# Incidence Rates and Pathology Types of Boxing-Specific Injuries

## A Systematic Review and Meta-analysis of Epidemiology Studies in the 21st Century

Yunhe Mao,* MD, Dongmei Zhao,* MB, Jian Li,* MD, and Weili Fu,*† MD

*Investigation performed at the Department of Orthopedics, Orthopedic Research Institute, West China Hospital, Sichuan University, Chengdu, China*

**Background:** To the best of our knowledge, an evidence-based investigation into 21st-century boxing-specific injury rates and types has yet to be performed.

**Purpose:** To provide an overview and quantitative synthesis of the incidence rates (IRs) and pathological categorizations of boxing-specific injuries in the 21st century.

**Study Design:** Systematic review; Level of evidence, 3.

**Methods:** Following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, we searched literature published from January 2000 to November 2021 in PubMed and the Cochrane Library systematically for qualifying epidemiology studies of organized boxing activities across the world. Two independent reviewers completed the literature review, data extraction, and quality assessment. The IRs of injuries per 1000 boxers ($IR_N$), per 1000 competition exposures ($IR_E$), and per 1000 minutes of competition ($IR_C$) or training ($IR_T$) were subsequently calculated. Single-arm meta-analyses were performed for the subgroups of different types of boxing. Sample size weighted means were calculated using a random-effects model in all studies with 95% CIs.

**Results:** Out of an initial 9584 articles, 14 studies were included, with most (11/14) having a moderate level of quality. The pooled $IR_N$ in overall injuries was 223.9 (95% CI, 157.5-290.4), the $IR_E$ was 233.3 (95% CI, 161.3-305.2), and the $IR_C$ was 13.0 (95% CI, 8.9-17.1). In professional boxing, the $IR_N$ (399.8), $IR_E$ (379.8), and $IR_C$ (23.9) were all significantly higher than in the amateur and female groups. The $IR_E$ (76.6 vs 250.6; $P < .000$) and $IR_C$ (9.2 vs 15.4; $P < .000$) in amateur boxing were significantly lower in studies between 2010 and 2019 than in earlier studies. For pathology categorization, the pooled frequencies were 12.3% (95% CI, 8.7%-15.9%) for concussion, 21.4% (95% CI, 14.1%-28.6%) for skin laceration, 30.2% (95% CI, 22.1%-38.2%) for soft tissue contusion, 15.3% (95% CI, 7.7%-22.9%) for sprain and muscle/ligament injury, and 11.4% (95% CI, 2.7%-20.1%) for fracture.

**Conclusion:** IRs of injury remain high in professional boxing, although they have decreased in the past 10 years in amateur boxing. Soft tissue contusion was the most common injury type. Better exposure measurements and epidemiologic indicators should be applied in future studies.

**Registration:** CRD42021289993 (PROSPERO).

**Keywords:** boxing; epidemiology; general sports trauma; medical aspect of sports

Boxing, a world-class high-profile combat sport, has been in every modern Olympic Games since 1904. Apart from its athletic popularity, boxing plays an important role in modern sports culture, and boxers are associated with agility, resilience, and self-strengthening. Nevertheless, like any other confrontational sports, participation in boxing also makes boxers vulnerable to various types of physical injury or disease, some of which can be fatal and debilitating,[6] such as subdural hematoma and dementia pugilistica.[3,14] For some time, there have been health-related assertions claiming that boxing should be banned owing to safety concerns.[1,52,66]

Boxing has developed into 2 different formats: professional and amateur. Professional boxing has more bout rounds, longer round time, and fiercer fighting style, making it inherently more prone to injury.[56] Baird et al[6] identified 120 deaths globally between 1983 and 2007 resulting

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from professional fights. Much of the medical world's organized leadership speaks against professional boxing, including the British, American, Australian, and World Medical Associations.[2,4,11,12,67] Although amateur boxing has been defined as a relatively safer sport,[26] it has been criticized for its intrinsic "intent to harm" feature.[52] However, amateur boxing is still massively popular and participation continues to increase, especially in youth populations.[49,54] An estimated 96,000 to 136,000 boxing-related injuries presented to emergency departments annually from 2012 to 2016, just in the United States.[32] In addition, boxing has been among the top 3 sports with the highest injury rate in recent Olympic Summer Games.[20,28,57,59] Furthermore, there are potential long-term consequences, such as neurodegenerative diseases and traumatic encephalopathy, that might risk a boxer's whole career.[23,34,38]

Rules and safety checks are being modified constantly to make boxing much safer without losing its ornamentality. However, many of these endeavors, such as the introduction of headguards by the American Medical Association in 1984, were not based on scientific evidence and had limited efficacy.[17,55] Studies showed that headguards were effective in reducing superficial injury in punch speeds in the range between 5 and 9 m/s[39,40]; however, they provide very little attenuation in rotational punch forces, which are believed to be the main risk factor causing concussion.[63,64] And there is even evidence showing that removing headguards may reduce the risk of acute brain injury, because a bigger head is easier to hit.[36,55] In 2013, the International Boxing Association prohibited the use of headguards for elite male Olympic boxing competitions.[62] Major modifications on rules and formats are being made.[7] But, even today, little solid evidence exists of the ability of these rule changes to reduce injury. With further insights into the mechanisms and pathological features of boxing injuries, we believe the rules could be modified accordingly, not only to increase the safety of the boxers but also to meet audience and media expectations.

To further extend the capabilities and knowledge of medical support in boxing, it is important to understand which types of injuries are likely to happen. Minimizing the risk of injuries, especially those with severe and long-lasting consequences, will contribute to improved overall health and may contribute to fewer boxers discontinuing their career. The objectives of this systematic review and meta-analysis were to (1) provide an overview and quantitative synthesis of the incidence rates (IRs) of common injuries in boxing, (2) provide an overview and quantitative synthesis of the distribution of boxing injury by pathology categories, and (3) identify potential risk factors for boxing injury.

## METHODS

### Review Protocol

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 guidelines were used to design this systematic review and meta-analysis.[42] The online databases PubMed and the Cochrane Library were reviewed for all studies published from January 1, 2000, to November 1, 2021. This protocol was registered prospectively with the PROSPERO international prospective register for systematic reviews on December 8, 2021 (registration No. CRD42021289993).

### Selection Criteria

We included all primary studies from which we could extract data on outcomes, combat format, and event level, and there was no language restriction. However, eligible studies had to report at least 1 of the following: (1) epidemiologic data on boxing injury IRs (based either on number of boxers, number of match/bout exposures, or fighting/training exposure time); (2) a quantifiable collection of categorized injuries (eg, concussion, contusion, laceration, fracture, dislocation, sprain, muscle/tendon rupture, or nerve injury); (3) studies performed within the past 20 years (for the purpose of integrating modern concepts).

The exclusion criteria were (1) sporting events without boxing events (eg, winter Olympic Games, winter Youth Olympic Festival); (2) reviews, meta-analyses, in vivo studies, commentary, guidelines, and single case reports; (3) studies reporting only 1 category or 1 specified series of injury; (4) studies containing duplicate data from a previous publication by the same group; (5) studies related to the Paralympics.

### Literature Search

The following key phrases were used as the search subject terms: "injury" OR "epidemiology" OR "incidence" OR "incidence rate" OR "injury type" OR "injury distribution" AND "boxing." The detailed search strategy is provided in Supplemental Material 1. A manual search of the references of included articles was also conducted to ensure that no eligible studies were missed.

All titles and abstracts were reviewed by 2 independent reviewers (Y.M. and D.Z.) and assessed based on the above criteria. Duplicates, irrelevant studies, secondary studies, guidelines, commentaries, studies without epidemiologic data, and investigations with nonhuman participants were removed during screening of titles and abstracts. The full text of all potential eligible studies were then reviewed by the same reviewers before final inclusion. Any disagreements

†Address correspondence to Weili Fu, MD, Department of Orthopedics, Orthopedic Research Institute, West China Hospital, Sichuan University, No. 37, Guoxue Alley, Chengdu 610041, China (email: foxwin2008@163.com).

*Department of Orthopedics, Orthopedic Research Institute, West China Hospital, Sichuan University, Chengdu, China.

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were resolved through discussion or consultation with another senior author (W.F.).

## Data Extraction

Data were extracted by 1 author (Y.M.) and confirmed by another (D.Z.). Extracted information included (1) publication information; (2) designation information (sports event, location/region, study period, study design, study population, source of data, length of follow-up for cohort studies); (3) epidemiology information (definition of injury, injury rates [different types of rates that could be weighted], participant demographics [number of boxers, number of injuries, number of exposures, sex, average age, body weight, height, etc]); and (4) injury characteristics (pathology types and severity of injury [time lost, medical suspension days, etc]). For studies with multiple types of combat sports (eg, mixed martial art, wrestling, judo, and kickboxing), only data for boxing were extracted. The extracted information was recorded into an electronic spreadsheet (Supplemental Material 2).

## Assessment of Study Quality

A published checklist was used to evaluate the quality of all included epidemiological studies and to assess the potential links between exposure to risk factors and harm.[34] The checklist was developed by following the protocol of the Meta-Analysis of Observational Studies in Epidemiology Group[60] and included 6 measures in total: (1) prospective study design, (2) groups comparable on all important confounding factors, (3) outcome assessment blind to exposure status, (4) follow-up long enough for outcomes to occur (defined as >1 year), (5) relation between outcome and exposure appropriately measured, and (6) appropriate statistical analyses used.[34] The quality of the studies was evaluated by 2 authors independently (Y.M. and D.Z.), with any disagreements resolved through discussion or consultation with a third author (J.L.). The quality evaluations are available in Supplemental Material 2.

## Data Analysis

Based on reported data, different exposure measurements were used to calculate IR as follows:

- Injuries per 1000 boxers $\left(IR_N = \frac{\text{Total number of injuries}}{\text{Number of boxers}} \times 1000\right)$
- Injuries per 1000 competition exposures $\left(IR_E = \frac{\text{Number of injuries in competition}}{\text{Number of competition exposures}} \times 1000\right)$
- Injuries per 1000 exposure minutes of competition $\left(IR_C = \frac{\text{Number of injuries in competition}}{\text{Minutes of competition exposures}} \times 1000\right)$
- Injuries per 1000 exposure hours of training $\left(IR_T = \frac{\text{Number of injuries in training}}{\text{Hours of training exposure}} \times 1000\right)$.

Studies with homogeneous measures of exposure were considered for single proportion meta-analysis; subgroup analyses were also performed.

Statistical analyses were performed with Stata Version 15.0 (Stata Corp LLC). The statistical methods followed the procedure used by Bae et al,[5] which was adapted from the method of single-arm meta-analysis by Einarson.[19] The injury IRs were considered for pooling if the measures of exposure were homogeneous. The heterogeneity was analyzed by $Q$ test (test level $\alpha = .1$) and quantitatively measured by $I^2$. The random-effects model was used for meta-analysis. Summary group proportion forest plots were then created for visual inspection of the data. To identify outliers, externally studentized residual $Z$ values >3 were screened and leave-1-out analysis was performed. In the case of this analysis, no studies were identified, and removal of outlier studies was not necessary. Subgroup divisions were performed upon the category of boxing (amateur, professional, female, and National Electronic Injury Surveillance System [NEISS] data). The significance level was set to $\alpha = .05$. Where pooling was precluded, data were reported descriptively.

# RESULTS

A total of 9584 records were identified through the initial key words search. Of these, 78 articles were carefully reviewed in full text for eligibility assessment, and 14 studies were ultimately included in this systematic review and meta-analysis (Figure 1).[‡]

## Basic Characteristics of the Included Studies

There were 14 studies reporting the incidence or occurrence of common boxing-related injuries in an overall manner; basic information is presented in Table 1. Methodological details and key injury findings for boxing can be found in Supplemental Material 2.

*Definition of Injury.* The definitions of boxing injury varied across the studies but still shared the following features: (1) injuries resulting directly from organized boxing activities; (2) injuries resulting in interruption of a boxer's normal competition or training or requiring medical intervention; and (3) injuries confirmed by accredited doctors or ringside physicians.

*Study Design and Sample Size.* There were 6 prospective cohort/longitudinal studies,[35,37,47,56,59,68] and the other 8 were of retrospective cross-sectional or descriptive designations. Apart from studies using NEISS data, the reported cohort size fell between 44 and 970. Sample weights provided by the NEISS were used to generate national estimates of boxing injuries in the United States in 2 studies.[43,48]

*Study Population and Competition Format.* The study population was mostly registered athletes/boxers of various kinds of boxing federations or commissions or national squad, while 2 studies investigated the injury epidemiology by using US population census data (NEISS database), which were of a wider range of participants and higher heterogeneity. Boxing participants were mostly male (>90%); 2 studies reported injuries in female boxing.[8,9]

[‡]References 8-10, 29, 35, 37, 43, 47, 48, 56, 59, 68-70.

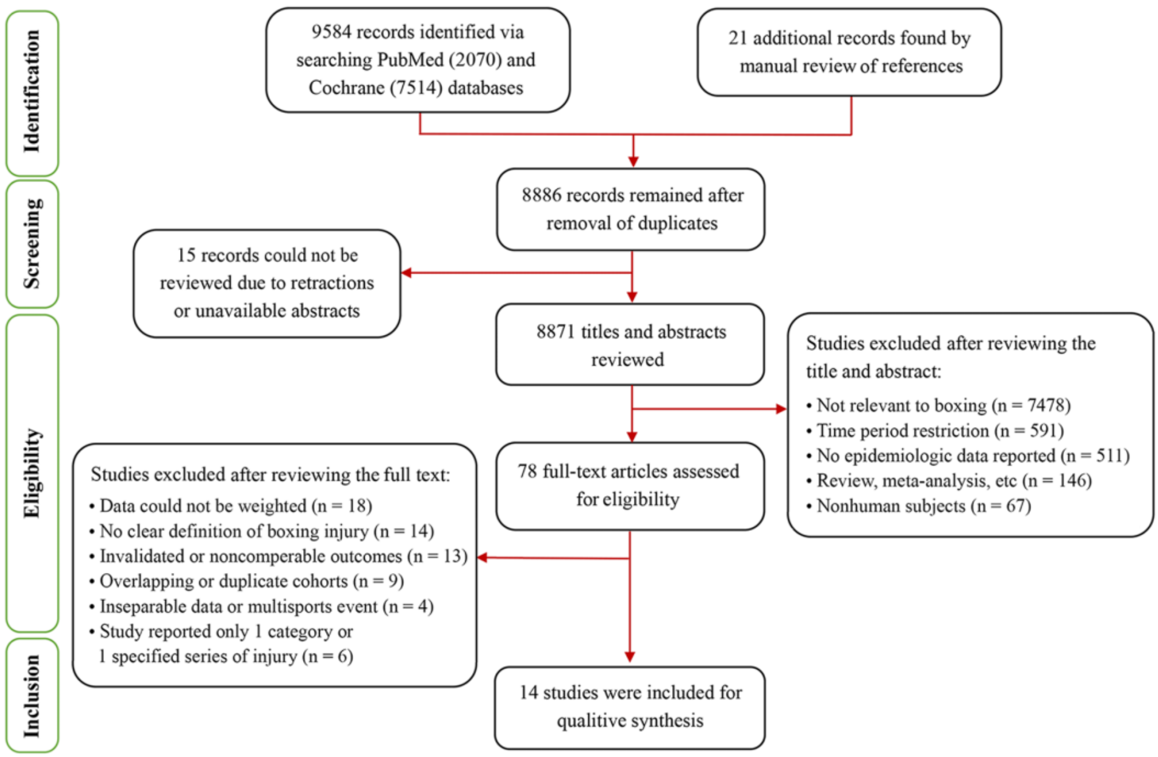


**Figure 1.** PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart of the selection process for inclusion in the systematic review and meta-analysis.

TABLE 1
Basic Characteristics of Included Studies[a]

| Lead Author (Year) | Study Period | Setting/Source of Data | No. of Boxers | Mean Age, y | Study Design | Competition Level |
|---|---|---|---|---|---|---|
| Lystad (2021)[37] | 2016/2012/2008 | 3 consecutive Olympic Games | 850 (87.0% male) | NR | PCS | Amateur |
| Steffen (2020)[59] | 2018 | Youth Olympic Summer Games | 82 (65.8% male) | 17.7 | PCS | Amateur |
| Karpman (2016)[29] | 2000-2013 | Edmonton Combative Sport Commission | 550 (80.5% male) | NR | RCS | Professional |
| Siewe (2015)[56] | 2012-2013 | German Federal Ministry of Research and Education | 44 (95.4% male) | 20.2 | PCS | Professional |
| Loosemore (2015)[35] | 2005-2009 | British Amateur Boxing Association | 66 (100% male) | 22.0 | PCS | Amateur |
| Bianco (2011)[9] | 2002-2007 | Italian Boxing Federation | 970 (0% male) | 24.1 | RCS | Amateur |
| Potter (2011)[48] | 1990-2008 | NEISS | 726,333 (90.9% male) | 16.4 | RCS | Mixed |
| Zazryn (2009)[70] | 1997-2005 | VPBCSB | 545 (98.3% male) | 27.9 | RCS | Professional |
| Pappas (2007)[43] | 2002-2005 | NEISS | 1774 (88.2% male) | NR | RCS | Mixed |
| Zazryn (2006)[68] | 2004-2005 | VPBCSB | 47 (91.5% male) | 25.9 | PCS | Professional |
| Bledsoe (2005)[10] | 2001-2003 | Nevada State Athletic Commission | 688 (92.2% male) | NR | RCS | Professional |
| Zazryn (2003)[69] | 1985-2001 | VPBCSB | 484 (100% male) | 27.3 | RCS | Amateur |
| Porter (1996)[47] | 1992-1993 | All amateur bouts held in Dublin | 147 (100% male) | >16 | PCS | Amateur |

[a]NEISS, National Electronic Injury Surveillance System; NR, not reported; PCS, prospective cohort study; RCS, retrospective cross-sectional study; VPBCSB, Victorian Professional Boxing and Combat Sports Board.

Most of the participants (>95%) were aged between 17 and 27 years old. There were 3 multisport studies that encompassed other combat sports[37,43,59]; the cohorts were separable, and only boxing-related data were extracted. A total of 7 studies reported injuries in amateur boxing,[8,9,35,37,47,59,69] while 5 studies covered professional boxing.[10,29,56,68,70] The NEISS studies were not identifiable in terms of competition formats and were defined as "mixed." One study reported boxing injuries in 3 consecutive Olympic games with exclusive disclosure from the International Olympic Committee.[37] Three articles were published respectively for these 3 Olympic Games[20,28,57]; however, they were excluded from meta-analysis due to incomplete data on boxing cohorts.

## Assessment of Study Quality

We have summarized results for the main outcome measures in order of general quality (Table 2). The overall quality for the included study was moderate (median score 4/6; range 3-5). No study was of poor quality (score <3). There was an absence of blinding of the outcome measurements across all studies. One study did not clarify the specific statistical methodology,[9] but it would not hinder the pooling of IR. Support for authors' judgments can be found in Supplemental Material 2.

## Incidence Rates

The IRs of overall injuries in boxing were reported in all 14 studies and are available in Supplemental Material 3.

*IR of Injuries per 1000 Boxers.* All 14 studies reported the total number of injuries and participants, with calculated $IR_N$ available for pooling in 12 studies. A total of 733,113 boxing participants and 10,567 boxing-related injuries were pooled, a synthesized $IR_N$ of 223.9 was identified (95% CI, 157.5-290.4; $P = .000$) (Figure 2A). The $IR_N$ was 270.8 (95% CI, 147.1-394.6) in subgroup studies reporting amateur boxing.[37,47,59,69] In contrast, the subgroup $IR_N$ was significantly higher in 4 studies reporting professional boxing (399.8; 95% CI, 289.7-509.2; $P < .000$).[10,29,68,70] However, $IR_N$ was significantly lower in 2 studies reporting female boxing (30.1 and 55.6),[8,9] and even lower in 2 studies using NEISS data (12.7 and 42.3).[43,48] Loosemore et al[35] reported an $IR_N$ of 4500 among elite-level amateur boxers in the Great Britain squad. In addition, Siewe et al[56] reported an $IR_N$ of 4363.6; these extraordinarily high incidences were contributed to by the overlapping of injuries sustained by the same boxers during the study period.

TABLE 2
Quality of Included Studies[a]

| Study | Prospective | Groups Comparable on Confounding Factors | Blinded Outcome | Long Enough Follow-up | Exposure Response Measured | Appropriate Statistics | Overall Quality (max 6) |
|---|---|---|---|---|---|---|---|
| Siewe (2015)[56] | Yes | Yes | No | Yes | Yes | Yes | 5 |
| Loosemore (2015)[35] | Yes | Yes | No | Yes | Yes | Yes | 5 |
| Zazryn (2006)[68] | Yes | Yes | No | Yes | Yes | Yes | 5 |
| Lystad (2021)[37] | Yes | Yes | No | No | Yes | Yes | 4 |
| Steffen (2020)[59] | Yes | Yes | No | No | Yes | Yes | 4 |
| Karpman (2016)[29] | No | Yes | No | Yes | Yes | Yes | 4 |
| Bianco (2005)[8] | No | Yes | No | Yes | Yes | Yes | 4 |
| Bledsoe (2005)[10] | No | Yes | No | Yes | Yes | Yes | 4 |
| Zazryn (2009)[70] | No | Yes | No | Yes | Yes | Yes | 4 |
| Zazryn (2003)[69] | No | Yes | No | Yes | Yes | Yes | 4 |
| Porter (1996)[47] | Yes | Yes | No | No | Yes | Yes | 4 |
| Bianco (2011)[9] | No | Yes | No | Yes | Yes | No | 3 |
| Potter (2011)[48] | No | No | No | Yes | Yes | Yes | 3 |
| Pappas (2007)[43] | No | No | No | Yes | Yes | Yes | 3 |

[a]Checklist developed by following the protocol from Meta-Analysis of Observational Studies in Epidemiology Group.[60]

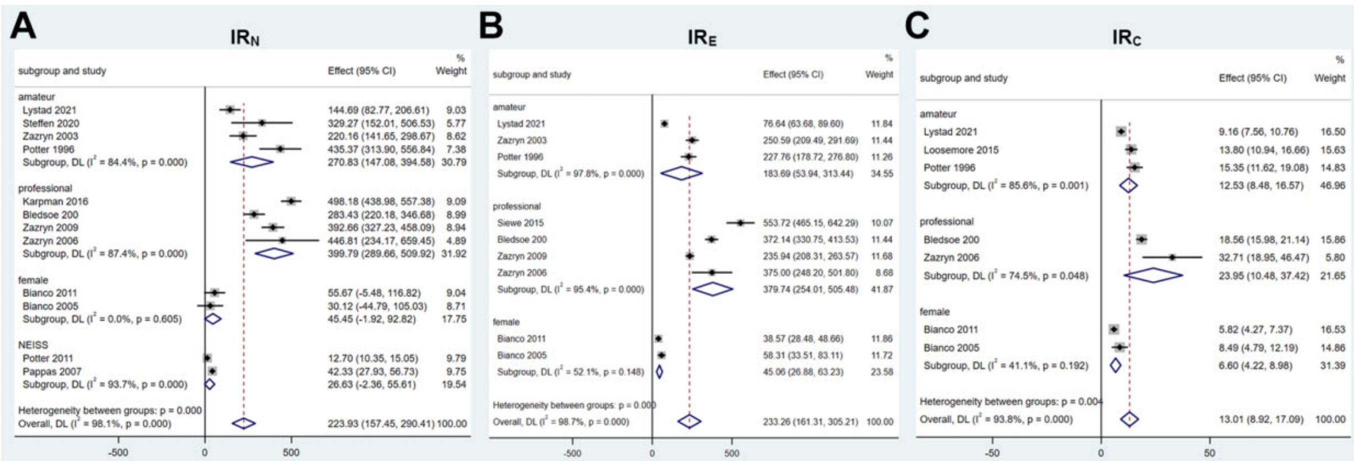


**Figure 2.** Forest plots of IRs of (A) $IR_N$ (synthesized $IR_N$ = 223.9 [95% CI, 157.5-290.4]; $P < .000$), (B) $IR_E$ (synthesized $IR_E$ = 233.3 [95% CI, 161.3-305.2]; $P < .001$), and (C) $IR_C$ (synthesized $IR_C$ = 13.0 [95% CI, 8.9-17.1]; $P < .001$). Weights and between-subgroup heterogeneity tests are from the random-effects model. DL, DerSimonian-Laird estimate of tau$^2$; IR, incidence rate; $IR_C$, IR per 1000 minutes of competition; $IR_E$, IR per 1000 competition exposures; $IR_N$, IR per 1000 boxers; NEISS, National Electronic Injury Surveillance System.

*IR of Injuries per 1000 Competition Exposures.* Nine studies reporting the number of matches or bouts[8-10,37,47,56,68-70] and the number of injuries occurring during those competitions were extracted for the calculation of $IR_E$. A total of 5677 boxing matches and 866 competition injuries were pooled, a synthesized $IR_E$ of 233.3 was identified (95% CI, 161.3-305.2, $P < .001$) (Figure 2B). Similarly, significantly higher $IR_E$ could be observed among studies of professional boxing (379.8; 95% CI, 254.0-505.5; $P < .001$).[10,56,68,70] Interestingly, a much lower $IR_E$ of 76.6 was noted in the latest Olympic boxing (amateur level) than earlier amateur boxing (227.8 to 250.6; 1996-2003)[37,47,69]; this might be attributed to the revisions of rules from time to time, making amateur boxing much safer.

*IR of Injuries per 1000 Exposure Minutes of Competition.* Time of competition exposures (in minutes) could be extracted from 7 studies.[8-10,35,37,47,68]. A total of 46,869 competition minutes and 566 competition injuries were pooled; a synthesized $IR_C$ of 13.0 was identified (95% CI, 8.9-17.1; $P < .001$) (Figure 2C). $IR_C$ in professional boxing (23.9; 95% CI, 10.5-37.4) was still higher than in amateur boxing (12.5; 95% CI, 8.5-16.6).[10,35,37,47,68] Unlike the extraordinarily high $IR_N$ in the study by Loosemore et al,[35] the reported $IR_C$ was very close to the synthesized rate (13.8 vs 13.0). Because measuring by competition minutes could avoid the overlapping of injuries, $IR_C$ might be a more accurate measurement of the risk of competition exposure than $IR_N$. However, only a minority of the included studies reported this indicator.

*IR of Injuries per 1000 Exposure Hours of Training.* Only 2 studies on professional boxing reported the exposure time of training (in hours).[56,68] Meta-analysis was not performed, as there were too few studies. The reported $IR_T$ values were 1.96 and 12.88.

## Percentage of Injuries by Pathology Type

A total of 12 studies reported the pathological distribution of boxing injuries.[¶] The frequencies of each type of injury were extracted and pooled with subgroup analysis (Supplemental Material 4 and Figure 3).

*Concussion.* The synthesized frequency of concussion was 12.3% (95% CI, 8.7%-15.9%) (Figure 3A), and there was no significant difference between the pooled subgroup frequencies of amateur and professional boxing; however, it was individually higher in 3 studies on professional boxing (20%-33%; $P < .05$).[29,56,68] In the amateur group, Porter and O'Brien[47] reported a proportion of 51.2% concussion in a prospective amateur boxing cohort; however, the definition of concussion was "any blows to boxer's head that stopped the contest" in that study, which was overgeneralized and might overvalue the actual incidence of real concussion.

*Laceration.* Skin laceration had relatively stable frequencies among studies, although significantly higher frequencies were noted in 2 studies by Zazryn et al[69,70] (Figure 3B). A possible explanation could be that the authors defined the soft tissue injuries of contusion and laceration ambiguously; some of the contusions were counted as lacerations and increased the frequency.

*Contusion.* The most common injury was soft tissue contusion. It consisted of 30.2% (95% CI, 22.1-38.2) of injuries in either amateur or professional boxing, and it was the dominant type of injury in female boxing (67%-90%) (Figure 3C).[8,9] Yet, the proportion of contusion was relatively lower in 3 studies by the same authors (Zazryn et al[68-70]). These frequencies were underestimated due to the incompatible definition of *contusion* previously mentioned.

[¶]References 8, 9, 29, 37, 43, 47, 48, 56, 59, 68-70.

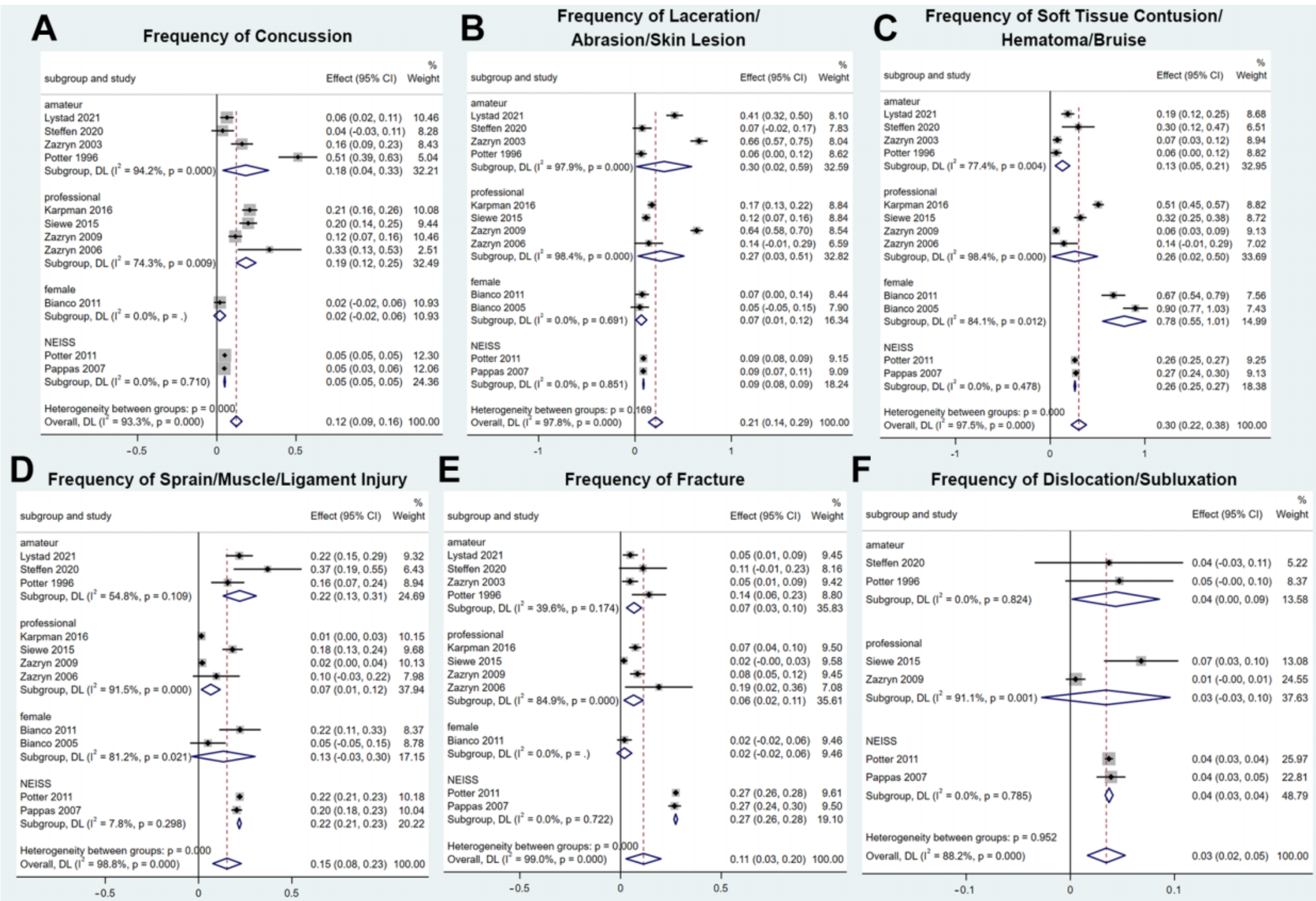


**Figure 3.** Forest plots of injury frequencies for (A) concussion (synthesized frequency = 12.3% [95% CI, 8.7%-15.9%]), (B) laceration/abrasion/skin lesion (synthesized frequency = 21.4% [95% CI, 14.1%-28.6%]), (C) soft tissue contusion/hematoma/bruise (synthesized frequency = 30.2% [95% CI, 22.1%-38.2%]), (D) sprain, muscle/ligament injury (synthesized frequency = 15.3% [95% CI, 7.7%-21.9%]), (E) fracture (synthesized frequency = 11.4% [95% CI, 2.7%-20.1%]), and (F) dislocation/subluxation [synthesized frequency = 3.4% [95% CI, 1.6%-5.3%]). Weights and between-subgroup heterogeneity tests are from the random-effects model. DL, ; NEISS, National Electronic Injury Surveillance System.

*Musculoskeletal Injury.* Sprain/rupture of the muscle or ligament accounted for 15.3% (95% CI, 7.7%-21.9%) of all boxing injuries (Figure 3D). Steffen et al[59] reported a higher proportion of sprains/muscle injuries in boxing athletes in the 2018 Youth Olympic Summer Games, although the sample size was quite small (N = 27) and might be insufficient to produce an accurate rate at a macro level. The frequencies of fracture ranged between 1.6% and 27.4%, and the synthesized frequency was 11.4% (95% CI, 2.7%-20.1%) (Figure 3E). Potter et al[48] and Pappas[43] both reported higher proportions of fractures using the NEISS database (26.8% and 27.4%). By thoroughly reviewing the original articles, we found that NEISS incorporated injuries resulting from punching bags, and fracture is the major injury type while striking punching bags (>35%). This might explain the higher frequency of fracture. In addition, we found an extremely low incidence of fracture in female boxers (0%-1.9%), mostly because the punching force is much lower. Dislocation/subluxation and nerve injuries were relatively rare cases, with frequencies of only 3.4% and 3.2% (Figure 3F). The 5.2% encompassing other injuries (95% CI, 2.9%-7.6%) included meniscal or cartilage injury, aponeurosis injury, impingement, and so forth.

## DISCUSSION

In the present study, we revealed features and the quantitative risk of overall boxing injuries across the 21st century by IR and pathology category frequencies. We found higher incidence of injury (including $IR_N$, $IR_E$, and $IR_C$) and higher risk of concussion in professional boxing; amateur boxing has become safer in the past decade. $IR_E$ and $IR_C$/$IR_T$ are the most effective exposure indicators and should become the primary outcome measures in future studies. These findings are highlighted below.

## Higher Incidence of Injuries in Professional Boxing

The pooled results confirmed that there are higher risks of injury in professional than in amateur boxing. This has been claimed previously, but not based on solid evidence or statistically proven.[31,38,53,65] Despite the risks, Clausen et al[15] found no indication of a decline in professional boxing participation over the past 70 years. Violence is justified in the context of sport when it would otherwise be considered a crime.[45] In the early 1900s and up to 1929, the number of professional boxing rounds varied from 20 to 40[16,58]; bouts would not terminate until 1 side was knocked-out (KO). This was more like a life-and-death battle between gladiators than a sport. It was not until the 1980s that the British Boxing Board of Control, in line with many international sanctioning bodies, mandated a maximum of 12 by 3-minute rounds. Yet, with the higher $IR_N$, $IR_E$, and $IR_C$ in new-century professional boxing noted in this study ($IR_N$ = 283.4-498.2, $IR_E$ = 235.9-553.7, $IR_C$ = 18.7-32.6), this sport needs further regulation.

## Safer Amateur Boxing in the Past Decade

The $IR_N$, $IR_E$, and $IR_C$ were all significantly lower in the past decade in amateur boxing than in earlier times ($IR_N$: 144.7-329.2 vs 220.2-435.4; $IR_E$: 76.6 vs 227.8-250.6; $IR_C$: 9.6-13.8 vs 15.4). The same trend was found in a study by Bianco et al[7]; in the 1952 Olympic Games, the rate of KO was 17.1%, compared with the 2012 London Olympics (0%) and the rules used currently (0.7% ± 0.9%). The Amateur International Boxing Association has been very mindful in making rule changes in response to concerns about boxers' health and safety, and these have proven effective in many aspects.[17] However, robust evidence is still scarce, both in absolute numbers and in scale, so continued medical surveillance is still needed to ensure that new rule changes do not result in poorer medical outcomes for the boxers.

## Concussion in Boxing

Higher rates of concussion in professional boxing (21%-33%) were observed in this study compared with earlier studies.[24,30] Repetitive concussive head impact is a major risk factor for chronic traumatic brain injury,[18,50] which can cause cognitive impairment and greatly jeopardize quality of life in later years.[33,51] The introduction of headguards to boxing in 1984 was a reaction to a threat from the American Medical Association to ban amateur boxing from the United States[17,56]; headguards became mandatory to decrease concussion risk. However, in 2013, the headguard was no longer permitted in amateur boxing. In the current study, concussion rates before 2013 (33%-51%) were not lower than rates after 2013 (4%-21%) but, due to the high heterogeneities and a limited number of relevant studies, we cannot conclude that wearing headguards would increase the risk of concussion. The study by Loosemore et al[35] reported that headguards might offer a degree of protection to the face, ears, and eyes and likely contributed to the low number of lacerations and contusions in the head and face. In addition, in a study by Hojjat et al,[25] the incidence of facial lacerations seemed to increase upon the removal of headguards (in 2013). Thus, if future studies can verify that headguards would not increase the risk of concussion and are effective in reducing facial lacerations/contusions, would it be beneficial to bring headguards back to the ringside? And in the setting of rules, would it be beneficial to reduce the score reward brought by strikes to the head, to reduce the incidence of concussion?

## Role of the NEISS Database

The study population of NEISS was emergency department visits from a network of approximately 100 hospitals in the United States.[44,61] As presented here, an obvious disparity was found between NEISS studies and studies with registered athletes/boxing cohorts, whether looking at IRs or pathology frequencies. Apart from the heterogeneity in participants, NEISS included literally any injuries related to boxing activities (eg, punching bag injuries, injuries sustained during warming up, falling from the ringsides, etc), so data for training and competition were not separable. Besides, related exposure factors (number of bouts, time of competition/training) were not trackable either, and there was no means to identify patients who were treated multiple times. As such, the NEISS data have limited efficacy and accuracy in identifying the actual risk of boxing, although it would be quite useful to estimate the national medical burden, census demographic characteristics, and general participation in this sport.

## Suggestions for Future Studies

Considerable variability in injury IRs was observed across the primary studies included here (every boxer sustained 0.17-3.02 injuries).[8,10,29,35,37,43,70] This variability might be attributed to differences in injury definitions, exposure and outcome measurements, surveillance methods, overlapping of boxers, study populations, span of research, and other contextual factors (eg, changes in competition rules over time). Published systematic reviews of injuries in boxing focused mainly on 1 category or 1 specified series of injury,[21,22,46] or included boxing injuries only at Olympic class,[13] and there is a scarcity of overall reviews providing integrated information on common injuries in boxing. This scarcity might result from the complexity of performing such a review, from the diversity of injuries, and from the significant methodological heterogeneity in primary studies.

Recommended exposures used to calculate incidence and prevalence are number of matches/bouts ($IR_E$) and time of training and/or competition ($IR_T$, $IR_C$).[13] Unfortunately, current literature reports only $IR_N$ for the most part. This indicator is prone to the effect of overlapping and depends on the length of the study period and thus might not be an ideal exposure measurement, although it was still adopted by many recent studies.[20,35,37,57,59] Consistent with the suggestion of Bromley et al,[13] future research should address this problem by using time and number of exposures in both training and competition.

The review also highlighted that most studies did not report the severity of injury. Average time loss from the sport during a competition season is effective at revealing whether a sport is "dangerous" or not; a "severe injury" is defined as injury estimated to lead to absence from training or competition of more than 1 week.[27] If the proportion of severe injury could be identified across studies, there would be a more intuitive presentation on the risk of different types of boxing.

## Limitations

Our systematic review has several limitations. First, although subgroup divisions were conducted as far as possible, there was still considerable heterogeneity in study design and in the characteristics of the enrolled patients. Second, there were varied definitions of injury, unachievable separation on weight class and severity of injury, and different contexts of surveillance. Third, meta-analysis of single populations could have methodological faults. However, we attempted to integrate the outcomes of all homogeneous studies and used statistical methods validated in previous studies.[5,19,41] Finally, to assess quality, most of the included studies used the direct collection of injuries by ringside physicians or by questionnaires, all requiring recall on the athlete's part and potentially introducing recall bias. There should be consistent and regular prospective surveillance across training and competition.

## CONCLUSION

The present systematic review and meta-analysis revealed the IRs of boxing-related injuries in the 21st century and provided boxing-specific data that identify pathology categories with frequencies, which can provide direction to clinicians, enabling them to focus their attention on the pathologies most likely to occur. Injury IRs still remain high in professional boxing, although the IRs of injury in amateur boxing have decreased in the past 10 years. Soft tissue contusion is the most common injury type, and higher rates of concussion in professional boxing were observed. Finally, better exposure measurements and indicators should be applied in future studies.

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