الإصابات غير المرئية في حرب مرئية: إصابات الدماغ الرضّية في إقليم كردستان العراق في ضوء القانون الدولي الإنساني

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Invisible Injuries in a Visible War: Traumatic Brain Injury in the Kurdistan Region of Iraq under International Humanitarian Law

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Keywords : International Humanitarian Law, Traumatic Brain Injury (TBI), Proportionality, Civilian Protection, Kurdistan Region of Iraq, Invisible Injuries.

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الملخص:

تتناول هذه الدراسة الآثار الإنسانية والقانونية لإصابات الدماغ الرضّية (TBIs) الناجمة عن الانفجارات في النزاعات المسلحة المعاصرة، مع تركيز خاص على إقليم كردستان العراق (KRI). وبينما يؤكد القانون الدولي الإنساني (IHL) على مبادئ التمييز والتناسب والاحتياط لحماية المدنيين، فقد ركّزت التفسيرات القانونية التقليدية إلى حدّ كبير على الإصابات الجسدية الظاهرة والفورية. غير أن الأبحاث العلمية الحديثة تُظهر أن التأثيرات الارتجاجية للانفجارات يمكن أن تتسبب بأضرار عصبية ونفسية غير مرئية ومتأخرة الظهور، مما يطرح تحديات معقدة لكلٍّ من التقييمات القانونية والتخطيط العملياتي العسكري. تستكشف هذه الدراسة كيفية إدماج هذه التأثيرات الارتجاجية، وتحديدًا إصابات الدماغ الرضّية الناجمة عن الانفجارات، ضمن المبادئ الأساسية للقانون الدولي الإنساني المتمثلة في التمييز والتناسب والاحتياط، كما تنظر

في كيفية تكييف التدابير العملياتية للتخفيف من هذه الأضرار. علاوةً على ذلك، تبحث الدراسة فيما إذا كان استخدام الأسلحة المتفجرة في إقليم كردستان العراق يؤدي فقط إلى إصابات جسدية ظاهرة، أم أنه يتسبب أيضًا بـ«إصابات غير مرئية»، مثل إصابات الدماغ الرضّية الناجمة عن الانفجارات، لدى السكان المدنيين.

Abstract:

This paper examines the humanitarian and legal implications of blast-induced traumatic brain injuries (TBIs) in contemporary armed conflicts, with a particular focus on the Kurdistan Region of Iraq (KRI). While international humanitarian law (IHL) emphasizes the principles of distinction, proportionality, and precaution to protect civilians, traditional legal interpretations have largely focused on visible and immediate physical trauma. Modern scientific research, however, demonstrates that the concussive effects of explosions can cause delayed, invisible neurological and psychological harm, presenting complex challenges for both legal assessments and military operational planning. This study explores how these concussive effects, specifically blast-induced TBIs, can be integrated into the core IHL principles of distinction, proportionality, and precaution, and considers how operational measures might be adapted to mitigate such harms. Furthermore, it investigates whether the use of explosive weapons in the KRI results solely in visible physical injuries, or if it also inflicts "invisible injuries," such as blast-induced traumatic brain injury, upon the civilian population.

1. Introduction

In contemporary warfare, civilians are increasingly subjected to both visible and invisible forms of harm from modern weaponry, particularly traumatic brain injuries (TBIs). The traditional international humanitarian law (IHL) framework is predominantly predicated on assessing immediate, visible casualties among the civilian population. However, scientific research has demonstrated that explosions and the forces generated by concussive blasts can result in delayed, internal, and sometimes permanent brain injuries that remain largely undetectable through conventional field assessments. In active conflict zones such as the Kurdistan Region of Iraq (KRI), civilians are continuously exposed to high-intensity blast waves from indirect fire, airstrikes, mortars, and improvised explosive device (IED) detonations. This exposure has resulted in significant, yet largely unquantified, cognitive, psychological, and neurological trauma across the population.

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The primary question guiding this study is two-fold: first, how should concussive effects, particularly blast-induced TBIs, be integrated into the core IHL principles of distinction, proportionality, and precaution; and second, how can military operational measures be adapted to mitigate these harms in contemporary conflicts? Building upon this foundation, the study further investigates whether the utilization of explosive weapons in the KRI inflicts only visible physical scars on civilians, or if it also results in "invisible injuries," such as blast-induced traumatic brain injury. Accordingly, this study aims to examine both the manifest consequences of explosive weapons and the less apparent neurological and psychological trauma they cause. Furthermore, it analyzes the scientific mechanisms underpinning blast-induced TBIs, evaluates their legal significance under the IHL framework, assesses operational methodologies for preventing and mitigating such harm, and situates these findings within the empirical context of civilian exposure in the KRI.

The significance of this study lies in bridging the critical gap between evolving neuroscientific knowledge and existing legal obligations, thereby highlighting the often-overlooked humanitarian consequences of concussive injuries and proposing actionable frameworks to enhance civilian protection in contemporary armed conflicts. Additionally, it seeks to inform relevant stakeholders in the KRI regarding the long-term effects of high-yield weaponry utilized in regional conflicts. These weapons inflict invisible injuries, such as TBI, upon civilians, a consequence that, as of this writing, has not been widely recognized as a salient violation of international humanitarian law. By synthesizing evidence from neuroscience, military operational planning, and legal analysis, this study underscores the ethical and pragmatic necessity of accounting for invisible injuries both during targeting operations and in post-conflict assessments.

Consequently, this paper first establishes the scientific understanding of invisible brain injuries induced by explosions, followed by a rigorous examination of the legal implications of concussive effects regarding targeting, proportionality, and precautionary measures under international humanitarian law. It then provides an in-depth analysis of foreseeability, causation, and incidental injury, addressing the distinct challenges these factors pose to proportionality assessments and the operationalization of precautionary measures designed to mitigate concussive harm. Finally, the study anchors these theoretical and legal frameworks within a

localized case study examining the prevalence and implications of traumatic brain injury in the KRI.

2. Research Methodology

This study employs an interdisciplinary, qualitative research methodology that synthesizes doctrinal legal analysis with scientific and empirical insights. Primarily, the study utilizes doctrinal legal research methods, involving a rigorous examination of the core sources of IHL including treaty law, customary international law, and military manuals, specifically focusing on the principles of distinction, proportionality, and precautions in attack. In parallel, the study integrates medical and neuroscientific literature pertaining to TBIs to establish the objective biological and neurological realities of concussive and blast-induced trauma. To bridge the gap between legal frameworks and military practice, the analysis incorporates policy documents, military operational frameworks, and advanced technological methodologies, such as blast modeling and collateral damage estimation tools. Furthermore, a localized case study approach is employed to analyze the KRI. This component utilizes available conflict data, humanitarian reports, and clinical findings to evaluate the real-world implications of explosive weapon use on civilian populations. This empirical framework is supplemented by qualitative insights derived from semi-structured interviews with key stakeholders, including medical specialists and field experts, aimed at identifying and documenting cases of blast-induced TBI among civilians in the KRI. However, clinical perspectives offered by local experts consistently highlight systemic challenges, including a failure to systematically document diagnoses, limited diagnostic capabilities in acute field circumstances, a scarcity of specialized medical units with appropriate follow-up protocols, and inadequate long-term monitoring. Consequently, these systemic deficiencies result in a significant under-reporting of TBI as a prominent civilian casualty outcome in contemporary armed conflicts.

3. Invisible Brain Injuries Caused by Explosions and the Scientific Understanding of Blast-Induced Traumatic Brain Injury

The health risks of invisible brain injuries arising from explosive blasts, as well as the concussive impacts of heavy weaponry, are substantial and significantly underrepresented within contemporary public health and international legal discourses. Although these invisible injuries, particularly TBIs, typically present no external signs of physical trauma and frequently evade detection via conventional neuroimaging

techniques, extensive scientific evidence indicates they can cause severe, protracted, and permanent damage to the central nervous system, cognitive faculties, and emotional functioning. Consequently, a rigorous scientific investigation into these invisible injuries is a prerequisite to understanding their distinct mechanisms of trauma, clinical severity, and long-term potential for permanent disability. Moreover, from an IHL perspective, understanding the precise medical magnitude of concussive injuries is imperative to ensuring meaningful civilian protection. Establishing an accurate, scientifically grounded comprehension of the full spectrum of trauma inflicted by modern weaponry provides the necessary empirical justification for integrating invisible brain injuries into proportionality assessments and precautionary duties during armed conflict.

Blast injuries resulting from explosions manifest as a distinct class of traumatic brain injury that differs fundamentally from traditional blunt-force trauma, such as injuries sustained from a vehicular impact or a direct blow to the head. The vast majority of blast-induced TBIs do not require physical impact to the cranium; rather, they are pathologically characterized by the absence of a penetrating wound or visible external trauma. Nevertheless, these closed-head injuries can precipitate profound, long-term neurological consequences. Explosive weapons generate rapidly expanding, high-pressure shockwaves that propagate through both the surrounding atmosphere and the human body. These waves can inflict severe damage upon internal organs—including the brain—even in the absolute absence of a direct physical blow to the head.

Blast injuries resulting from explosions manifest as a distinct class of traumatic brain injury that differs fundamentally from injuries associated with blunt-force trauma to the head, such as being struck by a vehicle. Most blast-induced TBIs do not require physical impact to the cranium; rather, they are characterized by the absence of a penetrating wound and a lack of visible external trauma. Nevertheless, these closed-head injuries can precipitate profound, long-term neurological consequences. Explosive weapons generate rapidly expanding, high-pressure shockwaves that propagate through the air and into the human body, causing severe damage to internal organs including the brain even in the absence of a direct physical blow to the head[1]. Consequently, a significant cohort of these individuals will exhibit neurotrauma without demonstrating any overt external evidence of physical trauma.

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Blast injuries fall into four types according to medical texts - primary, secondary, tertiary, and quaternary. The initial kind comes from sudden pressure shifts affecting air-heavy parts like the lungs or brain. Flying fragments cause the second form, while people thrown by forceful winds hit walls or the ground in the third case. The last group covers fire harm, breathing in smoke, plus contact with poisons. Past doubts existed about whether shockwaves alone harmed brains; now, research on animals shows nerve cells do change without flying bits or crashes involved[2].

Blast-related brain injuries unfold through complex cascades of physical harm inside the body. When shockwaves hit, sudden pressure spikes appear to weaken the blood-brain barrier, allowing harmful molecules to slip into delicate areas and trigger neuroinflammation. Laboratory work on cells reveals hyperactive glial support cells alongside a reduction in nerve cell numbers, especially in zones tied to cognition and memory, where the hippocampus suffers significant damage. Sudden twisting motions deep within the skull can shear the microscopic wiring between neurons, breaking these connections without appearing clearly on standard imaging techniques like CT or MRI scans. Cellular energy shifts occur as well; brains metabolize fuel differently after blasts and electrical signals misfire, indicating hidden functional deficits despite an otherwise normal-looking anatomy[3]. Out in the field, one reality stands out: understanding how blasts affect the brain has become impossible to ignore. Right now, most diagnostic tools used to spot head injuries miss numerous cases, especially the less severe, mild traumatic brain injuries that happen frequently during explosions. Consequently, new efforts are emerging globally, including wearable blast sensors attached to gear, advanced neuroimaging, and biomarker tests based on blood clues, all trying to capture what conventional methods overlook. This is not just about assisting injured personnel; it also directly connects to establishing an accurate record of events when violence occurs. Absolute clarity matters long after the dust settles[4].

Clinically, headaches show up a lot after blast exposure - so do balance problems, trouble remembering things, difficulty focusing, mood swings, and disrupted sleep. Because post-traumatic stress disorder (PTSD) shares many of these signs, doctors sometimes assume the issues are only mental health-related, even when brain injury is involved. That mix-up means real neurological damage gets missed, especially milder cases, whether among soldiers or everyday people caught in explosions. When disasters strike cities or war areas, broken bones and bleeding take center stage in hospitals, while head trauma slips through the cracks without

much notice[5]. However, recent studies show how multiple blasts add up across time. Evidence suggests frequent minor impacts - below concussion level - slow thinking, weaken recall, and affect movement control, while gradually altering links within the brain[6].What stands out is that people in cities caught in long conflicts face ongoing risks, exposed again and again when explosions strike neighborhoods repeatedly instead of just once.

Despite advances in scientific understanding, substantial knowledge gaps remain. We still do not understand how blast intensity, duration of exposure, and long-term neurologic effects in humans relate to one another. These gaps are primarily due to ethical concerns and the lack of appropriate study designs. Standard diagnostic tools remain inadequate for detecting mild blast-induced TBIs, reinforcing their characterization as "invisible injuries"[7]. However, there is no internationally accepted threshold for safe blast exposure, particularly for civilian populations, creating uncertainty in both medical assessment and legal accountability.

Consequently, TBI has become widely accepted by many governments as a public health problem. National healthcare strategies, veteran compensation systems, and funding for TBI studies have all changed due to this. For instance, both the United States and Canada have developed comprehensive screening, treatment, and compensation programs for affected personnel, illustrating how governmental acknowledgment of TBI leads to the structuring of healthcare systems as well as legal entitlements for veterans[8]. Also, at the international level, the North Atlantic Treaty Organization (NATO) established a specific task force to identify knowledge gaps and create uniform diagnostic and treatment guidelines for mild TBIs related to deployments, demonstrating the potential significance of TBI as an injury in both operational and humanitarian contexts[9]. In this context, it is essential that similar attention be directed toward the KRI, where traumatic brain injury, particularly that caused by explosive weapons, remains insufficiently recognized and formally addressed, which will be discussed further in the following sections. TBI in such environments often constitutes a "silent injury," as its symptoms may not be immediately visible despite its long-term neurological and psychological consequences. Given the Region's location within a volatile geopolitical landscape, especially in light of ongoing hostilities involving Iran, the United States, and Israel, and the increasing use of ballistic missiles, drones, and other explosive weaponry, civilians are exposed to repeated blast effects that significantly heighten the risk of TBI. Therefore, integrating TBI into public health policy, legal

frameworks, and humanitarian response mechanisms in the Kurdistan Region is not only necessary but urgent, in order to ensure proper diagnosis, treatment, and protection of affected populations.

What we have seen so far shows that science confirms blast-related brain injuries are dangerous, though frequently missed when people face blasts from explosives. Without outward signs of injury, the force from an explosion still disrupts brain activity via hidden biological shifts inside nerve tissues. Poor detection methods, paired with symptoms that mimic mental health struggles, mean many cases go unnoticed - especially in non-combatants enduring constant blasts during war. So it turns out silent brain wounds add up into a major issue that few truly account for in aid efforts or health planning. Seeing these injuries as real, lasting problems shapes how doctors respond - and also affects how IHL rules judge harm done to civilians.

4. Concussive Effects in International Humanitarian Law: Implications for Targeting, Proportionality, and Precautions

This part addresses the legal considerations related to concussive effects in the context of IHL. This section discusses governing rules around targeting, proportionality, and precautions in an attack. The primary goal of IHL was to safeguard non-combatants from obvious, direct forms of harm, but the idea of concussive brain injuries creates a new type of harm (i.e., non-obvious), as well as a new set of challenges in applying the current legal framework. The discussion here examines how concussive injuries relate to targeting laws. It questions whether these injuries should factor into proportionality assessments and how the obligation to take precautions can realistically consider the risk of traumatic brain injuries. By critically evaluating current practices, this section identifies gaps and highlights them.

4.1 Concussive Effects and Their Legal Significance in Targeting Law

The relevance of concussive effects to targeting law arises directly from the foundational IHL obligation of distinction, codified in Article 48 of AP I, which mandates that parties to a conflict “In order to ensure respect for and protection of the civilian population and civilian objects, the Parties to the conflict shall at all times distinguish between the civilian population and combatants and between civilian objects and military objectives and accordingly shall direct their operations only against military objectives.” This rule is universally recognized as customary

international humanitarian law, applicable in both international and non-international armed conflicts[10]. In practice, a military unit striking an ammunition depot or command center must ensure that the attack is not directed at civilians as such. However, the application of distinction becomes legally complex when civilians suffer harm not from direct targeting, but from the collateral effects of the weapon used including concussive forces that propagate beyond the intended target.

At this point, targeting law becomes engaged not only with who or what is targeted, but also with how attacks are carried out and what effects they foreseeably produce. The concussive impacts of combat raise important normative questions about how hostilities are conducted, particularly under the legal rules governing targeting. These rules impose several distinct obligations. First, forces must ensure that the chosen weapons are not inherently indiscriminate and are utilized in a manner that can be accurately directed at a specific military objective. Second, any individual or object selected for attack must constitute a lawful military objective. Third, the methods of conducting the attack must comply with the principle of distinction, ensuring the operation itself is not indiscriminate. Fourth, any incidental civilian harm or damage to civilian objects must not be excessive in relation to the concrete and direct military advantage anticipated. Lastly, all persons planning or deciding upon an attack must take all feasible precautions in the choice of means and methods to minimize or entirely avoid incidental civilian loss and damage[11].

Because explosive weapons are not inherently unlawful, the concussive effects of a specific weapon are unlikely to change whether that weapon is lawful *per se*[12]. From a strict formalist perspective, concussive effects do not automatically violate the principle of distinction, which requires attacks to be directed solely against military objectives,since an attack deliberately aimed at civilians is unlawful regardless of the mechanism of harm. Similarly, the prohibition against indiscriminate attacks is not inherently dependent on concussive forces; failing to properly target a weapon, or treating several distinct military objectives in a civilian area as a single target (area bombardment), is unlawful in itself.

However, while the traditional application of distinction focuses primarily on target identification, modern urban warfare demonstrates that this framework is incomplete. Even when a target is entirely legitimate, catastrophic civilian casualties frequently arise from blast overpressure waves without any direct intent to harm civilians. A stark illustration of this occurred during the Battle of Mosul (2016–2017),

where extensive civilian casualties and severe primary blast injuries were caused by the overpressure waves of coalition airstrikes targeting ISIS combatants in densely populated neighborhoods. Research by Human Rights Watch (HRW) confirms that civilian brain injuries and blast-induced trauma occurred significantly far from the immediate impact zones of otherwise lawful strikes[13].

Article 51(4) of AP I states "Indiscriminate attacks are prohibited. Indiscriminate attacks are: (a) those which are not directed at a specific military objective; (b) those which employ a method or means of combat which cannot be directed at a specific military objective; or (c) those which employ a method or means of combat the effects of which cannot be limited as required by this Protocol; and consequently, in each such case, are of a nature to strike military objectives and civilians or civilian objects without distinction". This specific provision carries direct legal relevance when explosive weapons with wide-area effects are deployed in populated environments, generating concussive forces that cannot be spatially contained. A stark operational illustration of this challenge is found in the bombardments of Gaza (2014 and 2021). Independent humanitarian assessments indicate that civilians sheltering inside structures that were not directly targeted nonetheless sustained severe blast-related trauma from nearby detonations, including internal organ disruption and neurological damage propagated by shockwaves[14].Crucially, documentation by the UN Office for the Coordination of Humanitarian Affairs (UNOCHA) and medical NGOs highlighted a prevalent pattern of civilians presenting with closed-head trauma and acute neurological symptoms in the absolute absence of external, penetrating wounds, a clinical profile entirely consistent with blast-induced TBIs[15].

Recent discussions among IHL scholars, particularly Emanuela-Chiara Gillard, contend that targeting law must account for the foreseeable effects of weapons rather than merely their intended point of impact. Gillard emphasizes that commanders are legally obligated to consider how modern weapons behave within specific operational environments, especially dense urban terrain where blast forces inevitably propagate far beyond the immediate target zone[16]. This doctrinal position is starkly validated by empirical evidence from the conflict in Ukraine (2022–present). There, the deployment of heavy explosive weapons against military objectives within cities like Kharkiv and Mariupol generated powerful overpressure waves that penetrated reinforced structures, inflicting severe concussive injuries on civilians sheltering indoors—

trauma extensively documented by international medical NGOs[17]. This analytical framework is further reinforced by the work of Isabel Robinson, Ellen Nohle, and Gianluca Maspoli, who have explored the legal implications of "reverberating" or indirect effects—those consequences that predictably impact civilians and civilian infrastructure beyond the immediate kinetic footprint of an attack. This conceptual model aligns precisely with evidence from Syria, where sustained aerial bombardments have inflicted severe blast-related trauma on civilians residing near military objectives. Field reports from humanitarian medical professionals in Syria have consistently documented widespread cognitive impairment and chronic neurological symptoms among the affected population[18].

The International Committee of the Red Cross (ICRC) has incorporated these operational realities into its guidance on explosive weapons in populated areas , maintaining that factoring in wide-area blast effects is essential even when the principle of distinction is formally observed. The ICRC explicitly references recent urban conflicts in Iraq and Syria as empirical proof that limiting collateral damage assessments strictly to immediately visible injuries fundamentally undermines the framework of civilian protection[19]. From a critical perspective, some military practitioners contend that targeting law should not extend to complex, non-line-of-sight medical outcomes like concussive brain injuries, attributing this exclusion to scientific uncertainty and the difficulty of real-time battlefield assessment. However, this defense is fundamentally undermined by evolving state and military practice. For example, the U.S. Department of Defense enforces mandatory TBI screening protocols for service members exposed to specific blast overpressure thresholds, explicitly recognizing that concussive neurological trauma is a direct, foreseeable consequence of explosive forces[20]. This recognition undermines claims that such injuries are too speculative to be legally relevant when civilians are exposed to similar conditions.

Accordingly, concussive effects are relevant to targeting law not as a hypothetical expansion of existing legal duties, but as a direct reflection of documented, systematic harm occurring in contemporary armed conflicts. These operational precedents demonstrate that when blast forces foreseeably cause civilian brain trauma, a failure to account for such collateral effects directly undermines the object and purpose of the principle of distinction and violates the prohibition against indiscriminate attacks under IHL.

4.2 Integrating Concussive Effects into Proportionality Assessments

This section examines whether concussive effects specifically blast-induced TBIs, fall within the scope of the IHL rule of proportionality. Codified in Article 51(5)(b) of AP I, the principle of proportionality balances military necessity against humanitarian protection by prohibiting attacks expected to cause incidental loss of civilian life, injury to civilians, or damage to civilian objects that would be excessive in relation to the concrete and direct military advantage anticipated. Traditionally, operational assessments of this rule have focused primarily on immediate, visible kinetic damage, leaving the legal status of invisible or medically complex injuries like TBIs highly contested. This section will critically analyze the divergent perspectives among legal scholars and military practitioners, examine empirical data from recent armed conflicts, and evaluate how emerging scientific evidence regarding blast overpressure is actively reshaping contemporary legal standards.

4.2.1 The Threshold of Foreseeability for Concussive Harm

A central element of the proportionality rule in IHL is the concept of foreseeability. Under Article 51(5)(b) of AP I, an attack is prohibited if it is “an attack which may be expected to cause incidental loss of civilian life, injury to civilians, damage to civilian objects, or a combination thereof, which would be excessive in relation to the concrete and direct military advantage anticipated.” The phrase "may be expected" thus establishes both a temporal and a cognitive parameter, requiring commanders to anticipate potential civilian harm prior to launching an attack, based on information reasonably available to them at the time. The ICRC Commentary states that this may be "expected, but in relation to what can be foreseen, and not what happens to transpire," tying the foreseeability element to the conditions of planning and operation.

The rule of proportionality explicitly addresses the unintended harm to civilians and civilian property that “may be expected” to result from an attack. From the perspective of an operational commander, the threshold question is whether blast-induced concussive injuries constitute the type of harm that legally satisfies this expectation requirement. Under the Vienna Convention on the Law of Treaties, treaty terms must be interpreted in good faith, according to their ordinary meaning, within their context, and in light of the treaty’s object and purpose. The ordinary meaning of the term “expect” has remained remarkably consistent since the drafting of AP I[21].

Standard lexicographical definitions converge on probability; for instance, the Merriam-Webster Dictionary defines it as regarding something as probable or reasonably certain to occur, while the Cambridge English Dictionary characterizes it as the belief that a specific event will take place. This focus on probability is explicitly confirmed by the drafting history of AP I. During the Diplomatic Conference, delegates debated replacing the phrase "which may be expected to cause" with the more expansive "which could cause." Ultimately, the committee retained the original wording to underscore that the legal standard requires a high degree of objective foreseeability rather than mere hypothetical possibility[22].

This textual and historical understanding perfectly aligns with the mandate of Article 31(1) of the Vienna Convention on the Law of Treaties which requires that "a treaty shall be interpreted in good faith in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of its object and purpose." Applying this interpretive framework ensures that the foreseeability standard is assessed strictly as an ex ante, objective evaluation. Legal accountability must be predicated on the information reasonably available to the commander at the time of planning and execution, rather than on the distorting clarity of retrospective hindsight.

The structural reliance on the term "expected" confirms that the rule of proportionality must be evaluated strictly *ex ante*, prior to the execution of an attack rather than through the lens of retrospective outcomes. Consequently, compliance depends entirely on what actors within the targeting process could reasonably anticipate regarding probable incidental civilian harm, rather than the actual damage that ultimately transpires. The legal threshold is entirely objective, predicated on what a reasonable military commander in the same circumstances should have anticipated given the information available at the time. Therefore, harm that ought to have been foreseen remains legally relevant to the assessment, even if it was neglected by the specific attacker. For this reason, leading scholarship and customary indicators characterize this framework as a standard of "reasonable foreseeability" or "objective probability"[23].

Although it is well-established that incidental harm must be reasonably foreseeable to figure into a proportionality assessment, a critical question remains: what degree of certainty must a decision-maker possess for that harm to legally count as foreseeable? In jurisprudential terms,

foreseeability occupies a specific point along a continuum of certainty at which legal responsibility for an outcome attaches[24]. If the potential consequences of an attack fall short of this threshold, no legal duty arises, as an actor cannot be held accountable for outcomes that lie beyond reasonable anticipation. Conversely, applying an overly expansive standard to targeting operations would inadvertently impose a regime of absolute liability on military commanders for any and all incidental injuries resulting from an attack. To remain legally viable, the rule of proportionality must be interpreted in a manner that is operationally practicable; demanding absolute certainty or total liability would fundamentally disrupt the structural equilibrium between humanitarian protection and military necessity that underpins the entirety of IHL.

The challenge of incorporating concussive injuries into this foreseeability framework arises directly from their invisible, delayed, and cumulative nature. Unlike acute penetrating trauma or immediate structural destruction, blast-induced TBIs are frequently undetectable during initial post-strike field assessments. Instead, these neurological injuries typically manifest complex clinical symptoms days, weeks, or even months after the initial exposure[25].

Within IHL, the foundational concept of "reasonableness" governs the boundaries of foreseeability. An outcome is legally deemed foreseeable if a reasonable military commander or any other actor responsible for planning, authorizing, or executing an attack, would have anticipated that outcome with a requisite degree of certainty under the prevailing circumstances. This objective approach has led state actors and military legal experts to adopt a "reasonable certainty" benchmark when evaluating whether the collateral effects of an attack were sufficiently predictable. Under this standard, operational decision-makers do not require absolute empirical proof; rather, they must possess a reasonable belief, derived from facts available at the time, that the anticipated harm is probable[26]. While reasonableness disavows mathematical precision, it strictly excludes mere conjecture or speculation. Instead, as recognized within general jurisprudence, a standard of reasonable certainty demands rigorous, probabilistic judgment based on logical inferences from verified baseline facts[27]. Consequently, whether blast-induced concussive injuries to civilians are sufficiently probable to necessitate inclusion in a proportionality assessment depends entirely on the intersection of specific operational variables and contemporary scientific literacy regarding TBIs. The legal pivot hinges on the accessibility of this data to military staff during the planning phases of an operation. This framework effectively

elevates scientific data regarding blast overpressure, extensively documented in medical literature linking low-level shockwaves to neurological trauma, from a matter of clinical insularity to a core legal obligation under IHL. Commanders are thus legally compelled to integrate widely accessible epidemiological data, such as World Health Organization (WHO) reports on blast-induced neurotrauma, directly into their collateral damage estimation models.

However, critics of integrating blast-induced concussive injuries into proportionality assessments raise distinct operational and doctrinal concerns. First, they argue that the scientific certainty required to legally deem an injury foreseeable remains unsettled outside controlled clinical or experimental settings. The late legal scholar Yoram Dinstein consistently cautioned against incorporating complex, attenuated medical outcomes into the proportionality calculus without established, linear causal algorithms, suggesting that doing so risks transforming an operational legal judgment into a highly speculative medical forecast that exceeds a commander's core competence[28].

Second, acute operational limitations mean that commanders must frequently make rapid, high-stakes decisions with severely fragmented intelligence. For example, during the Battle of Raqqa in 2017, high-intensity urban combat involving the extensive deployment of explosive ordnance left military staff with virtually no temporal window to calculate nuanced estimations of delayed neurological harm; instead, commanders were forced to prioritize immediate, kinetic threats and active civilian evacuation pathways. Though independent field assessments by Amnesty International subsequently documented that numerous civilians suffered mild TBIs and persistent neurological symptoms in the weeks following the battle's conclusion, critics argue that this pattern whilst entirely consistent with *ex post* epidemiological studies, was fundamentally unforeseeable under the strict *ex ante* legal doctrine in force at the time of the operations[29].

In light of the above, the foreseeability of concussive harm under IHL ultimately requires commanders to evaluate anticipated civilian injuries strictly through an *ex ante* lens, utilizing information reasonably accessible at the time of operational planning rather than relying on retrospective hindsight. While Article 51(5)(b) of AP I and foundational principles of treaty interpretation establish an objective "reasonable certainty" benchmark, the delayed, non-line-of-sight nature of blast-induced TBIs undeniably introduces complex evidentiary challenges into

the proportionality calculus. Nevertheless, contemporary medical science and evolving state practice have matured to a level that enables—and doctrinally compels—decision-makers to account for the predictable overpressure effects of explosive ordnance within populated environments. Although acute operational constraints and fluid battlefield dynamics preclude mathematical precision, integrating verified epidemiological and blast-physics data ensures that modern collateral damage estimations remain structurally aligned with the dual, co-equal pillars of international humanitarian law: humanitarian protection and military necessity.

In light of the above, it is clear that the foreseeability of concussive harm under IHL requires that commanders assess likely civilian injuries based on information reasonably available at the time of planning, rather than on hindsight. While Article 51(5)(b) of API and treaty interpretation principles establish an objective "reasonable certainty" standard, the delayed and often invisible nature of blast-induced TBIs complicates their inclusion in proportionality assessments. Nevertheless, contemporary scientific knowledge enables and arguably obliges decision-makers to take into account the concussive effects of explosive force when assessing anticipated civilian harm. Although operational constraints and inherent uncertainties may prevent precise prediction, the incorporation of available medical and scientific evidence helps ensure that proportionality assessments remain aligned with the principles of humanitarian protection and military necessity.

4.2.2 Causation and the Legal Relevance of Concussive Effects

The existence of a causal connection between the military attack and civilian damage is essential to an IHL proportionality analysis. As explained earlier, Article 51(5)(b) of AP I prohibits attacks that can be expected to cause incidental civilian death or injury that would be excessive in relation to the anticipated military advantage, implicitly requiring that civilian harm be caused by the attack itself. Yet, the notion that only immediate and visible consequences, such as deaths, physical injuries, or the destruction of civilian objects, fall within this causal requirement is overly restrictive and inconsistent with both contemporary medical evidence and the humanitarian purpose of IHL. The injuries that must be accounted for in proportionality assessments are those that the attack "causes".

Although AP I does not specify what constitutes the causation of harm, and neither the negotiating history nor the ICRC Commentary provides a

clear explanation, both direct and indirect consequences may generally fall within the scope of the term, provided that they were reasonably foreseeable. This lack of a precise definition creates a significant complication: it remains uncertain whether indirect and non-visible injuries, such as traumatic brain injury (TBI) resulting from blast exposure, can legally be attributed to an attack. For example, U.S. military doctrine has traditionally emphasized only immediate or direct harms in proportionality assessments, excluding longer-term neurological effects despite growing scientific evidence supporting their causal connection to blast exposure[30]. As Gillard emphasizes, this interpretation should extend beyond immediate blast-related deaths and physical wounds to encompass reasonably foreseeable follow-on effects, such as disease, psychological harm, and certain infrastructure-related consequences, so long as a causal link to the attack can be established and the harm could have been anticipated by a reasonable commander[31].

Direct effects are the immediate, first-order consequences of a military action and are not shaped by intervening events or mechanisms. They usually occur at the time of the attack and are relatively easy to identify. Indirect effects, by contrast, are delayed, displaced, or higher-order consequences that arise through intermediate events or systems[32]. These distinctions are standard in humanitarian analysis and are important for proportionality assessments under international humanitarian law because they help clarify which harms are reasonably foreseeable. Direct effects are generally confined to the area of the blast itself, whereas indirect effects may spread through interconnected systems, with their duration and reach depending on the resilience of those systems, for example, whether water, electricity, or health services possess redundancies that allow them to absorb shocks[33]. However, concussive brain injuries, although biomechanically direct, may appear with delayed symptoms or manifest internally, thereby complicating the assessment of what constitutes direct versus indirect harm[34].

While direct effects such as concussive brain injuries caused by blast overpressure are typically immediate and biomechanical, often resulting in conditions such as cerebral cavitation without visible external signs, internal organ trauma may initially remain undetected. By contrast, a failure to receive timely care for a pre-existing chronic condition due to a nearby hospital damaged by the blast would constitute an indirect effect[35]. In conflict zones such as Iraq and the Kurdistan Region, which are the focus of this study and will be discussed in the following sections, blast-induced TBIs should be classified as direct effects, underscoring the need

for heightened precautions in populated areas. However, the delayed and invisible manifestation of such injuries presents an additional legal challenge, as harm that is not immediately apparent may be difficult to attribute to the attack within conventional legal frameworks, even though medical research clearly establishes a causal link between blast exposure and neurological injury[36].

There is significant academic debate regarding how broadly causation should be interpreted in proportionality assessments. The stricter interpretation seeks to preserve practical manageability and legal certainty by limiting proportionality assessments to the immediate and direct consequences of an attack. For instance, W. Hays Parks argues that the proportionality rule is intended to regulate specific combat situations and that "it should be applied on the basis of prompt and practical judgments of visible and reasonably foreseeable impacts, rather than hypothetical or long-term effects"[37]. Similarly, Geoffrey Corn asserts that proportionality must be assessed according to the "situation confronting commanders at the moment of attack," and that introducing "speculative or uncertain scientific or health effects" undermines the predictability and legal certainty that the rule seeks to establish[38]. This point deserves emphasis, as expanding causation to encompass all subsequent injuries, including hidden or delayed TBIs, may not be practically feasible.

In contrast, Sandesh Sivakumaran argues that the application of proportionality cannot be limited to immediate and readily calculable harm, but must encompass all foreseeable injuries caused by an attack, including indirect and delayed harm, if IHL is to remain responsive to modern warfare[39]. This perspective aligns with the ICRC's notion of "reverberating effects," discussed earlier, under which foreseeability and causation extend beyond purely physical trauma, such as where the destruction of infrastructure leads to subsequent disease outbreaks or displacement. If a blast that results weeks later in cholera due to the destruction of a water facility can be attributed to an attack, it is difficult to understand why neurological injuries caused by the blast wave itself cannot likewise be attributed merely because they are internal and less immediately visible than a disease outbreak affecting the public.

Reality itself confirms this notion: blast injuries can cause extensive brain damage without producing any obvious external wounds. In the 2020 Beirut explosion, one of the largest non-nuclear explosions ever recorded, the detonation of ammonium nitrate injured more than 6,500 individuals and generated powerful overpressure waves throughout the city.

Subsequent medical research on the explosion found that exposure to blast overpressure can induce neuropathological and neurobehavioral changes in the brain, including diffuse axonal injury and long-term neurological deficits consistent with mild TBIs, with many patients experiencing cognitive and psychological impairments months after the event[40].

Normatively, the exclusion of concussive injuries from the scope of the proportionality inquiry undermines the humanitarian purpose of IHL. By disregarding the causal link between blast exposure and neurological injury in certain circumstances, a hierarchy of suffering is created in which visible harm is recognized while invisible harm is neglected, thereby privileging factual convenience over substantive humanitarianism. It is inconsistent with a proper conception of legal causation to disregard injuries where scientific evidence demonstrates that blast exposure can cause neurological harm, that such harm is reasonably foreseeable, and that it has in fact occurred. Under these circumstances, a sufficient nexus is established for the purposes of proportionality analysis. Concussive injuries should therefore be recognized as cognizable civilian harm within proportionality assessments.

It is clear that, within the framework of IHL, establishing a causal relationship requires the recognition of both immediate and mediated harms that are reasonably foreseeable, including delayed and less visible harms such as blast-induced TBIs. Although proportionality analyses have commonly been limited in practice to immediate and observable harms for operational and pragmatic reasons, medical research and real-world incidents, such as the 2020 Beirut explosion, have demonstrated that blast-induced concussive TBIs are direct consequences of an attack and may result in delayed yet severe injury. Ignoring such harm undermines the protective function of IHL and prioritizes evidentiary convenience over humanitarian considerations. Accordingly, concussive effects should be legally recognized and incorporated into proportionality assessments so that the full extent of potential civilian harm resulting from military attacks can be reasonably anticipated and evaluated.

4.2.3 Legal and Scientific Challenges in Defining Incidental Injury in Brain Trauma

The definition of “incidental injury” is critical to the application of proportionality under IHL, yet its application to blast-induced TBI presents both legal and scientific challenges. Incidental injuries refer to

unintended harm to civilians or civilian objects that is expected or foreseeable and occurs in the course of achieving a legitimate military objective. Traditionally, as discussed earlier, IHL has tended to focus primarily on directly observable physical injuries, such as burns, lacerations, and amputations. However, this approach is inadequate in the context of blast-induced TBI, as such injuries are often invisible and may manifest through delayed cognitive, neurological, or psychiatric symptoms. These characteristics complicate commanders' ability to identify and account for such harm within proportionality assessments.

From a conceptual standpoint, E. Lieblich et al. focus on the psychological dimensions of brain injury, particularly cognitive and emotional harm that may occur independently of any overt physical trauma to the brain. In terms of implementation, they note the difficulty of applying the concept of incidental mental damage under the current framework, given the lack of detailed guidance for States, commanders, judges, and fact-finding missions on how such harm should be assessed. Accordingly, they propose incorporating incidental mental damage into the proportionality calculus through an adaptation of existing rules, urging that such harm be "taken seriously"[41]. Finally, they emphasize that psychological damage, while formally acknowledged, remains underdeveloped in theory, and argue that the principle of proportionality should encompass physical, emotional, and cognitive dimensions of trauma.

In contrast, G. Noll focuses on emerging neurotechnologies and neuro-effects, including so-called neuroweapons. He identifies structural challenges in the applicability of traditional IHL rules, arguing that IHL presupposes cognition as embodied within a single human being and closely linked to language. As neuroweapons potentially distribute cognitive functions across humans and machine systems and significantly reduce the role of language in cognitive processes.[42] this presumption becomes increasingly difficult to sustain. In this context, key IHL concepts—particularly those concerning responsibility and the relationship between subordinate and superior actors—are called into question. Unlike E. Lieblich et al., Noll does not provide an explicit definition of brain injury nor does he distinguish between incidental and intentional brain injury. Nor does he propose concrete frameworks or solutions for applying IHL to such scenarios; instead, he highlights a more fundamental incompatibility between existing IHL structures and emerging technologies, suggesting that more than incremental adjustment of current legal rules may be required[43]. He further speculates about a

scenario in which the distinction between accidental and intentional brain injuries becomes increasingly blurred.

There is widespread recent academic consensus defining "incidental" injury within the context of IHL as unintentional but foreseeable consequences of otherwise lawful attacks. Aurel Sari defines incidental injury as an unintended but foreseeable result of attack, describing it as an "unforeseen by-product" of warfare, and noting that "incidental" does not itself imply proportionality[44]. Likewise, Luigi Daniele treats incidental harm as foreseeable but unintended civilian harm that arises within the framework of proportionality assessments under the law governing the conduct of hostilities[45]. E. Lieblich similarly includes unintended psychological harm within the concept of incidental harm in the context of proportionality, whereas Janina Dill notes that it "encompasses foreseeable but unintended, as opposed to accidental or speculative" harm[46].

"Incidental" signifies that the injury is not intended, though it may be foreseeable. However, what constitutes an "injury" is far less clear, particularly in relation to cognitive and psychological harm. There is no universally accepted definition of injury in either treaty law or customary international humanitarian law. While debates have addressed concepts such as "superfluous injury" under Article 35 of Additional Protocol I and "serious injury" in the context of responsibility under Article 85 of Additional Protocol I, there has been little substantive discussion of the meaning of "incidental injury" as used in Articles 51 and 57 of AP I. Nor is significant clarification available in the 1987 ICRC Commentary or relevant case law, both of which reflect a notable gap in doctrine and legal guidance[47].

The concept of "wounded and sick" has been examined in the context of Article 12 of Geneva Convention I (1949). According to the ICRC Commentary to the Convention, there have been no attempts to provide a precise definition of "wounded and sick" soldiers or to specify the required level of gravity for protection. This is because "any official definition … would have to be overly strict and thus easily fallible," and the notion is instead intended to rely on "good faith and common sense" in its application[48]. According to L. Gisel, military medical personnel and combatants who are inadvertently injured or killed should also be included within this category, in light of military practice and instructions in military manuals, as well as the preparatory work of Additional Protocol I. Interpretation is further supported by the updated Commentary

to the First Geneva Convention, which clarifies the treatment of the wounded and sick where specific definitions are absent, with reference to the ordinary meaning of terms under the Vienna Convention on the Law of Treaties[49]. However, other scholars, such as Emily Crawford and Alison Pert, note that while related rules governing the means and methods of warfare aim to prevent unnecessary suffering or superfluous injury, none of these instruments provide a precise definition of "wounded and sick" or of the ordinary meaning of "injury"[50].

Recent interdisciplinary work suggests that the distinction between physical and psychological injury may have a neurologically verifiable basis. Neuroscientific experiments indicate that particular brain regions are differentially activated in response to psychological harm as compared to physical harm, suggesting that this distinction may have a neurobiological foundation that could be relevant in armed conflict[51]. While this evidence continues to emerge, existing legal and public health literature maintains that current interpretations of proportionality remain excessively focused on physical harm, while the severity and significance of mental health harms are still not adequately accounted for in legal decision-making[52].

In conclusion, the determination of "incidental injury" within the framework of IHL becomes more complex when applied to blast-induced TBIs. Traditionally, proportionality assessments have focused predominantly on tangible physical effects; however, it is clear from current academic and scientific understanding that neurological, cognitive, and psychological effects of injury may also constitute significant civilian harm. In addition, there is no definitive legal interpretation of "injury" in either IHL treaty law or customary international law, which further complicates the inclusion of such effects within proportionality analysis. Accordingly, medical and neurological evidence is necessary to inform and support legal interpretation and, in turn, to facilitate the recognition of incidental effects of TBI within the scope of IHL protections.

4.2.4 The Challenge of Weighing Concussive Harm in Proportionality Judgments

Assessing whether expected civilian harm is "excessive" in relation to the anticipated military advantage constitutes the central balancing test of the proportionality principle in IHL. However, concussive effects, such as blast-induced TBIs, reveal significant conceptual, operational, and ethical limitations in how this assessment is currently conducted. As noted

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earlier, Article 51(5)(b) of AP I prohibits attacks that "may be expected to cause incidental civilian loss or injury which would be excessive in relation to the concrete and direct military advantage anticipated." However, it does not explain how to measure and balance harm that is not immediately visible, that emerges over time, or that is uncertain in its manifestation at the moment of assessment.

Contemporary armed conflict is increasingly characterized by its impact on civilians through explosive violence that produces severe yet often immeasurable short-term and delayed neurological consequences. This reveals a gap in the legal framework for civilian protection. The 2024 ICRC report on international humanitarian law and the challenges of contemporary armed conflict reiterates that new and evolving weapons and means of warfare generate harms that do not easily fit within traditional legal categories, including neurological injury and other "less visible injuries"[53]. Three interconnected questions arise from this: first, the quantification of proportionality by commanders; second, the standards for assessing acceptable concussive injury within an international framework; and third, what empirical models might facilitate ethically informed command decision-making.

Military commanders often approach proportionality through a utilitarian calculation, balancing anticipated civilian harm against expected military value, with particular attention to strategic importance in asymmetric conflicts[54]. While this account accurately captures the ethical reasoning underlying proportionality, it raises a conceptual difficulty; in requiring the estimation and comparison of military value with the probability of civilian injury, the framework may fail to account for the fact that many injuries particularly concussive TBIs or long-term neurological conditions, are not immediately perceptible. For example, even where combat takes place in urban civilian environments affecting a heterogeneous population ranging from young children to the elderly and infirm, it is plausible that a single blast may result in limited immediate physical injuries while nonetheless producing long-term cognitive disabilities in a significant minority of those exposed. The limitation is evident: analyses grounded in utilitarian reasoning may reduce civilian harm to immediately ascertainable figures, thereby underestimating the broader humanitarian costs.

On the normative plane, IHL regimes frame permissible harm to civilians through the concept of "incidental" injury, which has been described as "misunderstood or applied imprecisely in the proportionality calculation,"

leading some scholars to advocate a stricter construction of incidentality as a requirement for "just and lawful action"[55]. Similarly, in the field of international military law, proportionality and precautions in attack are designed to minimize civilian harm; however, there are no established rules of thumb for assessing concussive injury in comparison to anticipated military advantage[56]. This reflects a structural gap in the law: while it specifies what must be taken into account, it does not prescribe how these factors should be weighed, particularly where injury is probabilistic, delayed, or the result of internal neurological damage. As a result, commanders may comply with the formal requirements of proportionality while still systematically underestimating "invisible" injuries.

Expanding on the computational paradigm, Clara Maathui developed an agent-based model (ABM) that simulates proportionality evaluation by accounting for the relationships among decision-makers, context, and operational parameters[57]. This approach offers several theoretical advantages over rule-based models, particularly in recognizing that decision-making is shaped by a dynamic and context-sensitive environment rather than a fixed set of rules. However, its limitations restrict its use primarily to theoretical explorations of operational decision-making, as there is not yet a quantitative basis for estimating concussive damage with operational utility. Moreover, ABM relies heavily on the accuracy and granularity of available data; poor field measurements and incomplete civilian casualty profiles can result in outputs that may be analytically valid but operationally unreliable. This reveals an important tension in the scholarly literature, whereby advances in modelling techniques do not yet translate into ethically and legally robust guidance for commanders in real-time warfare.

The proportionality rule in IHL, as articulated by Henderson and Reece, is based on the idea that predicted incidental harm must be weighed against anticipated military advantage, although the literature acknowledges that there are no widely accepted methods for calculating proportionality in contemporary warfare[58]. This adds to Ori Pompon's (2022) observation that commanders are not under a formal obligation to take the loss of civilian use of an objective into account, revealing a gap in the normative framework[59]. Taken together, these points indicate a structural problem: as computational methods and doctrinal analyses evolve, there remains no developed way of translating probabilistic, delayed, or cognitive harm into proportionality assessments. A commander may be able to estimate immediate TBI risks using blast

sensor data, but no clearly defined method exists for incorporating potential long-term memory loss, cognitive decline, or psychological trauma.

The question of an acceptable level of concussive damage relative to expected military advantage has not been explicitly defined through numerical standards in international military legal instruments or accepted thresholds. Instead, it has largely been subsumed within risk management approaches rather than a harm-threshold framework. As reflected in the Netherlands Defence Doctrine, operational guidance focuses on blast mitigation and minimum civilian distances required to withstand blast overpressure effects[60]. Similarly, NATO Allied Joint Doctrine for Joint Targeting references the need to weigh reasonable military advantage against all reasonably foreseeable civilian harm, including potential long-term effects on health and human dignity, but it does not establish numerical targets and instead instructs commanders to base assessments on a standard of reasonable certainty grounded in available knowledge of effects.[61] This absence of clear quantitative limits on concussive harm remains a recurring issue in military doctrine. Article 51(5)(b) of Additional Protocol I explicitly requires a balancing of expected civilian harm against military advantage but does not delineate any numerical threshold of permissible harm relative to the magnitude of military advantage. This underlines that the provision was never intended to function as a formulaic computation of military and humanitarian values, but rather as a context-dependent evaluative standard.[62].

The Collateral Damage Estimation Methodology (CDEM), used by NATO and various developed countries for proportionality and precautionary planning, provides a systematic empirical method for assessing the trade-off between the risk of concussive injury and the expected military advantage gained[63]. The CDEM methodology does not rely solely on qualitative judgment; instead, it offers a means of modelling expected incidental harm from weapons systems using available data on weapon effects, while also incorporating environmental and demographic considerations. By using CDEM, planners can estimate the probability of civilian harm and injury including harm that may not be immediately visible, and quantitatively compare the expected value of the target with these estimated probabilities and the severity of anticipated civilian harm.

Generally, weighing concussive harms within proportionality assessments reveals significant conceptual and operational challenges in IHL. The

principle of proportionality requires a comparison between expected civilian injury and anticipated military advantage; however, because blast-induced TBIs are invisible, delayed, and probabilistic, their identification, measurement, and incorporation into decision-making are considerably more complex. While existing legal frameworks and military doctrines recognize that foreseeable civilian injury must be taken into account, there is limited guidance on methodology or quantitative standards relating specifically to neurological injury. Consequently, although emerging empirical tools such as modelling approaches and collateral damage estimation methods, offer new possibilities, further legal and methodological development is required to support proportionality assessments that adequately account for concussive injuries and fully reflect the protective purpose of IHL in contemporary armed conflict.

5. Operationalizing Precautions and Constant Care to Mitigate Concussive Harm

The obligation to take precautions in attack—rooted in Article 57 of AP I and recognized as customary international humanitarian law—requires parties to an armed conflict to take all feasible measures to minimize civilian harm, including during the planning and execution of military operations. Concussive effects such as blast-induced TBIs pose a particular challenge to this duty because they are often invisible, delayed, and not immediately quantifiable, even though scientific evidence increasingly links specific levels of blast overpressure with a heightened probability of neurological injury[64]. Systematically assessing and minimizing such harm therefore calls for the integration of epidemiological risk models into operational planning, enabling patterns of blast exposure and civilian presence to be mapped against injury-probability curves. For example, recent studies have used computational tools such as the Airman Modeling System (AMS) to model civilian TBI risk gradients resulting from blast propagation. One way military planners may use outputs from AMS is to identify zones of concussive overpressure and adjust either the choice of weapon or the timing of an attack to reduce the likelihood of neurological injury to civilians in densely populated areas. Another framework that emphasizes the inclusion of concussive effects and reverberating consequences in area-effect analysis is the joint ICRC–UNIDIR work on explosive weapons in populated areas[65].

Military operations and humanitarian intervention are increasingly challenged by concussive injuries resulting from blasts. According to L. Moffett et al., military commanders can systematically assess and mitigate civilian concussive injury through integrated blast models, real-time monitoring, and precautionary protocols, as reflected in Article 57 of Additional Protocol I, which requires "constant care" and "all feasible precautions." Moffett highlights the operational integration of collateral damage assessment tools, including blast overpressure radii, demographic data, and sensor networks, to predict otherwise hidden concussive injury. Advance warning and civilian evacuation, he argues, are both legally required and practical means of ensuring compliance, as they demand the proactive integration of scientific data rather than post hoc justification of operations[66]. However, while Moffett's framework is operationally robust, it relies on assumptions regarding the availability of advanced sensors and predictive tools that may not exist in low-resource or highly volatile environments, leaving open questions about the practical limitations of these strategies in such contexts.

Defining what constitutes "feasible precautions" in diverse operational contexts has proven contentious. Article 57(2)(a)(ii) of Additional Protocol I requires parties to "take all feasible precautions in the choice of means and methods of attack with a view to avoiding, and in any event to minimizing, incidental loss of civilian life, injury to civilians and damage to civilian objects." In practice, feasible precautions extend beyond tactical choices to include strategic decisions regarding weapon selection, timing of engagement, trajectory planning, and the use of non-explosive alternatives where possible. Efforts by the U.S. Department of Defense already demonstrate attempts to integrate live sensor inputs into blast overpressure monitoring tools to mitigate concussive threats during weapons training while maintaining mission effectiveness. For high-yield explosives, reducing immediate exposure through increased standoff distance and modified firing positions, supported by 3D blast modelling, may also constitute a potential course of action while preserving operational objectives[67]. Objectively evaluating feasibility requires metrics that balance the operational cost of precautionary measures (such as time delays or alternative resource expenditure) against reductions in predicted civilian risk, as measured through probabilistic models such as Blast Exposure Risk Mapping tools.

Both active and passive warning strategies form essential components of precautionary duties under international humanitarian law. Active measures include advance notification to civilians prior to explosive

operations, while passive measures encompass public education on blast risks, evacuation advisories, and the provision of safe shelters. During the September 2023 Azerbaijani offensive in Nagorno-Karabakh, Azerbaijani evacuation warnings and calls for dissolution were issued during and after the offensive via text messages, leaflets, and social media, prompting a mass exodus of approximately 100,000 people, but also illustrating how warnings issued concurrently with or after attacks may fail to prevent injuries from blast overpressure among civilians still within or near blast zones[68]. An analysis of explosive violence in Yemen found that between 2014 and 2023, the extensive use of explosive weapons in populated areas, including in and around the Sana'a region, resulted in significant civilian casualties and injuries, underscoring the importance of effective warning and risk-reduction measures. Data from the Explosive Violence Monitor by Action on Armed Violence indicates that thousands of Yemeni civilians have suffered harm from explosive weapons over the past decade, and emphasizes that early warning systems, evacuation advisories, and safe sheltering are critical in reducing civilian vulnerability to blast effects and serious injury[69]. Therefore, these findings suggest that where timely warnings successfully prompt civilians to leave high-risk blast areas, resulting harm from both blast and concussive effects may be reduced. However, substantial obstacles remain, particularly in the context of ongoing hostilities and limited access to protective infrastructure.

The central challenge in meeting the precautionary obligation is the lack of comprehensive knowledge concerning concussive phenomena and their variability across different settings and populations. Military research has quantified blast overpressure ranges associated with traumatic brain injury primarily among relatively homogenous groups, such as trained soldiers wearing body armor. However, data on how building materials, urban topography, and civilian vulnerabilities—such as children, the elderly, and medically fragile individuals—affect concussive outcomes remains limited. A 2024 LIMBIC-CENC systematic review noted that the blast injury literature predominantly relies on studies of U.S. service members, which differ significantly from real-world combat environments in which blast injuries occur, thereby limiting the applicability of these findings to diverse civilian populations.[70] This deficit in data quality undermines the precautionary process, as policymakers lack reliable empirically grounded models of civilian vulnerability. Consequently, although some states have implemented precautionary planning measures by establishing expanded

exclusion zones around blast targets, the effectiveness and legal consistency of such policies vary considerably, as they are not based on standardized thresholds.

Legal scholars such as Vos and Smedt argue that operationalizing the precautionary principle requires data-driven risk assessment models analogous to those used in environmental health, where policy is informed by dose–response relationships and exposure levels rather than binary decision-making[71]. However, such health risk models are difficult to apply in IHL without robust datasets and sustained interdisciplinary collaboration, capacities that are unlikely to exist in most conflict-affected contexts. Moreover, an overreliance on modelling risks obscuring important qualitative humanitarian factors that shape the civilian experience and reporting of concussive trauma, including the social and cultural impacts of displacement.

Real-time blast monitoring, demographic vulnerability analysis, and operational warning systems require an urgent multidisciplinary framework to address legal, operational, and ethical challenges at the intersection of these fields. U.S. military pilot initiatives such as CONQUER and INVICTA now use body-worn sensors to capture geocoded blast exposures linked to health outcomes, offering examples of how data gaps may be addressed. Preliminary findings suggest improved predictive capacity in precautionary risk-assessment models, with such data enabling commanders to tailor mitigation strategies, including adjustments to standoff distances[72].

Blast injuries from improvised explosive devices were identified as the most common mechanism of mild traumatic brain injury (mTBI) during the Global War on Terrorism, contributing significantly to research on the diagnosis of mTBI, including its relationship to PTSD and its longer-term effects[73]. Although these studies were important for advancing both the understanding and treatment of military mTBI, they did not address how to reduce concussive injury risks for civilians exposed to similar blast threats, distinguishing them from the work of Moffett, Daniele, and other humanitarian-focused scholarship. While historically and clinically valuable, the extent to which this research informs practical humanitarian or proportionality-oriented decision-making appears more limited in contemporary operational contexts.

Considering all the above, it is clear that the duty to take precautions in attack under Article 57 of AP I and customary international humanitarian law is both legally and ethically well-established, yet particularly

complicated by blast-induced concussive injuries. While scientific advancements, blast-modelling tools, and precautionary practices offer significant promise for both predicting and preventing such injuries, limitations in available data and in the capacity to develop reliable models of civilian exposure and vulnerability have been highlighted. Reducing the risk of harm to civilians from concussive injuries therefore requires improved integration of legal and scientific approaches, including the incorporation of operational considerations into the assessment and implementation of precautionary measures.

6. Case Study Analysis: Traumatic Brain Injury in the Kurdistan Region of Iraq

The KRI has been engulfed in a prolonged security crisis marked by systematic attacks involving state forces, non-state actors, and militia groups. It has also experienced persistent federal–regional tensions and the presence of multiple armed actors. In northern Iraq, warring parties frequently use heavy explosive weapons in or near populated areas. As a result, civilian populations bear the impact of high-intensity blast waves, repeated explosions, and prolonged acoustic shock, increasing the risk of civilian harm and damage to infrastructure. Because explosions and gunfire often produce visible physical injuries, attention tends to focus on immediately observable harm. However, brain injuries caused by blast overpressure and acoustic effects constitute serious yet largely overlooked “invisible” injuries. Despite the absence of obvious external symptoms, medical evidence indicates that such exposure can lead to long-term neurological damage. In particular, TBIs often remain undetected at the time of injury and are only identified through subsequent clinical assessment over time. This case study uses these invisible injuries to explore conflict dynamics, healthcare capacity, and potential violations of IHL in the KRI. It also highlights gaps in the recognition, reporting, and legal assessment of blast-related brain injuries.

6.1 Explosive Weapons, Civilian Traumatic Brain Injury, and International Humanitarian Law Violations in the KRI

For decades, the KRI has experienced armed conflict, with the period between 2014 and 2017 being particularly violent following ISIS’s seizure of large areas of northern Iraq. Operations to retake these territories were characterized by the extensive use of explosive weapons in populated areas, including airstrikes, artillery, mortars, and improvised

explosive devices. As a consequence, there was likely a substantial yet poorly documented burden of blast-related TBIs and concussive injuries among civilians. Between 2012 and 2022, Iraq ranked as the second worst-affected country in the world for civilian casualties resulting from explosive violence. Violence in the Kurdistan Region comprising the governorates of Erbil, Duhok, Sulaymaniyah, and Halabja, was particularly intense because the region functioned both as a frontline battlespace against ISIS offensives and as a refuge for displaced populations. However, available clinical evidence remains fragmented. According to specialist physicians Dr. Srood Nazar and Dr. Nishwan, some data concerning trauma and brain injuries are recorded at facilities such as Rojava Emergency Hospital; however, there is no comprehensive dataset or precise statistical record identifying cases specifically caused by blast overpressure from drones or rockets. This gap reinforces the characterization of civilian TBI as "largely undocumented," despite its apparent clinical prevalence (Interviewed, 13- 17 March 2026).

These decades of exposure to violent acts, including explosions, have not subsided amid rising tensions across the regional geopolitical landscape. Recent developments illustrate another escalation that began on 28 February 2026, when airstrikes conducted by U.S. and Israeli forces against Iran were followed by subsequent drone and missile attacks across the region. Since 28 February 2026, the KRI has reportedly been subjected to approximately 650–700 drone and missile attacks, representing a dramatic increase in hostilities[74]. The consequences have included the deaths of at least 16 civilians, including a 7 March airstrike near Erbil that killed a married couple, and these figures account only for recorded fatalities. Spatially, Erbil has experienced nearly 80 percent of the attacks within the KRI, amounting to approximately 500 strikes, with many injuries occurring near residential areas such as Bakhtiyari and rural villages including Darashakran. In Sulaymaniyah, there were 106 strikes, including several air raids on residential homes in early April 2026. Duhok also experienced approximately 25 drone and missile strikes targeting agricultural fields and residential areas near political residences[75]. Although casualties are typically recorded as "wounded," "critically injured," or "treated for shrapnel injuries," blast-related traumatic brain injuries remain significantly underreported in the immediate aftermath of attacks. One major reason for this underreporting is the inherent difficulty in identifying "invisible injuries." Clinical specialists such as Dr. Kawa Omar emphasize that many blast-induced TBIs do not appear on standard imaging techniques, including CT scans

or MRIs, and instead require longitudinal neurological assessment and follow-up, which is often absent in emergency-based reporting systems (Interviewed, 16 March 2026).

Under Article 48 of Additional Protocol I to the Geneva Conventions, the principle of distinction entails a continuing obligation upon all parties to an armed conflict to distinguish between civilians and combatants, and between civilian objects and military objectives. It constitutes the foundational principle upon which military operations must be directed exclusively against lawful military targets, thereby safeguarding civilians and civilian infrastructure. However, the use of explosive weapons in populated areas of the Kurdistan Region demonstrates a pattern of conduct fundamentally incompatible with this obligation. The wide blast and overpressure effects of artillery shells, rockets, and large air-delivered bombs make it inherently difficult, if not impossible, to distinguish between military objectives and civilian persons when such weapons are used in residential neighborhoods. This concern is further reinforced by empirical evidence from the Battle of Mosul (October 2016–July 2017), which resulted in at least 10,000 civilian deaths. During this period, the Emergency Management Center in Erbil, located approximately 90 kilometers east of Mosul, served as a major trauma facility receiving casualties. A retrospective analysis of 1,219 patients admitted to this center found that explosive weapons were the leading cause of injury, with 55 percent of admissions involving female civilians, thereby underscoring the disproportionate impact on non-combatants[76].

Observations by clinical specialists in neurosurgery, including Dr. Nishwan Nashaat, further suggest that the majority of blast-related incidents occurring during the Mosul campaign were classified as mild traumatic brain injuries, more specifically medically diagnosed as “concussions,” and that patients were often discharged following initial examination without substantial clinical follow-up. The implication is that the full neurological sequelae of blast injury remain significantly underreported, and that the true scale of civilian harm is consequently gravely underestimated.

Medical evidence demonstrates that TBI constitutes a significant component of blast-related harm in conflict settings. Research on military personnel deployed in Iraq and Afghanistan revealed that blast mechanisms accounted for 33.1 percent of all traumatic brain injuries among deployed soldiers, making blast exposure the single most common cause. However, no comparable systematic screening or documentation

infrastructure existed for Iraqi and Kurdish civilians exposed to the same, or even more severe, blast environments in populated areas. At the institutional level, both Dr. Srood Nazar and Dr. Kawa Omar have indicated that although emergency reporting procedures, follow-up mechanisms, and diagnostic tools such as CT scans and MRIs are available in major hospitals in Erbil, including Rojava Emergency Hospital and Rizgari Hospital, a critical structural gap nevertheless remains. In particular, there is no dedicated system for tracking war-related neurological trauma, especially trauma associated with blast injuries. They further emphasize the need to establish a specialized registry center and multidisciplinary follow-up teams in accordance with international standards of medical care.

The primary mechanism of TBI in the current conflict within the KRI is blast overpressure generated by one-way attack drones carrying explosive payloads. When these munitions detonate in urban environments such as Erbil or Sulaymaniyah, they produce supersonic pressure waves capable of causing primary blast TBI through direct cranial transmission. As explained by Dr. Srood Nazar and Dr. Nishwan, this process involves shock waves passing through the skull, resulting in phenomena such as “spalling” at tissue–fluid interfaces and “cavitation” within the brain’s vasculature, which may disrupt the blood–brain barrier even in the absence of direct physical impact to the head. Within the framework of IHL, the principle of proportionality, as codified in Article 51(5)(b) of AP I, prohibits attacks expected to cause incidental civilian harm that would be excessive in relation to the concrete and direct military advantage anticipated. However, from a medical perspective, proportionality assessments are significantly undermined when the long-term and often delayed consequences of blast-induced TBI are not adequately taken into account. Clinical observations highlighted by Dr. Kawa Omar further emphasize that, particularly among children, blast exposure may result in delayed cognitive impairments, learning disabilities, and psychological disorders that may only manifest years after the initial injury, thereby extending the scope of civilian harm far beyond what is immediately visible at the time of attack.

The use of explosive weapons and the resulting traumatic brain injuries and concussive blast effects on civilians raise serious concerns regarding compliance with the principle of proportionality in the KRI. The prohibition against attacks expected to cause excessive civilian harm, as reflected in Article 51(5)(b) read together with Article 57 of AP I, does not appear, based on the available evidence, to have been meaningfully

incorporated into military decision-making in and around KRI cities. Proportionality assessments and targeting decisions seem to have focused primarily on anticipated direct physical harm and damage to structures, rather than on the neurological consequences and long-term brain injuries associated with blast exposure. As previously noted, blast-induced TBI may produce symptoms such as chronic headaches, dizziness, impaired concentration, memory loss, sleep disturbances, and emotional instability, many of which may persist for months or even years after the injury. This concern is further reinforced by clinical observations from Dr. Nishwan, who confirmed that individuals exposed to blasts may initially appear asymptomatic yet later develop long-term neurological and psychological conditions, including chronic headaches, memory impairment, concentration difficulties, and PTSD, all of which significantly affect daily functioning and overall well-being. This conclusion is also supported by primary field data collected for this study. Local residents interviewed for the research, including Salim Jamil and Shifa Ibrahim, explained that they experienced dizziness and psychological distress as a result of the intense noise and blast effects generated by Iranian shelling near their workplaces during the fighting that occurred on 24 March 2006. Both individuals reported that their condition required them to remain at home for several days and seek medical treatment. Their experiences reinforce the argument that neurological and psychological harm constitutes a substantial, foreseeable, and real form of civilian injury, even where no immediately visible physical wounds are present. Accordingly, proportionality assessments under IHL should also take such injuries into account.

The principle of precaution, codified in Article 57 of Additional Protocol I, obliges parties to an armed conflict to take all feasible precautions in the choice of means and methods of warfare in order to avoid, or at least minimize, incidental harm to civilians. This obligation must be understood not only in terms of conduct during attacks, but also in relation to preparedness for the foreseeable consequences of those attacks. In this regard, both Dr. Kawa Omar and Dr. Nishwan agree that precautionary obligations should extend beyond immediate physical safety to include healthcare preparedness following an attack, particularly through the establishment of rapidly deployable emergency medical systems, routine neurological assessment of civilians exposed to blast injuries, and increased availability of diagnostic imaging technologies such as MRI, which remain unevenly accessible in emergency settings.

The implementation of such precautionary measures within the KRI, however, has remained limited in scope. The continued reliance on explosive weapons with wide-area effects in or near civilian areas has resulted in sustained civilian exposure to significant blast overpressure and acoustic shock, thereby increasing the risk of head trauma and other injuries. This danger is further compounded by the lack of effective air defence systems and insufficient radar coverage capable of detecting incoming threats, such as drones, which severely limits early warning capabilities and civilians' ability to protect themselves. Although warnings have occasionally been issued in anticipation of military operations, their short notice, combined with inadequate evacuation routes and the limited availability of shelters, has rendered them largely ineffective. In practice, many civilians had little genuine opportunity either to escape or to seek adequate protection. Findings by the United Nations Assistance Mission for Iraq (UNAMI)[77] support this conclusion, noting that the impact of air operations on civilian populations in northern Iraq demonstrated that civilians were effectively denied a meaningful opportunity to flee due to restricted escape routes, the absence of sufficient shelter facilities, and the continued presence of combatants within populated areas.

Children in the KRI constitute one of the most vulnerable groups affected by explosive weapons and concussive injuries. According to reports by UNICEF and United Nations Mine Action Service, between 2018 and 2020, unexploded and abandoned explosive ordnance caused the deaths of, or severe injuries to, more than 519 children in Iraq, predominantly boys, across conflict-affected areas. During the first three months of 2023 alone, 16 children were affected by unexploded ordnance in seven separate incidents; four were killed and 12 sustained severe and permanent injuries, illustrating the continuing danger posed to Kurdish and other Iraqi children[78]. Beyond immediate physical harm, and as reflected in Dr. Kawa Omar's experience as a pediatric specialist, children exposed to blast injuries may suffer long-term neurological consequences. Such injuries can have serious implications for brain development, learning capacity, and psychological well-being. It is therefore possible to conclude that one often overlooked danger associated with the use of high-impact explosive weapons in civilian areas, particularly with respect to children, is the emergence of symptoms such as vertigo, cognitive impairment, and psychological disorders despite the absence of immediately visible external injuries. These "invisible" or delayed harms are not ordinarily incorporated into existing

methodologies for assessing civilian harm. When such injuries are disregarded, this omission may amount to a failure to fully comply with IHL obligations, particularly the principles of proportionality and precaution.

In 2022, eighty-six states supported the Political Declaration on Strengthening the Protection of Civilians from the Humanitarian Consequences Arising from the Use of Explosive Weapons in Populated Areas, recognizing that the use of explosive weapons in populated areas (EWIPA) has contributed to a pattern of harm to civilians and civilian objects[79]. Although this Political Declaration represents significant normative progress, it arrived after many civilians in the KRI had already suffered widespread TBI and concussive injuries, particularly during the 2014 –2017 period. However, the Declaration does not establish a legal prohibition, as it constitutes a political commitment rather than a binding legal instrument. Moreover, it does not explicitly address "invisible" injuries such as blast-induced TBI, which remain underrepresented in both reporting and protection frameworks.

In light of the above, the implementation of IHL rules in relation to civilian TBI in the KRI reveals a significant gap between legal standards and operational reality. The use of explosive weapons with wide-area effects in civilian areas has, in practice, undermined the effective application of the principles of distinction, proportionality, and precaution, due to the persistent exposure of civilian populations to blast overpressure known to cause measurable and foreseeable injury to the nervous system. In particular, the absence of TBI considerations in pre-attack assessments, proportionality analysis, and post-attack evaluations indicates an undervaluation of this category of civilian harm within current targeting paradigms. This concern is supported by clinical experts in the region, who have identified systemic and institutional barriers to TBI care, including the absence of dedicated data collection mechanisms, limited capacity to diagnose TBI at the point of emergency admission, the lack of specialized units to monitor war-related neurological trauma, and insufficient follow-up systems for affected patients. Moreover, the geographical position of the KRI, situated in close proximity to recurring interstate military tensions particularly those involving Iran, the United States, and Israel in 2026, has further increased civilian exposure to indirect effects of hostilities. In this context, the growing body of evidence on civilian traumatic brain injuries as "invisible wounds" should be understood not only as a humanitarian concern but also as a legal warning to military actors. It underscores that the use of high-impact and

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acoustically intense explosive weapons in or near populated areas is likely to produce forms of harm that are less visible yet foreseeable and severe. Consequently, the failure to adequately account for such injuries risks undermining compliance with international humanitarian law, particularly where these effects are excluded from precautionary planning and proportionality assessments despite their foreseeable occurrence.

7. Conclusions

The changing nature of modern warfare has further highlighted the limitations of a traditionally visibility-based understanding of IHL. As this research has shown, the fact that blast-induced TBI is "invisible" does not diminish its reality as a direct and foreseeable consequence of explosive weapon use. It is through the integration of neuroscientific evidence with legal doctrine that a significant humanitarian and legal gap becomes apparent: namely, the persistent failure to acknowledge and incorporate concussive injury within civilian protection frameworks.

On a scientific level, the findings of this study demonstrate that primary blast waves are damaging at a biomechanical level, causing axonal shearing and disruption of the blood–brain barrier even in the absence of visible external injuries. This form of neurological injury is not merely theoretical; it is a direct consequence of the mechanical forces generated by modern munitions. From a legal perspective, this fact calls for a reassessment of certain foundational elements of IHL. The foreseeability of TBI, already acknowledged through mandatory screening protocols for military personnel in several armed forces, supports its inclusion within the scope of the principles of distinction and proportionality, particularly under Article 51(5)(b) of AP I. Accordingly, assessments of incidental harm should incorporate blast-induced neurological effects. This also gives rise to concrete operational implications: the duty of "constant care" under Article 57 requires the integration of predictive blast modelling, overpressure mapping, and improved risk-assessment tools into targeting processes. In this context, the failure to account for concussive harm is increasingly difficult to justify, particularly where technological capabilities to detect and anticipate such harm already exist.

More importantly, in the specific context of the Kurdistan Region of Iraq (KRI), these conclusions highlight a significant gap between international law and its practical implementation on the ground. The persistent nature of bombings and missile strikes across cities such as Erbil, Sulaymaniyah, and Duhok results in substantial "invisible" trauma among civilian populations. The absence of a dedicated registry for patients with blast-

related injuries, combined with the continued use of explosive weapons in densely populated areas, further underscores challenges in the practical realization of the principles of distinction and precaution. Whether the number of recorded cases of blast-induced TBI is high or low, the obligation to recognize, document, and mitigate such harm remains grounded in international humanitarian law. The failure to account for foreseeable neurological injury on the basis that it is "invisible" is not neutral in effect; rather, it raises concerns regarding compliance with the principle of constant care and highlights the need for closer integration between legal frameworks and scientific evidence. In this sense, "invisible" injury often developing as a delayed or progressive condition, represents a serious and ongoing risk to civilian populations that relevant authorities in the KRI must take into account in both policy and practice.

7.1 Recommendations

1.The KRI Ministry of Health, in cooperation with international actors, should establish and operationalize a longitudinal registry to document war-related neurological trauma among civilians exposed to blast incidents.

2.Stakeholders at regional and international levels should accelerate the deployment of advanced radar systems and integrated early-warning mechanisms within the KRI to detect incoming drones and missiles. The timely and accurate warning of aerial bombardment constitutes a basic prerequisite for preserving civilian physical safety against both direct impact and blast overpressure.

3.Armed actors operating within or adjacent to the KRI should update the Collateral Damage Estimation Methodology (CDEM) to incorporate blast overpressure gradients as a means of estimating "invisible" neurological effects on civilian populations.

4.KRI stakeholders should expedite the deployment of advanced neuro-diagnostic tools, such as MRI imaging and blood-based biomarkers, across conflict-affected governorates to facilitate the detection of otherwise unidentifiable mild TBI in emergency care settings.

5."Neurological harm" should be formally recognized as a distinct category in the reporting of civilian casualties by humanitarian organizations and fact-finding commissions, in order to classify blast-induced TBI as a legally cognizable injury under international law.

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