neuropathology of traumatic brain injury. Handbook of Clinical Neurology, 127, 45–66. https://doi.org/10.1016/B978-0-444-52892-6.00004-0
26. National Academies of Sciences, E., Division, H. and M., Services, B. on H. C., Policy, B. on H. S., Care, C. on A. P. in T. B. I. R. and, Matney, C., Bowman, K., & Berwick, D. (2022). Acute Care After Traumatic Brain Injury. In Traumatic Brain Injury: A Roadmap for Accelerating Progress. National Academies Press (US). https://www.ncbi.nlm.nih.gov/books/NBK580074/
27. Price, J., Lachowycz, K., Major, R., McLachlan, S., Keeliher, C., Finbow, B., Moncur, L., Sagi, L., Targett, M., Steel, A., Sherren, P. B., & Barnard, E. B. G. (2025). Prehospital Postintubation Hypotension and Survival in Severe Traumatic Brain Injury. JAMA Network Open, 8(11), e2544057. https://doi.org/10.1001/jamanetworkopen.2025.44057
28. Proctor, A., Billing, J., Lyttle, M., Voss, S., & Benger, J. (2025). Factors influencing paramedic conveyance decisions when attending children with minor head injury: A qualitative study. Emergency Medicine Journal : EMJ, 42(6), e214467. https://doi.org/10.1136/emermed-2024-214467
29. Ramesh, A., Fezeu, F., Fidele, B., Ngulde, S. I., Moosa, S., Krebs, E., Gress, D., Calland, J. F., Petroze, R., Young, J. S., Nkusi, A. E., & Muneza, S. (2014). Challenges and Solutions for Traumatic Brain Injury Management in a Resource-Limited Environment: Example of a Public Referral Hospital in Rwanda. Cureus. https://doi.org/10.7759/cureus.179
30. Rubenson Wahlin, R., Nelson, D. W., Bellander, B.-M., Svensson, M., Helmy, A., & Thelin, E. P. (2018). Prehospital Intubation and Outcome in Traumatic Brain Injury—Assessing Intervention Efficacy in a Modern Trauma Cohort. Frontiers in Neurology, 9. https://doi.org/10.3389/fneur.2018.00194
31. Spaite, D. W., Bobrow, B. J., Keim, S. M., Barnhart, B., Chikani, V., Gaither, J. B., Sherrill, D., Denninghoff, K. R., Mullins, T., Adelson, P. D., Rice, A. D., Viscusi, C., & Hu, C. (2019). Association of Statewide Implementation of the Prehospital Traumatic Brain Injury Treatment Guidelines With Patient Survival Following Traumatic Brain Injury: The Excellence in Prehospital Injury Care (EPIC) Study. JAMA Surgery, 154(7), e191152. https://doi.org/10.1001/jamasurg.2019.1152
32. Suarilah, I., Zulkarnain, H., Saragih, I. D., & Lee, B.-O. (2024). Effectiveness of telehealth interventions among traumatic brain injury survivors: A systematic review and meta-analysis. Journal of Telemedicine and Telecare, 30(5), 781–794. https://doi.org/10.1177/1357633X221102264

33. Suokonautio, B., Kouvonen, A., & Nordquist, H. (2024). Role identities of emergency medical services personnel and their associations with intention to leave the profession. BMC Emergency Medicine, 24, 96. https://doi.org/10.1186/s12873-024-01008-8
34. Thapa, K., Khan, H., Singh, T. G., & Kaur, A. (2021). Traumatic Brain Injury: Mechanistic Insight on Pathophysiology and Potential Therapeutic Targets. Journal of Molecular Neuroscience: MN, 71(9), 1725–1742. https://doi.org/10.1007/s12031-021-01841-7
35. Zhang, D., Sheng, Y., Wang, C., Chen, W., & Shi, X. (2024). Global traumatic brain injury intracranial pressure: From monitoring to surgical decision. Frontiers in Neurology, 15. https://doi.org/10.3389/fneur.2024.1423329