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Health Risks, Injury Mechanisms and Long-Term Consequences of Mixed Martial Arts – A Literature Review

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Abstract

Background: Mixed martial arts (MMA) combines striking and grappling and permits intentional head blows, creating risks of acute and cumulative trauma despite modern regulations.

Aim: To review injury incidence, mechanisms, risk factors and long-term health consequences of MMA training and competition.

Materials and methods: PubMed, Scopus, Web of Science and Google Scholar were searched for peer-reviewed studies, reviews and case reports on MMA, injury, traumatic brain injury and chronic traumatic encephalopathy. Twenty-three sources were included.

Results: Injury rates ranged from 23.6 to 54.5 per 100 athlete-exposures, with the head and neck most often affected. Concussion incidence was approximately 14.7–16.1 per 100 athlete-exposures, while knockout statistics underestimated total concussive and subconcussive exposure. Rotational acceleration, facial strikes, repeated blows and delayed stoppage increased neurological risk. Heavier male fighters, older athletes, professionals, athletes with previous knockouts and losing fighters were especially vulnerable. Long-term effects included impaired memory and processing speed, psychomotor deficits, structural brain changes, sensory dysfunction and reduced quality of life.

Conclusions: MMA carries a high burden of acute and cumulative injury. Earlier stoppages, individualized medical suspensions, baseline testing, ringside care and long-term neurological monitoring are required, together with standardized prospective research.

Keywords: mixed martial arts, traumatic brain injury, chronic traumatic encephalopathy, injury, contact sports

1. Introduction

Mixed martial arts (MMA) is a full-contact combat sport integrating punches, kicks, knees, elbow strikes, takedowns, grappling, joint locks, and chokeholds within a single competitive

framework. Unlike sports in which contact with the head is accidental or prohibited, MMA permits deliberate strikes to the head as legitimate techniques for gaining tactical advantage and ending a contest. A fighter may win by knockout, technical knockout, submission, referee or physician stoppage, disqualification, or judges' decision. Neurological incapacitation, the inability to defend intelligently, and the cumulative effects of repeated physical trauma are therefore embedded within the sport's competitive structure. [1–3]

Modern MMA has adopted weight divisions, timed rounds, gloves, ringside physicians, medical suspensions, and prohibitions against selected techniques such as headbutting, spinal attacks, and certain strikes against grounded opponents. These regulations were introduced partly to transform early unregulated contests into a standardized professional sport and to reduce avoidable injury. Nevertheless, the Unified Rules continue to permit repeated intentional blows to the head and victory through loss of consciousness or an inability to continue defending. Regulation has consequently altered the circumstances and mechanisms of trauma without removing the central source of neurological risk. [4, 5]

A knockout generally occurs when a fighter becomes unconscious, severely disoriented, or physically unable to continue after a strike. A technical knockout may be declared when a referee, physician, or fighter's corner determines that the athlete is no longer capable of defending safely. Technical knockouts are heterogeneous because they may result from repetitive head strikes, body strikes, exhaustion, orthopedic injury, laceration, or another medical condition. A knockout caused by direct head trauma is strongly suggestive of concussion or more severe traumatic brain injury, whereas a technical knockout caused by repetitive head strikes is a probable but not automatically clinically confirmed concussive event. [1, 2]

The distinction between a knockout or a technical knockout is a matter of sports terminology. However distinguishing between different types of injuries and levels of severity is essential when interpreting MMA epidemiology. Studies that count only physician-diagnosed concussions identify a narrower category than investigations that classify all knockouts or head-strike technical knockouts as traumatic brain injuries. Analyses of other injuries include lacerations, fractures, contusions, sprains, strains, joint trauma, and ocular or upper-airway injuries. Fight records may identify dramatic outcomes but fail to capture concussions that do not end a contest, delayed symptoms, or repetitive subconcussive exposure. Injury incidence, concussion incidence, match-ending head trauma, and total head-impact exposure are therefore related but non-equivalent measures. [6, 7]

Available research consistently characterizes MMA as a sport with a substantial injury burden, although numerical estimates vary according to jurisdiction, study period, competitive level, injury definition, and surveillance method. [4, 7]

The biomechanical severity of a head impact depends on multiple factors. Linear acceleration, rotational acceleration, direction of movement, impact duration, strike location, tissue deformation, frequency of impacts, and the time between impacts may all influence injury risk. [8, 9]

MMA athletes do not experience traumatic risk uniformly. Epidemiological studies identify differences associated with weight class, sex, age, professional status, previous knockout history, contest duration, bout significance, and whether the athlete wins or loses. [1, 8, 10]

The consequences of MMA trauma extend beyond acute concussion. Research involving combat-sport athletes has identified abnormalities or deficits involving memory, processing speed, reaction time, psychomotor performance, attention, olfactory function, speech characteristics, quality of life, brain structure, diffusion imaging, and biochemical markers. Repetitive head-impact exposure is also associated with concern about chronic traumatic encephalopathy. [11–14]

Other anatomically important injuries include orbital fractures, optic-nerve injury, nasal and mandibular fractures, periocular lacerations, retinal injury, tympanic-membrane injury, auricular hematoma, vascular injuries and laryngopharyngeal trauma associated with chokeholds. These conditions may produce lasting functional impairment even when no intracranial lesion is identified. [15–18]

The MMA related injuries are diverse, vary greatly in severity depending on a multitude of factors and are often characterized by delayed consequences. It is therefore justified to continuously broaden and summarize available knowledge on this matter, in order to provide more effective care for MMA athletes.

2. Objective of the Article

The objective of this article is to review the current literature regarding the health risks and potential long-term consequences of mixed martial arts training and competition. The authors aimed to determine injury incidence, types of sustained injuries, population-specific risks based on sex and weight class and the long-term neurological outlook for practitioners.

3. Materials and Methods

The methodology for this review involved a systematic and comprehensive search of established scientific databases, including PubMed, Scopus, Web of Science, and Google Scholar. The search focused on peer-reviewed literature, original articles, systematic reviews, review papers and clinical case reports. The literature search was conducted using a combination of keywords to identify relevant studies. Primary search terms included: "mixed martial arts", "acute injury", "chronic injury", "MMA", "MMA health risk", "chronic traumatic encephalopathy", "trauma-related encephalopathy". A total of 23 core sources were selected for this review, providing a possibility for addressing the aims of this paper.

4. Results

4.1. Epidemiological Burden and Interpretation of Injury Incidence

The reported incidence of injury in MMA depends heavily on how exposure is defined. Athlete-exposure commonly represents one athlete participating in one contest, meaning that one bout produces two athlete-exposures. Some studies report injuries per 100 athlete-exposures, others use injuries per 1,000 athlete-exposures, and still others calculate injury relative to rounds, minutes, or contests. Direct comparison requires conversion to equivalent denominators and consideration of whether multiple injuries sustained by one fighter were counted separately. [4, 7]

The weighted injury rate of 246.4 per 1,000 athlete-exposures reported for male fighters corresponds to approximately 24.6 injuries per 100 athlete-exposures. This does not necessarily mean that 24.6% of athletes were injured because a single athlete may sustain multiple injuries during one contest. The female estimate of 101.9 injuries per 1,000 athlete-exposures was based on a smaller amount of samples and is consequently much less precise than the estimate generated from the substantially larger male sample. [7]

Post–Unified Rules competition injury rates ranged between 23.6 and 54.5 injuries per 100 athlete-exposures. This broad range reflects differences in whether researchers used direct ringside examination, post-bout assessment, official commission records, public fight databases, video analysis, or combinations of these sources. Ringside and post-bout assessment may detect injuries omitted from public records, whereas large retrospective databases provide broader samples but less clinical detail. [4, 7]

Soft-tissue injuries are consistently prominent in MMA. Lacerations, abrasions, and contusions accounted for approximately 20.7% to 56.9% of injuries in studies conducted after adoption of the Unified Rules, while earlier systematic evidence placed the combined proportion of these injuries even higher. Such injuries may be visible and readily documented, which partly explains their frequency in commission and ringside records. Their prominence should not be interpreted as evidence that most MMA injury is clinically minor, because superficial trauma can occur simultaneously with concussion, fracture, or ocular damage. [4, 7]

One of the studies of UFC fights from 2016 through 2019 identified 288 head injuries in 408 fights, corresponding to approximately 35 head injuries per 100 athlete-exposures. Traumatic brain injury was the most frequently recorded category of head injury and occurred at a rate of approximately 16 per 100 athlete-exposures. Injury rates were particularly high in fights ending by knockout or technical knockout, demonstrating the relationship between fight outcome and acute neurological trauma. [19]

Match-ending head trauma has also been assessed separately from total injury incidence. In 844 professional fights held between 2006 and 2012, the knockout rate was 6.4 per 100 athlete-exposures and the technical-knockout rate caused by repetitive strikes was 9.5 per 100 athlete-exposures. The combined incidence of match-ending head trauma was therefore 15.9 per 100 athlete-exposures, with approximately 31.9% of matches ending through one of these mechanisms. [20]

Australian data from 143 events conducted between 2020 and 2023 showed that 34% of male contests and 23% of female contests ended by knockout or technical knockout secondary to head strikes. The corresponding rates were 16.6 per 100 athlete-exposures for amateur men, 18.7 for professional men, 12.6 for amateur women, and 7.4 for professional women. These findings demonstrate both sex-related and competition-level differences within a national MMA system outside the principal North American datasets. [1]

Knockout and technical-knockout rates do not represent the full incidence of concussion. Concussion may occur without loss of consciousness, and a technical knockout may be declared for reasons unrelated to brain injury. Athletes can sustain a clinically meaningful concussion during a fight that continues to a decision or ends through submission. [6, 9]

Contemporary systematic evidence places reported concussion incidence at approximately 14.7 to 16.1 per 100 athlete-exposures, but the estimate varies with diagnostic criteria. Studies that classify every knockout and technical knockout as a concussion may overestimate clinical concussion when stoppages are caused by body strikes or orthopedic injury. Studies relying

only on physician diagnosis, athlete self-report, or observable unconsciousness may underestimate cases with less dramatic or delayed symptoms. Concussion can produce confusion, memory disturbance, headache, dizziness, irritability, fatigue, poor concentration, visual disturbance, imbalance, and slowed information processing without prolonged unconsciousness. Fighters may interpret these symptoms as ordinary consequences of exertion, dehydration, weight cutting, pain, or routine gym training. The normalization of post-impact symptoms within combat-sport culture can reduce reporting and delay medical evaluation. [4, 6, 9, 17]

Comparison with taekwondo illustrates how injury patterns are shaped by sport-specific rules and techniques. A systematic review of taekwondo reported weighted injury rates of approximately 58 per 1,000 athlete-exposures for males and 52.7 for females. Concussion rates were approximately 13.3 per 1,000 athlete-exposures for males and 11.4 for females. Lower-extremity injuries were especially prominent in taekwondo, whereas MMA literature more consistently identifies the head and face as the principal injury region. [4, 21]

The continued presence of substantial injury after the adoption of the Unified Rules raises questions about how much protection regulation can provide while deliberate head striking remains legal. The contemporary systematic review concluded that injury rates and injury types appeared broadly similar to those recorded before full adoption of the modern rules. This finding does not prove that the Unified Rules failed to prevent specific catastrophic mechanisms, but it indicates that prohibiting selected techniques cannot eliminate trauma intrinsic to repeated intentional head contact. [4, 5]

4.2. Total Impact Exposure and Limitations of Head Injury Reporting

Knockout statistics substantially underestimate total head-impact exposure. Professional fight data indicate that athletes receive an average of 2.41 significant head strikes and 6.30 total head strikes per minute. Even a contest of moderate duration can therefore expose a fighter to dozens of head contacts, although the distribution between opponents depends on tactical dominance, defensive performance, and fight location. [20]

Most recorded head impacts do not immediately produce an observable concussion. In instrumented-mouthguard research, 451 verified impacts above 10 g were recorded during nineteen sparring sessions and eleven competitive events. Most recorded impacts were below the highest acceleration ranges thus making subconcussive impacts the most common type. A subconcussive impact is an impact that does not produce a recognized or clinically diagnosed

concussion. Repeated subconcussive exposure has been associated with imaging, cognitive, and biochemical changes in contact-sport populations, although the long-term clinical significance of specific changes remains uncertain. [9, 11, 22] A fighter who rarely loses by knockout may accumulate substantial head-impact exposure through various training activities. The limited surveillance of training injury is therefore one of the most serious deficiencies in MMA epidemiology. Competition records provide only intermittent snapshots of a much larger exposure history. [4, 7] Lower-weight fighters may be particularly relevant to the study of cumulative exposure. Lighter athletes frequently maintain higher movement rates and participate in longer combinations or striking exchanges. An individual lightweight punch may be less likely to produce immediate unconsciousness than an individual heavyweight strike, but the greater number of impacts may produce a distinct cumulative-risk profile. [8, 10]

4.3. Biomechanical Mechanisms of Concussion and Loss of Consciousness

Head impact produces both translational and rotational motion. Linear acceleration contributes to pressure gradients and focal contact effects, whereas angular acceleration produces rotational deformation and shear strain within neural tissue. [6, 9]

Instrumented-mouthguard research shows that competitive MMA impacts can reach substantial acceleration levels. Across all recorded impacts, the mean resultant linear acceleration was approximately 38 g, while mean resultant angular acceleration was approximately 2,567 rad/s². Competitive impacts were generally more severe than sparring impacts, supporting the expected relationship between fight intensity and impact magnitude. Five of the eleven instrumented competitive events resulted in physician-diagnosed concussion. In those events, the impact with the highest angular acceleration averaged approximately 86.7 g and 7,561 rad/s². Maximum Head Impact Power averaged approximately 20.6 kW in concussion events and 7.15 kW in events without diagnosed injury. [9]

The researchers could not always identify a single injury-producing strike because concussed fighters experienced multiple impacts during their bouts. This suggests that concussion may result from an interaction between one severe event, preceding impacts, individual susceptibility, and incomplete neurological recovery between blows. A model based only on the single largest linear acceleration is unlikely to capture this complexity. [8, 9]

Head-motion direction is strongly associated with transient loss of consciousness. In a case-control analysis of knockout and non-knockout strikes, axial-plane head motion had an odds ratio of 45.3 for transient loss of consciousness. Sagittal and coronal movement, non-fist

striking implements, and impacts to the mandible or maxilla were also associated with loss of consciousness. [23]

The mandible is an especially important impact location because a blow to the jaw can create rapid rotation around the cervical axis. In the large professional video analysis, more than half of the reviewed knockouts resulted from direct impact to the mandibular region. Maxillary and temporal impacts also accounted for substantial proportions of knockout-producing blows. Secondary contact with the arena may also compound the primary strike. An incapacitated fighter may sustain an initial blow, lose postural control, strike the floor or cage, and then receive additional opponent strikes before the referee intervenes. This sequence exposes the athlete to impacts arising from different directions and mechanisms within a very short period. [2, 23]

The time between functional incapacitation and stoppage is clinically significant. The average delay between the knockout-producing strike and contest stoppage was approximately 3.5 seconds. During that period, losing fighters received an average of 2.6 additional head strikes, with as many as twenty additional strikes recorded in an extreme case.

Technical knockouts caused by repetitive strikes may involve an even larger accumulation of impacts. During the thirty seconds immediately preceding stoppage, losing athletes sustained an average of 18.5 strikes, approximately 92.3% of which were directed toward the head. The attack rate increased as stoppage approached, indicating a potential prevention window in which earlier recognition of failed intelligent defense could eliminate several unnecessary impacts. [2]

4.4. Weight Class as a Determinant of Traumatic Risk

Weight class influences both the probability of fight-ending trauma and the distribution of repeated impacts. Heavier fighters generally generate greater striking momentum. Lighter fighters often move and strike at higher rates. The association between weight and neurological risk therefore seems to be multidimensional. In an analysis of 1,903 contests, combined knockout and technical-knockout rates were approximately 19.53 per 100 athlete-exposures in middleweight, 20.8 in light heavyweight, and 26.09 in heavyweight competition. Knockout or technical-knockout stoppage occurred in 52.1% of male heavyweight fights but only 7.9% of female strawweight fights. Relative to male lightweights, the risk of a contest ending through knockout or technical knockout caused by head strikes was approximately 80% higher for middleweights, 100% higher for light heavyweights, and 206% higher for heavyweights. These

results identify the upper male weight divisions as priority groups for prevention of acute fight-ending neurological trauma. [8, 10]

Biomechanical reconstruction provides additional detail. Lightweight and heavyweight fighters sustained broadly similar overall head-impact frequencies and intervals within the analyzed fights, but the types and magnitudes of their impacts differed. As suggested earlier, lightweights experienced a greater frequency of very low and high-magnitude punch impacts, whereas heavyweights experienced more high-category brain strains from elbow strikes. [8]

4.5. Sex-Related Differences

Male and female fighters display different patterns of fight-ending trauma and total strike exposure. Men generally experience a greater proportion of contests ending by knockout or technical knockout secondary to head strikes. In the Australian cohort, 34% of male contests and 23% of female contests ended through these outcomes. [1]

The UFC craniofacial and traumatic-brain-injury analysis similarly found a higher head-injury rate in male athletes. Male fighters experienced approximately 37 head injuries per 100 athlete-exposures, compared with approximately 23 per 100 athlete-exposures in female fighters. The imbalance in available fight numbers means that the male estimate is more statistically stable. [19]

Lower fight-ending trauma among women does not necessarily mean lower total head-impact exposure. In the analysis of 2,488 fights, women delivered more total and significant head strikes per minute than men. Female fights were consequently characterized by a relatively high frequency of head contact despite a lower proportion of stoppages caused by head trauma. Head trauma ended approximately 32.2% of male contests and 23.1% of female contests in that dataset. The coexistence of higher strike frequency and lower fight-ending trauma among women may reflect differences in absolute striking force, head and body mass, tactical pacing, defensive behavior, or the relationship between impact frequency and impact magnitude. [20]

Within women's competition, weight class remains relevant. Female bantamweights had a substantially greater risk of fights ending through knockout or technical knockout than female strawweights. However, the smaller number of female divisions and comparatively limited number of female contests restrict detailed analysis across the weight spectrum. [10]

Potential biological contributors to sex differences remain uncertain. Differences in neck strength, head mass, hormonal status, axonal structure, symptom reporting, and recovery have

been discussed in concussion research, but MMA-specific evidence has not established a single mechanism explaining the observed patterns. [6, 20]

4.6. Age, Previous Knockout, Professional Status, and Other Populations at Risk

Older age is associated with a greater probability of knockout and technical knockout. Professional fighters aged thirty-five years or older had approximately twice the odds of these outcomes compared with younger competitors in the analyzed cohort. Age may represent accumulated exposure, slower reaction time, reduced recovery capacity, changes in defensive performance, or selection effects rather than a purely chronological mechanism. Previous knockout history is another relevant predictor. Each previously sustained knockout or technical knockout was associated with increased odds of a future knockout. Prior knockout may indicate greater cumulative trauma, a high-risk fighting style, defensive limitations, prolonged career exposure, or increased neurological susceptibility. [6, 20]

Professional competitors appear to have higher overall injury rates in several studies. Earlier evidence reported approximately 135.5 injuries per 1,000 athlete-exposures among professionals and 71.0 among amateurs. The contemporary systematic review also concluded that professional fighters appeared to sustain more lacerations, fractures, and cartilage injuries. [4, 7]

The losing fighter is consistently a high-risk participant. Losing athletes are exposed to progressively increasing attack rates, repeated unanswered strikes, impaired defensive behavior, and possible secondary impact with the floor or cage. Eye- and facial-injury data also show greater injury odds among losing fighters. [2, 16]

Bout significance and duration may influence risk. High-profile contests may involve closely matched elite opponents, greater psychological pressure, and a greater willingness to continue through injury. Longer fights provide more time for cumulative exposure, although severe knockouts can also occur during early exchanges. [2, 20]

4.7. Craniofacial, Maxillofacial, Ocular, and Other MMA-Related Trauma

Neurological injury in MMA frequently coexists with structural trauma to the face and skull. Lacerations are common because facial tissues contact gloves, elbows, knees, feet, the opponent's skull, and the arena surface. Fractures may involve the nasal bones, orbit, zygomatic complex, frontal bone, maxilla, or mandible. The middle third of the face is particularly vulnerable because it contains the nasal bones, zygomatic complex, maxillary structures, and

orbital walls. Injuries to these regions may produce deformity, impaired breathing, diplopia, ocular-movement restriction, sensory loss, or damage to the globe and optic nerve. Lower-third injuries include mandibular fracture and soft-tissue trauma. [15, 19]

Facial contact and brain injury are biomechanically linked. Mandibular and maxillary strikes are associated with transient loss of consciousness because they may generate substantial rotational head motion. A facial fracture may therefore coexist with concussion or indicate that considerable force was transferred through the head and neck. [15, 23]

Eye trauma also constitutes a significant percentage of MMA-related injuries. Large-scale commission data identified 1,442 MMA injuries in 2,704 contests of which eye trauma represented approximately 25.59%. Periocular lacerations were the most common ocular-region injury, while orbital fractures represented a clinically important proportion of MMA eye trauma. Longer contests and losing status increased the odds of eye and facial injury. This finding is consistent with evidence that losing fighters receive repeated strikes as stoppage approaches. Earlier intervention may therefore prevent not only additional brain trauma but also orbital, eyelid, nasal, and facial injury. [16]

Ear trauma represents another distinct injury category. Repeated friction and blunt force during grappling can produce auricular hematoma and permanent cauliflower-ear deformity. Tympanic-membrane injury may also occur after direct impact or sudden pressure changes. Ringside and post-bout examination should therefore include the external ear and tympanic membrane when symptoms or mechanisms indicate possible injury. [5]

MMA injury is not limited to striking. Commonly performed chokeholds apply pressure to the neck, larynx, pharynx, airway, and vascular structures. Chokes are usually recorded as submission techniques rather than injuries, meaning that their medical consequences may be underrepresented in competition databases. A mixed-methods study of 160 Brazilian jiu-jitsu and MMA practitioners found that 88% had experienced at least one laryngopharyngeal symptom after chokehold exposure. Sore throat was reported by 79%, and painful swallowing was reported by 66%. Most symptoms resolved within one week, but some athletes experienced prolonged symptoms or permanent voice change. Loss of consciousness from chokeholds was reported by a substantial minority of respondents, with many experiencing more than one episode. Most episodes occurred during routine training rather than sanctioned competition. Training environments may lack ringside physicians, formal record systems, and standardized post-event medical assessment. Care-seeking behavior was limited. Most athletes continued training while symptomatic, and many indicated that they would not seek medical evaluation

unless symptoms persisted for an extended period. Among the small number who did seek medical care, a notable proportion were diagnosed with hyolaryngeal fractures. [1, 17]

4.8. Acute Neurocognitive Effects

Concussion can produce immediate impairment in reaction time, visual processing, attention, memory, balance, and executive function. Studies using the King–Devick test identified significantly slower post-fight performance among athletes who sustained head trauma. The task depends on coordinated eye movements, visual attention, processing speed, and language output. Memory and processing speed appear especially vulnerable. MMA research has identified poorer memory, slower cognitive processing, delayed reaction time, impaired auditory attention, and altered visuospatial performance following head trauma. The degree and duration of these deficits vary across athletes and studies. [6, 13]

Speech and language remain underexamined. The systematic review of concussion outcomes identified limited direct assessment of speech and communication despite the possibility that dysarthria, altered articulation rate, word-finding difficulty, and dysfluency may accompany neurological dysfunction. Speech analysis could become a useful component of longitudinal monitoring if validated in larger MMA-specific cohorts. [6]

4.9. Chronic Brain Changes and Cognitive Decline

Repeated head trauma has been associated with abnormalities involving the thalamus, caudate, hippocampus, amygdala, corpus callosum, cingulate regions, and other white- and gray-matter structures. These structures contribute to memory, processing speed, motor control, emotional regulation, attention, and communication between distributed brain networks. [11, 13]

The review of epidemiology and cognitive decline concluded that head trauma accounted for approximately 58% to 78% of all injuries reported in the included MMA literature. Processing speed, verbal memory, and psychomotor speed were repeatedly identified as affected functions. The thalamus and caudate were among the brain structures most consistently implicated. Professional-fighter research has associated greater fight exposure with smaller volumes in selected subcortical structures and with slower processing speed. Diffusion abnormalities have also been observed in white-matter regions involved in interhemispheric and network communication. These relationships are consistent with cumulative neurological stress but do not establish that every exposed fighter will develop clinical impairment. [11, 13]

The damage accumulating over time due to repeated head trauma ultimately leads to permanent and clinically significant changes. [11, 13]

Chronic traumatic encephalopathy is a neurodegenerative disease associated with repetitive concussive and subconcussive head-impact exposure. Its defining neuropathological feature is abnormal accumulation of hyperphosphorylated tau around small blood vessels at the depths of cortical sulci. Early changes commonly involve frontal, temporal, or parietal regions, while later disease may involve medial temporal structures, brainstem nuclei, olfactory bulbs, and additional areas. Advanced chronic traumatic encephalopathy may be accompanied by frontal or temporal atrophy, ventricular enlargement, cavum septum pellucidum, and septal abnormalities. These features are not individually specific to the disease and cannot establish a diagnosis in a living athlete. Definitive diagnosis currently requires postmortem neuropathological examination. [11]

Repetitive head-impact exposure is strongly associated with the known disease model, but not every exposed athlete develops chronic traumatic encephalopathy. The additional biological, genetic, environmental, and exposure-related factors determining individual susceptibility remain incompletely understood. Neuroimaging research seeks biomarkers that can detect or monitor chronic effects during life. Structural magnetic resonance imaging measures regional morphology and volume, diffusion imaging evaluates water movement and white-matter organization, magnetic resonance spectroscopy assesses selected metabolites, functional imaging evaluates patterns of brain activity, and positron-emission tomography can examine metabolism or molecular binding. [11]

Among professional fighters, structural imaging has identified associations between fight exposure and reduced volume in selected subcortical structures. Cavum septum pellucidum has also been reported more frequently in fighters than in control groups. These findings may indicate consequences of repeated trauma but are not specific enough to function as standalone diagnostic criteria. Diffusion-imaging findings suggest that knockout history may be associated with altered white-matter integrity in regions such as the corpus callosum and posterior cingulate. Diffusion measures are sensitive to changes in axonal organization or myelin but can be influenced by multiple neurological and developmental processes. They should therefore be interpreted as research indicators rather than proof of a specific neurodegenerative diagnosis. [11, 13]

4.10. Biochemical Evidence of Subconcussive Effects

Fluid biomarkers may reveal physiological changes that are not detected by routine symptom assessment. Glial fibrillary acidic protein is associated with astroglial injury, ubiquitin C-terminal hydrolase L1 is associated with neuronal injury, and brain-derived neurotrophic factor participates in neuronal survival, synaptic plasticity, regeneration, and memory-related processes. An exploratory study compared ten MMA fighters with ten resistance-training participants and ten sedentary controls. Blood samples were collected before, immediately after, and seventy-two hours after a sparring session. The researchers examined UCH-L1, GFAP, and BDNF concentrations to evaluate possible biological responses to repeated subconcussive head impacts. [22]

Baseline BDNF differed between fighters and active controls, and BDNF declined significantly between the immediate and seventy-two-hour post-sparring measurements. No comparable increase in the number or severity of reported symptoms occurred. The discordance between biochemical findings and self-reported symptoms supports the principle that symptom absence does not necessarily establish physiological normality. [22]

Biomarker responses did not follow a simple pattern in which every marker increased after exposure. Concentrations can be influenced by timing, release, clearance, baseline physiology, exercise stress, assay characteristics, and the cellular process measured. A reduction or lack of change cannot automatically be interpreted as absence of neurological effect. [22]

4.11. Olfactory Function, Cognition, and Quality of Life

Traumatic effects may involve sensory and functional domains not routinely included in concussion protocols. Olfactory pathways are vulnerable because head trauma can damage nasal structures, olfactory nerve fibers, olfactory bulbs, or frontal and temporal regions involved in smell identification and interpretation. A study comparing fourteen MMA fighters with fourteen age- and sex-matched controls found significantly poorer olfactory identification among fighters. Fighters did not report an equivalent subjective decline, suggesting that mild olfactory impairment may occur without conscious recognition. [14]

The same investigation identified poorer cognitive performance and reductions in multiple quality-of-life domains among fighters. Reported differences involved physical limitations, pain, general-health perception, vitality, social functioning, and emotional limitations. Taste performance was lower on average but did not differ significantly between groups. [14]

Olfactory impairment is clinically meaningful because smell contributes to hazard detection, food enjoyment, emotional memory, and social well-being. Unrecognized hyposmia may delay

medical investigation and can reduce flavor perception even when direct gustatory testing remains normal. [14]

The findings require cautious interpretation because the sample was small and cross-sectional. Nasal injury, infection history, smoking, medication use, and pre-existing olfactory differences could influence performance. Longitudinal research beginning before substantial combat exposure would provide stronger evidence regarding causality. [14]

4.12. Prevention, Medical Supervision, and Regulatory Implications

Prevention in MMA cannot rely on one intervention because the sport produces acute high-magnitude trauma, cumulative subconcussive exposure, laceration, fracture, ocular injury, orthopedic injury, and choke-related airway trauma. Prevention must operate during athlete education, training, pre-participation assessment, competition, immediate post-bout care, recovery, and long-term follow-up. Pre-participation assessment should document previous knockouts, technical knockouts, concussions, persistent neurological symptoms, visual injury, facial fracture, cervical-spine trauma, and relevant medical conditions. Previous knockout and older age predict greater future fight-ending risk and should influence medical assessment rather than being treated as descriptive background information. [4]

Baseline cognitive, visual, balance, speech, symptom, and potentially olfactory testing may improve interpretation after injury. No single normal test should automatically authorize immediate return to contact. Repeated evaluation is important because symptoms and performance deficits may evolve during the hours or days after trauma. [4]

Referee education offers a direct opportunity to reduce preventable exposure. Losing athletes received an average of 2.6 additional head strikes after the knockout-producing blow and approximately 18.5 strikes during the thirty seconds before technical-knockout stoppage. Earlier recognition of failed intelligent defense could prevent several impacts without changing the outcome of a contest in which the fighter is already incapacitated. Stoppage decisions should consider posture, visual tracking, purposeful defense, motor coordination, delayed reactions, repeated unanswered head strikes, and secondary impact with the floor. Athletes with previous knockout history, advanced competitive age, or participation in high-risk weight divisions may justify especially careful observation. [1, 4]

Protective equipment presents a difficult balance. Gloves protect the hands and may reduce some superficial injury, but existing evidence does not establish that small MMA gloves reliably prevent brain acceleration. Head protection may reduce selected superficial injuries in

training but may not prevent rotational acceleration and could alter athlete behavior. Equipment changes should therefore be evaluated biomechanically and behaviorally. [5, 9]

Ringside physicians must be prepared for neurological emergencies, cervical-spine injury, facial fracture, ocular trauma, airway injury, orthopedic injury, and laceration. An unconscious athlete should be treated as having a possible cervical-spine injury until appropriate assessment excludes it. Medical teams should coordinate emergency procedures and transport plans before competition begins. [5]

Post-bout medical suspension should reflect injury mechanism, symptoms, examination findings, previous history, and clinical recovery rather than relying only on the official fight result. A fighter who loses by decision may still have sustained substantial repetitive head trauma, while a submission loss may involve laryngeal, vascular, or joint injury. [17, 20]

Long-term monitoring should continue beyond the athlete's active career. Periodic evaluation of cognition, mood, speech, balance, olfaction, vision, and neurological function may identify persistent or progressive change. Retired fighters are especially important because chronic symptoms may become evident only after substantial exposure has ceased. [13]

5. Discussion

The supplied evidence demonstrates that traumatic injury is a frequent and structurally important feature of MMA. Competition injury rates commonly range from approximately 23.6 to 54.5 injuries per 100 athlete-exposures, although estimates vary with injury definition and surveillance method. The head and neck are the most frequently injured regions in most studies. [4]

Fight-ending statistics underestimate total neurological exposure because fighters sustain many impacts that do not stop a contest. Professional athletes receive an average of approximately 2.41 significant and 6.30 total head strikes per minute. Sparring also produces repeated verified impacts without necessarily producing an immediately diagnosed concussion. [9, 20]

Biomechanical evidence identifies rotational acceleration, head-motion direction, facial strike location, impact magnitude, and cumulative exposure as important determinants of injury. Axial-plane rotation is strongly associated with transient loss of consciousness, and mandibular or maxillary strikes are especially important mechanisms. [9, 23]

Risk differs across weight classes. Middleweights, light heavyweights, and heavyweights experience greater rates of knockout and technical knockout than lighter male reference

divisions. Lighter fighters may nevertheless experience a substantial cumulative burden because of frequent striking exchanges and repeated subconcussive impacts. [8, 10]

Sex-related patterns are multidimensional. Men generally have higher rates of fight-ending head trauma, whereas women may deliver and receive more head strikes per minute. The female evidence base remains too small to determine whether these patterns produce different long-term neurological consequences. [1, 20]

Older fighters, athletes with previous knockouts, professional competitors, losing fighters, and participants in heavier divisions appear to represent populations at elevated risk. Previous knockout increases the likelihood of future knockout, and losing fighters may receive multiple additional blows immediately before or after functional incapacitation. [2]

The trauma profile extends beyond concussion. Orbital fracture, optic-nerve injury, facial fracture, retinal injury, laceration, auricular trauma, tympanic-membrane injury, and laryngopharyngeal damage may produce permanent functional consequences. Severe visual loss can occur despite the absence of an intracranial lesion on initial imaging. Chokehold-related symptoms on the other hand, are common but frequently disregarded. Most surveyed practitioners continued training while symptomatic, and a clinically important proportion of those who sought medical assessment were diagnosed with hyolaryngeal fractures. Persistent voice change, painful swallowing, breathing difficulty, or structural neck findings require early evaluation. [15–17]

Acute and chronic neurological findings include delayed reaction time, impaired memory, slower processing speed, altered psychomotor performance, structural brain differences, diffusion abnormalities, sensory dysfunction, and potential speech changes. Olfactory impairment and reduced quality of life indicate that relevant consequences may extend beyond conventional concussion symptoms. [6, 13, 14]

Repetitive head-impact exposure is associated with concern about chronic traumatic encephalopathy, but current evidence does not permit definitive diagnosis in living athletes or precise prediction of which fighters will develop the disease. Imaging and fluid biomarkers are promising research tools rather than validated individual diagnostic tests. [11, 22]

MMA-related injury research still requires more in-depth, well designed studies. The principal limitation of current MMA injury science is heterogeneity. Studies use different definitions of concussion, injury, knockout, technical knockout, athlete-exposure, and significant strike. Without standardization, the same event may be classified differently across investigations, limiting comparison and meta-analysis. [4, 7]

Retrospective commission and fight-record studies are vulnerable to incomplete documentation. Official databases may include only injuries recorded immediately by ringside physicians, omitting delayed symptoms or conditions identified after specialist assessment. Public fight statistics contain little information about training exposure, neurological recovery, or long-term outcome. [7, 19]

Training exposure remains particularly underexamined. Earlier systematic evidence identified little reliable information on training injuries among professionals or amateurs and limited long-term neurological follow-up. Instrumented-mouthguard and biomarker studies have begun to address this gap but involve small samples and limited observation periods. [7, 9, 22]

Female fighters, amateur competitors, adolescents, and retired athletes remain underrepresented. Professional male competition dominates the evidence base because its video, statistics, and commission records are comparatively accessible. Risk estimates from elite male fighters should not be treated as universally applicable to all MMA populations. [4, 7]

Mixed cohorts of boxers and MMA fighters limit sport-specific interpretation of chronic brain findings. Future studies should report the sports separately and document sex, age, weight class, training style, sparring intensity, competition frequency, career duration, previous knockout history, and medical suspension history. [11, 13]

Prospective longitudinal cohorts should begin before substantial head-impact exposure. Athletes should undergo repeated cognitive, speech, visual, vestibular, olfactory, imaging, and biomarker assessment throughout their careers and after retirement. Direct impact measurements should be paired with video confirmation and detailed records of symptoms and recovery. [9, 11, 14]

Future research should distinguish cumulative low-magnitude exposure from isolated high-magnitude events. Frequency, magnitude, direction, interval, duration, and anatomical location should be modeled together. Such an approach may explain why heavyweights experience more fight-ending trauma while lighter fighters may accumulate large numbers of non-stoppage impacts. [8, 10]

6. Conclusions

This review demonstrates that mixed martial arts is associated with a substantial burden of acute and cumulative injury, with the head and neck representing the most frequently affected

regions. Although modern regulations have removed some avoidable hazards, they cannot eliminate the neurological risks inherent in repeated intentional head strikes.

Knockouts and technical knockouts capture only a portion of total brain trauma, because fighters may sustain numerous concussive and subconcussive impacts during both competition and training. Rotational acceleration, impact direction, strike location, repeated blows, and insufficient recovery time all contribute to the complexity of injury mechanisms.

Risk is not evenly distributed, as heavier male fighters, older athletes, professionals, competitors with previous knockouts, and losing fighters appear particularly vulnerable to severe outcomes. At the same time, lighter and female fighters may accumulate considerable exposure through a high frequency of head strikes, even when fight-ending trauma is less common.

The consequences of MMA participation extend beyond concussion and include craniofacial fractures, ocular injuries, auricular trauma, laryngopharyngeal damage, and other conditions capable of causing permanent impairment. Evidence of impaired memory, slowed processing speed, altered psychomotor function, structural brain changes, sensory deficits, and reduced quality of life raises concern about the long-term effects of repetitive trauma.

Chronic traumatic encephalopathy remains an important potential consequence, but current methods cannot reliably diagnose it in living athletes or predict individual susceptibility.

Improved prevention should therefore combine earlier referee stoppages, comprehensive ringside care, individualized medical suspensions, baseline testing, and long-term neurological follow-up.

However, the current evidence remains limited by inconsistent injury definitions, small study populations, insufficient monitoring of training exposure, and the underrepresentation of women, amateurs, adolescents, and retired fighters, demonstrating that further high-quality studies are urgently required. Future prospective and longitudinal research using standardized methods is essential to clarify the long-term health consequences of MMA and to develop more effective strategies for protecting athletes.

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The authors declare no conflicts of interest.

Declaration of the use of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used Gemini, ChatGPT and NotebookLM for the purpose of assistance in refining the academic English language of the manuscript, ensuring clarity, consistency, and adherence to scientific writing standards. AI were used for additional linguistic refinement of the research manuscript, ensuring proper English grammar, style, and clarity in the presentation of results. After using this tool/service, the authors reviewed and edited the content as needed and takes full responsibility for the substantive content of the publication.

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