

Head Trauma in Mixed Martial Arts

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Background: Mixed martial arts (MMA) is a full combative sport with a recent global increase in popularity despite significant scrutiny from medical associations. To date, the empirical research of the risk of head injuries associated with this sport is limited. Youth and amateur participation is growing, warranting investigation into the burden and mechanism of injuries associated with this sport.

Purpose: (1) To determine the incidence, risk factors, and characteristics of knockouts (KOs) and technical knockouts (TKOs) from repetitive strikes in professional MMA; and (2) to identify the mechanisms of head trauma and the situational factors that lead to KOs and TKOs secondary to repetitive strikes through video analysis.

Study Design: Descriptive epidemiology study.

Methods: Competition data and video records for all KOs and TKOs from numbered Ultimate Fighting Championship MMA events (n = 844) between 2006 to 2012. Analyses included (1) multivariate logistic regression to investigate factors associated with an increased risk of sustaining a KO or TKO secondary to repetitive strikes and (2) video analysis of all KOs and TKOs secondary to repetitive strikes with descriptive statistics.

Results: During the study period, the KO rate was 6.4 per 100 athlete-exposures (AEs) (12.7% of matches), and the rate of TKOs secondary to repetitive strikes was 9.5 per 100 AEs (19.1% of matches), for a combined incidence of match-ending head trauma of 15.9 per 100 AEs (31.9% of matches). Logistic regression identified that weight class, earlier time in a round, earlier round in a match, and older age were risk factors for both KOs and TKOs secondary to repetitive strikes. Match significance and previously sustained KOs or TKOs were also risk factors for KOs. Video analysis identified that all KOs were the result of direct impact to the head, most frequently a strike to the mandibular region (53.9%). The average time between the KO-strike and match stoppage was 3.5 seconds (range, 0-20 seconds), with losers sustaining an average of 2.6 additional strikes (range, 0-20 strikes) to the head. For TKOs secondary to strikes, in the 30-second interval immediately preceding match stoppage, losers sustained, on average, 18.5 strikes (range, 5-46 strikes), with 92.3% of these being strikes to the head.

Conclusion: Rates of KOs and TKOs in MMA are higher than previously reported rates in other combative and contact sports. Public health authorities and physicians should be cognizant of the rates and mechanisms of head trauma. Preventive measures to lessen the risks of head trauma for those who elect to participate in MMA are described.

Keywords: mixed martial arts (MMA); knockout; concussion; head injury; technical knockout; video analysis

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Mixed martial arts (MMA) is a competitive, full-contact sport that involves an amalgamation of elements drawn from boxing, wrestling, karate, taekwondo, jujitsu, Muay Thai, judo, and kickboxing.² Mixed martial arts has experienced a rapid increase in popularity in North America, which has then spread internationally, resulting in a tremendous global growth of the sport.^{15,22} In many areas, the sport has become much more popular than boxing despite scrutiny from medical groups, such as the American Medical Association,¹ Canadian Medical Association,⁸ British Medical Association,¹⁰ and Australian Medical Association,³ which have called for a complete ban of this sport.^{1,3,8,10} These organizations describe MMA as violent and dangerous, voicing concerns about the intent to cause physical harm to an opponent and the significant risk of brain injuries.^{3,8,10}

To date, the empirical research examining injuries sustained during MMA is limited. Although few would debate that a knockout (KO) meets current criteria for a concussion or a more severe traumatic brain injury (TBI),¹⁷ the

classification of a technical knockout (TKO) is less clear. A TKO occurs when a match is stopped because of a competitor's inability to logically or safely defend himself or herself, leaving himself or herself defenseless to uncontested punishment.⁷ Defenselessness secondary to repetitive strikes to the head can be the result of a loss of awareness and responsiveness,⁷ thus meeting the criteria for a concussion.¹⁷ To provide some preliminary insight into the burden of TBIs in the sport, it is necessary to determine what proportion of TKOs are the result of repetitive strikes or blows to the head.⁷

With this in mind, the purpose of this study was 2-fold: (1) to determine the incidence, risk factors, and characteristics of KOs and TKOs from repetitive strikes in professional MMA; and (2) to identify the mechanisms and situational factors that lead to KOs and TKOs from repetitive strikes using video analysis.

MATERIALS AND METHODS

A cohort study to examine professional MMA matches was conducted from December 2006 to May 2012 (Ultimate Fighting Championship [UFC] events 66-146). The research ethics review board of St Michael's Hospital approved the study (protocol reference No. 12-381). Video records of the events were publicly available; scorecards and competitors' fight history were accessible on the official UFC website (www.UFC.com) and on one of the largest MMA news sites (www.Sherdog.com).

As defined by the unified rules of MMA, all rounds are 5 minutes in duration, and matches consist of 3 rounds, except for all title matches and predetermined main event matches, which comprise 5 rounds.^{2,26} Less experienced and less skilled MMA competitors compete in undercard matches; higher ranked competitors fight in main-card matches. The UFC classifies competitors into 8 weight classes and a catch-weight, which is a predetermined weight at which 2 competitors in different weight classes agree to compete.²⁶

The UFC follows the unified rules of MMA² defining (1) a KO as occurring when a competitor is knocked down and is deemed unconscious or disoriented and (2) a TKO when a referee stops the contest when a competitor is unable to intelligibly defend himself or herself.²⁷ There were 2 distinct phases to this research. Study 1 included the analysis of match scorecards, which documented match outcomes along with competition and fighter characteristics. Study 2 included the analysis of publicly available digital video records of the KOs and TKOs secondary to repetitive strikes that were identified in study 1. The objective of the second study was to identify the principal mechanisms and situational factors associated with KOs and TKOs secondary to repetitive strikes.

Study 1: Scorecard Analysis

The official website of the UFC (www.UFC.com) maintains official records and scorecards of all competitions. This database was used to collect scorecard data, which included the match significance (ie, title match, main event, main card,

or under-card), match outcome (ie, win, loss, or draw), details of the match outcome (ie, decision, KO, TKO, submission, doctor or corner stoppage), competitor demographics (ie, competitor names, height, weight, age, previous fight record), and match characteristics (ie, date, location, match significance, number of rounds fought, time remaining within the round at match stoppage). The total number of previous KOs and TKOs that competitors had sustained during their professional careers, including competitions with promotions other than the UFC, was determined using www.UFC.com and www.Sherdog.com. Primary outcomes were KOs and TKOs, with identification of factors associated with KOs and TKOs secondary to strikes.

Study 2: Video Analysis

Video analysis was carried out using the "MMA Knockout Tool" (MMA-KT)¹⁴ to code the digital video records documenting the events and situational context surrounding KOs and TKOs secondary to repetitive strikes. The physical location and position of competitors within the octagon were documented. A striking profile was also captured for KOs and TKOs from repetitive strikes, which documented the striking implement and location of all strikes sustained by the loser in the 30 seconds before match stoppage. For KOs, the "KO-strike," or KO-inducing strike, was identified and characterized (ie, implement and location of the KO-strike) in addition to the events that occurred after the KO-strike.

The MMA-KT

The MMA-KT contains 20 factors, organized into 2 parts, and codes information on match characteristics and the situational context of the events preceding KOs and TKOs in addition to evaluating the mechanism of action and subsequent events surrounding a KO. A previous study examining the interrater agreement of the MMA-KT between 2 independent raters reported that the majority of factors have κ coefficients $>.81$, with an average κ coefficient for the 20 factors of $>.86$.¹⁴ See the Appendix for the MMA-KT (available in the online version of this article at <http://ajsm.sagepub.com/supplemental>).

Statistical Analysis

All statistical analyses were performed with Statistical Analysis Software version 9.2 (SAS Institute Inc, Cary, North Carolina, USA). In addition to descriptive statistics, multivariate logistic regression analyses were used to examine the outcomes of KOs and TKOs in study 1. Cases were defined as competitors who sustained a KO or TKO caused by repetitive strikes, and controls were all competitors who did not sustain a KO or TKO secondary to repetitive strikes. All tests were 2-tailed, and significance was set at $P < .05$ with 95% confidence intervals (CIs). The odds ratio (OR) was calculated for each variable after controlling for all other covariates. In study 2, the video analysis portion of the study, descriptive statistics of the outcome measures of interest were limited to KOs and

TABLE 1
Incidence of Match Outcomes by Year^a

| Year | Total Matches (n = 844) | Decision (n = 376) | Submission (n = 177) | Other ^b (n = 4) | TKO (n = 179) | | | | KO (n = 108) | MEHT (n = 269) |
|-------------------|----------------------------|-----------------------|-------------------------|-------------------------------|----------------------|-----------------------|-----------------------|-------------------------|-----------------|-------------------|
| | | | | | Strikes (n = 161) | Laceration (n = 4) | MSK Injury (n = 7) | C/D Stoppage (n = 7) | | |
| 2006 ^c | 9 | 1 | 2 | 0 | 4 | 0 | 0 | 0 | 2 | 6 |
| 2007 | 117 | 48 | 29 | 1 | 23 | 1 | 1 | 2 | 12 | 35 |
| 2008 | 129 | 45 | 31 | 0 | 33 | 0 | 3 | 0 | 17 | 50 |
| 2009 | 164 | 70 | 30 | 1 | 36 | 2 | 2 | 2 | 21 | 57 |
| 2010 | 178 | 86 | 46 | 0 | 27 | 1 | 1 | 1 | 16 | 43 |
| 2011 | 190 | 99 | 29 | 1 | 29 | 0 | 0 | 2 | 30 | 59 |
| 2012 ^d | 57 | 27 | 10 | 1 | 9 | 0 | 0 | 0 | 10 | 19 |

^aC, corner; D, doctor; KO, knockout; MEHT, match-ending head trauma; MSK, musculoskeletal; TKO, technical knockout.

^bIncludes disqualifications and no contests.

^cAs of December 2006.

^dAs of May 2012.

TKOs secondary to repetitive strikes identified with the digital video records.

RESULTS

An athlete-exposure (AE) was defined as participation in any competition in which an athlete was exposed to the possibility of an athletic injury. In total, 844 matches, or 1688 AEs, involving 508 individual competitors took place between December 2006 and May 2012 in 81 UFC events. The breakdown by weight class was as follows: 58 featherweight (61.2-65.8 kg), 185 lightweight (65.8-70.3 kg), 188 welterweight (70.3-77.1 kg), 147 middleweight (77.6-83.9 kg), 138 light heavyweight (83.9-93.0 kg), 109 heavyweight (93.0-120.2 kg), and 19 catchweight. We identified no flyweight (<56.7 kg) or bantamweight (57.2-61.2 kg) matches. Of the 844 matches, there were 433 undercard matches and 411 main-card matches, which included 87 main events and 51 title matches.

All competitors were male. Their average (\pm standard deviation) age was 29.8 \pm 4.1 years (range, 20-48 years), with an average of 1.0 \pm 1.3 previously sustained KOs or TKOs at the time of competition (range, 0-8 KOs or TKOs). Of the 844 matches, 468 (55.5%) ended before their scheduled time. We identified 108 (12.8%) matches that ended by a KO and 179 (21.2%) by a TKO. Match outcomes are summarized in Table 1. Of the 179 matches that ended in a TKO, 161 events (89.9% of 179 TKOs; 19.1% of all 844 matches) ended after repetitive strikes. Collectively, the results translate into an incidence of 6.4 per 100 AEs for KOs and 9.5 per 100 AEs for TKOs secondary to repetitive strikes.

Study 1: Score Card Analysis

Of the 1688 AEs during the study period, 1647 AEs were included in our multivariate logistic regressions, as 41 AEs had incomplete data for all required variables in the model. Table 2 provides summary results from the multivariate logistic regression.

In the regression analysis of KOs, each previous KO or TKO was associated with an increased risk of KOs (OR, 1.30; 95% CI, 1.12-1.50) as well as older (\geq 35 years of age) competitors (OR, 1.94; 95% CI, 1.03-3.61) after controlling for match significance, time of match stoppage, and round number. On the other hand, the middleweight class or undercard match designation decreased the risk of sustaining a KO (OR, 0.44; 95% CI, 0.20-0.97 and OR, 0.51; 95% CI, 0.32-0.81, respectively). Furthermore, each additional minute within a round and each additional round in a match were associated with a decreased risk of KOs (OR, 0.69; 95% CI, 0.59-0.81 and OR, 0.36; 95% CI, 0.26-0.49, respectively).

For TKOs secondary to repetitive strikes, the heavy-weight class was associated with an increased risk (OR, 2.12; 95% CI, 1.16-3.98). Similar to KOs, each minute of competition in a round and each round in a match were associated with a decreased risk of TKOs (OR, 0.76; 95% CI, 0.67-0.87 and OR, 0.64; 95% CI, 0.51-0.80, respectively), and older (\geq 35 years of age) competitors had an increased risk of sustaining a TKO (OR, 1.96; 95% CI, 1.18-3.22).

Study 2: Video Analysis

Publicly available digital records were only consistently available for main-card matches. As such, undercard matches were omitted from the video analysis, leaving 142 events (KOs, 65 outcomes; TKOs secondary to repetitive strikes, 77 outcomes) available for video analysis of the potential 269 total outcomes (KOs, 108 outcomes; TKOs secondary to repetitive strikes, 161 outcomes) identified in study 1.

For the 65 KOs, the fist was identified as the striking implement in the majority (55 KOs [84.6%]) of events (Figure 1). The head was the part of the body struck in all 65 events (100.0%). The predominant region of the head struck was the mandible (35 events [53.9%]), followed by the maxillary (13 events [20.0%]) and temporal (13 events [20.0%]) regions. Figure 2 provides a visual representation of the strike location involved in the KOs. Of the 65

TABLE 2
Multivariate Logistic Regression for KOs and TKOs Secondary to Repetitive Strikes^a

| Variables | Competitors With KO vs Competitors Without | Competitors With TKO Secondary to Strikes vs Competitors Without |
|---------------------------------|---|---|
| | OR (95% CI) | OR (95% CI) |
| Age, y ^b | | |
| 20-24 | 1.25 (0.47-2.92) | 0.75 (0.32-1.59) |
| 30-34 | 1.63 (0.97-2.75) | 1.29 (0.86-1.95) |
| ≥35 | 1.94 (1.03-3.61) ^e | 1.96 (1.18-3.22) ^e |
| Weight class ^c | | |
| Heavyweight | 0.64 (0.30-1.38) | 2.12 (1.16-3.98) ^e |
| Light heavyweight | 0.94 (0.47-1.92) | 1.54 (0.84-2.89) |
| Middleweight | 0.44 (0.20-0.97) ^e | 1.15 (0.61-2.20) |
| Welterweight | 0.68 (0.32-1.41) | 1.44 (0.80-2.63) |
| Catchweight | 0.98 (0.23-3.18) | 1.76 (0.53-5.03) |
| Featherweight | 1.30 (0.43-3.48) | 0.32 (0.05-1.14) |
| Previous KOs and/or TKOs | 1.30 (1.12-1.50) ^e | 1.08 (0.95-1.22) |
| Match significance ^d | | |
| Undercard match | 0.51 (0.32-0.81) ^e | 1.06 (0.72-1.56) |
| Main event | 1.31 (0.45-3.33) | 0.99 (0.36-2.33) |
| Title match | 1.92 (0.76-4.41) | 1.75 (0.81-3.54) |
| Time within a round, min | 0.69 (0.59-0.81) ^e | 0.76 (0.67-0.87) ^e |
| Round number | 0.36 (0.26-0.49) ^e | 0.64 (0.51-0.80) ^e |

^aKO, knockout; OR, odds ratio; TKO, technical knockout.

^bReference group was 25-29 years.

^cReference group was lightweight.

^dReference group was main-card match.

^eStatistically significant ($P < .05$).

competitors who lost by a KO, 41 (63.1%) sustained a secondary head impact with the fighting environment (ie, the floor, cage, or post). Of these 41, 37 competitors (90.2%) struck the arena floor, most frequently ($n = 30$, 73.2%) impacting the occipital region of the head.

The average time between the KO-strike and match stoppage was 3.5 ± 2.8 seconds (range, 0-20 seconds). During that time, competitors who were knocked out sustained, on average, 2.6 ± 3.0 additional strikes (range, 0-20 strikes) to the head. In the 30 seconds preceding the KO-strike, a losing competitor sustained, on average, 6.2 ± 7.3 strikes (range, 0-35 strikes). On average, 88.2% ($n = 352/399$) of these strikes were to the head, and 47.1% ($n = 188/399$) occurred in the 10-second interval immediately preceding the KO-strike (Figure 3).

For the 77 events involving TKOs secondary to repetitive strikes, the losing competitor sustained an average of 18.5 ± 8.8 strikes (range, 5-46 strikes) in the 30 seconds preceding a TKO, of which 92.3% ($n = 1317/1427$) were to the head. The 30 seconds before the referee stopped the match was stratified into 10-second intervals. Results indicate an increasing frequency of strikes leading up to the stoppage. On average, competitors sustained 3.0 ± 3.6 strikes (16.2%; range, 0-16 strikes) during the 30-second interval before the match was stopped, 5.0 ± 4.1 strikes (27.0%; range, 0-21 strikes) during the 20-second interval, and 10.5 ± 5.2 strikes (56.7%; range, 19-46 strikes) occurring in the 10-second interval immediately before the referee stopped the match (Figure 3).

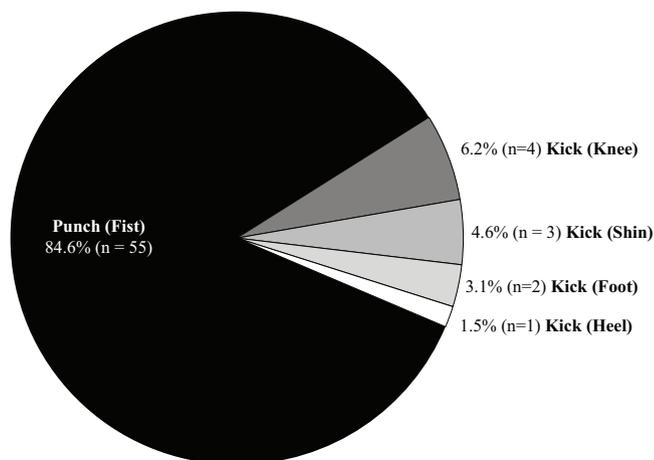


Figure 1. Breakdown of KO-striking implement involved in knockouts ($n = 65$).

DISCUSSION

The incidence of KOs in professional MMA identified in this study was 6.4 per 100 AEs (12.7% of all matches), which is higher than the previously reported rates of 1.6 per 100 AEs²⁰ and 4.8 per 100 AEs.⁷ We consider the KO incidence rate to be an underestimate of the incidence of TBIs in this sport, as a KO describes a very specific match outcome and fails to include head injuries that are not

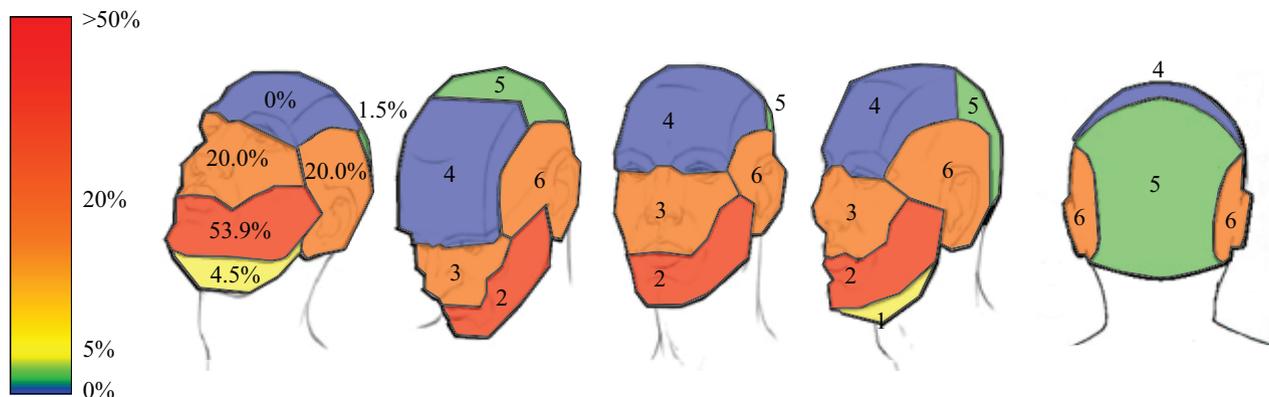


Figure 2. Breakdown of the KO-strike location involved in knockouts (n = 65). The 6 head zones are demarcated by surface-anatomic landmarks (1, submandibular; 2, mandibular; 3, maxillary; 4, frontal; 5, occipital; 6, temporal).

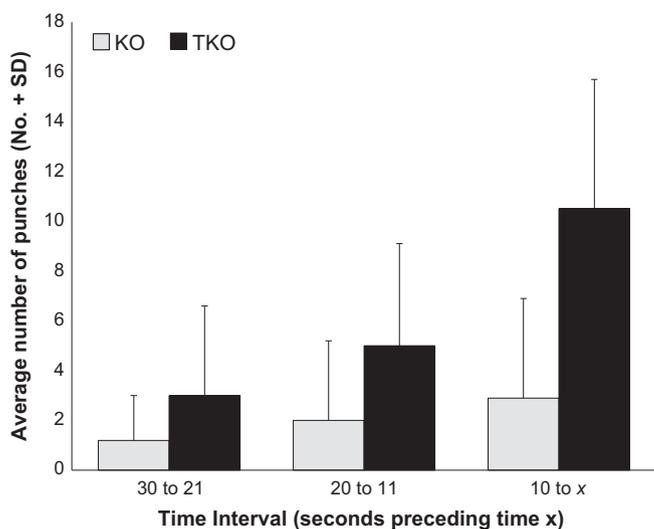


Figure 3. Average number of strikes sustained by a losing competitor in 10-second intervals of the 30 seconds before time x, stratified by knockouts (KOs) and technical knockouts (TKOs). (TKOs: time x, stoppage; KOs: time x, time of KO-strike). SD, standard deviation.

significant enough to visibly alter a competitor’s level of consciousness. Notwithstanding, our reported KO incidence estimates are considerably higher than those previously identified for concussions in boxing (4.9 per 100 AEs)²⁸ and kickboxing (1.9 per 100 AEs).²⁹ Our data clearly indicate a frequent mechanism associated with KOs by direct contact of a fist with the mandibular, maxillary, or temporal regions of the head. Identifying a predominant mechanism for KOs in the majority (85%) of events analyzed provides strong evidence of the need to consider preventive strategies such as rules or improvements to protective equipment (eg, protective head gear).

We found that when examining TKO outcomes of a match, the overwhelming majority (90%) were a result of repetitive strikes; the remaining 10% were classified as musculoskeletal injuries, lacerations, and corner and doctor

stoppages. When TKOs secondary to repetitive strikes were examined further through video analysis, the 30 seconds before match stoppage was characterized by the losing competitor sustaining a flurry of multiple strikes to the head that increased in frequency. Although the diagnosis of a concussion is not certain in these cases, an identifiable mechanism of direct blows to the head with increasing frequency, leading to a state of defenselessness requiring the intervention of a referee, is of considerable concern for the safety of fighters. Previous research that examined comparable events in boxing when a referee stopped the contest found significant cognitive impairment in competitors during neuropsychological testing after the match.¹⁹

Combining the KOs and TKOs secondary to repetitive strikes, previously referred to match-ending head trauma,⁷ the incidence of 15.9 per 100 AEs (31.9% of matches) represents a more liberal estimate of the incidence of TBIs in MMA. This incidence is higher than the reported incidence of concussions in professional American-style football (8.08 per 100 game positions)²¹ and ice hockey (2.2 per 100 AEs),⁹ both of which have received significant pressure from media and medical groups in recent years to reduce these rates.

Our multivariate logistic regression analyses revealed an increased risk of sustaining another KO for each previous KO or TKO that a competitor has sustained. These findings support the larger body of evidence suggesting that a positive history of sports concussions increases the relative risk of sustaining future concussions.^{9,11,16,28} We recognize that we cannot rule out the influence that less skilled fighters are more likely to sustain a KO; nonetheless, competitors, governing bodies, and health professionals should be aware of the potential influence of previous KOs and the risk of injuries. Our analysis also identified an association between heavyweight class and an increased risk for sustaining a TKO. These results are different from those of 2 previous studies^{5,20} in which weight was not a significant risk factor for all-cause injuries in MMA; however, these studies did not isolate the risk of head injuries nor categorize weight into classes but instead used a continuous variable in their

multivariate logistic regression. Our regression analysis further revealed a significant decrease in the risk of sustaining KOs for competitors fighting in undercard matches compared with those fighting in main-card matches. Other studies' findings that less competitive matches²⁰ and less experienced competitors²³ have a decreased risk of sustaining all-cause injuries in MMA are consistent with our findings.

Previous literature has not examined the influence of time within a round on the risk of injuries, KOs, or TKOs due to repetitive strikes. Our study found that fighters were at the greatest risk of sustaining KOs or TKOs from repetitive strikes during the first minute of a round, and in the first round of a fight, the risk of these outcomes decreases with each subsequent round or minute within a round. These are novel findings and contrast with those of previous works reporting that the risk of all-cause injuries increases with each minute fought.^{5,20} We speculate that competitors are less fatigued at the beginning of a round, which is temporally situated at the start of a fight or after a 1-minute rest period between rounds. Therefore, competitors can deliver higher velocity, more forceful head strikes earlier in a round, thus increasing the risk of KOs or TKOs due to repetitive strikes. We suggest that the mechanism and context of both of these match outcomes lend themselves to a more rapid presentation compared with other injuries, which have sport-specific mechanistic features that require a greater time to develop. A large difference in skill between fighters is also more likely to be exposed in an earlier round and manifest itself through KOs or TKOs from repetitive strikes.

Can the Sport Be Made Safer?

Given that participation at amateur levels of the sport is growing rapidly,⁴ we expect to see high rates of TBIs at more junior levels of amateur competition. The reported rates of KOs and TKOs due to repetitive strikes are a concern, given the potentially debilitating short- and long-term consequences associated with concussions and repetitive TBIs.¹⁷ A recent study has demonstrated that the number of KOs in MMA fighters is predictive of microstructural damage in the brain,²⁴ and early reports^{18,25} have suggested an association between chronic traumatic encephalopathy and repeated TBIs during participation in contact sports. These points strongly argue for banning the sport in youth and for preventive strategies to reduce the burden of TBIs in professional MMA fighters who elect to fight.

We recognize that implementing safeguards or procedures before KOs or TKOs to reduce the risk of head injuries is challenging in a sport in which this outcome is awarded victory and financial compensation (eg, "knockout of the night" receives a bonus award or KO bonus). With an average of 2.6 strikes to the head after a KO, at minimum, competitors would benefit from greater protection after KOs, and the sport should consider policies or practices to reduce continuing head trauma.

We clearly identified a pattern of competitors continuing to strike the defenseless opponent after a suspected loss of consciousness and/or falling to the ground. These

fighters also sustained additional secondary head trauma when they fell to the ground. We propose considering the introduction of a rule, similar to boxing, in which a fighter is stopped for a count of 10 seconds every time that a competitor is knocked down to allow for identification and evaluation of the effects of TBI while eliminating strikes after KOs. Mixed martial arts would still retain its appeal of incorporating standing and ground techniques by allowing the fight to continue to the ground only when an opponent is wrestled or thrown down "judo style." Referees must also be trained to identify defenseless fighters and those who have lost consciousness and be required to stop the fight immediately. With respect to TKOs due to repetitive strikes, the identified pattern of the increasing frequency of blows to the head of a losing competitor suggests that referees could be trained and educated to better recognize this pattern and intervene earlier.

After a KO or TKO in an MMA match, competitors are assessed by on-site medical staff, and based on guidelines from state or provincial athletic commissions, a medical suspension is issued to ensure appropriate recovery.^{6,13} According to the Minnesota Combative Sports Commission, a competitor is suspended from competition for a minimum of 60 days for a KO and 30 days for a TKO⁶; however, enforcement of the suspension can be variable, and fighters may return to training prematurely. Given the severity and force of blows sustained in KO and TKO events, mandatory imaging of all brain-injured fighters should be considered. Furthermore, the lack of uniform regulatory body processes enables fighters to "doctor shop" in order to receive licensing to return early to competition.¹³ In addition, amateur athletes may not have access to the same degree of medical attention as professional fighters. Medical authorities and regulatory bodies should consider implementing uniform policies across all jurisdictions to ensure that athletes undergo a thorough medical evaluation after a KO or TKO and before they return to training. A uniform cross-jurisdictional database that documents KOs and TKOs for all fighters would likely prevent a premature return to the sport after TBI events.

Limitations

The results of the current study are limited because of the inability to definitively identify the different types of TBIs induced by the KO or TKO due to repetitive strikes. Although a KO meets criteria for a concussion,²⁰ it may also be indicative of more severe forms of TBIs such as a cerebral contusion or hemorrhage. Furthermore, although the mechanism and sequelae of TKOs secondary to repetitive strikes are highly suggestive of a brain injury, we cannot confidently classify these events as concussions. Nonetheless, we have likely underestimated the incidence of TBIs in MMA as we have (1) reviewed only events immediately preceding the conclusion of a match and (2) recognized that a certain percentage of concussions have no observable signs evident on video footage. Further research is required to get a more accurate estimate of the burden of a TBI that each competitor sustains during a whole match.

Structured comprehensive video analysis applying coding tools such as the MMA-KT is a promising method to assess the mechanisms of KOs and TKOs in MMA. Similar to previous video analysis studies,¹² we recognize that the reproducibility of results may not be 100% because of a lack of agreement between raters at times. However, a previous study examining the utility of the MMA-KT reported high interrater agreement between 2 raters on the majority of factors included in the tool, which are useful to capture and code video content.¹⁴ Finally, the extent to which these findings can be generalized to other leagues or levels of MMA is uncertain; nonetheless, several important issues highlighted in this article are applicable to the MMA community at large. Concerted efforts by all stakeholders and further research will enhance recommendations to reduce the risk of head injuries associated with participation in MMA.

CONCLUSION

The rates of TBIs observed in MMA are higher than those reported in boxing and other martial arts. Public health authorities and physicians should be cognizant of the high rates of head trauma associated with participation in MMA, in addition to the risk of brain injuries associated with KOs and TKOs from repetitive strikes, and manage and counsel patients and other stakeholders appropriately. The mechanisms of head trauma in this sport can form the foundation for efforts that make the sport safer for those who insist on competing in jurisdictions where it is permitted.

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