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Review Article

Attention to competitive diving injuries: A systematic review

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ABSTRACT

Competitive diving is a popular sport that attracts numerous participants worldwide; unfortunately, competitive divers experience a notable frequency of injuries during training and competition. Despite this, injuries in diving often received less attention compared to those in other aquatic sports. The purpose of this study was to conduct a systematic review to update the scientific evidence on injury incidence in competitive divers to offer insights into the prevalent injury patterns and help develop injury prevention strategies. This involved analyzing injury data collected from the Injury Surveillance Programme (ISP) across various levels of competition events and assessing case reports involving a wide spectrum of diving injuries. Four online bibliographical databases were consulted: Google Scholar, PubMed, Scops, and Web of Science from their inception until December 6, 2023.819 studies were initially identified, and 15 studies were finally included in this review. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISM) guidelines and PRISMA in Exercise, Rehabilitation, Sport Medicine, and Sport Science (PERSiST) were followed. Two independent reviewers evaluated the methodological quality of the studies. The majority of diving injuries are concentrated on the upper body/trunk, including the shoulder, spine, hand/wrist, head/face, and neck, with overuse injury being a main contribution. Regarding diving incidence, the actual injury rate in competitive athletes could be even higher than currently reported, primarily due to limitations in implementing injury surveillance protocol for diving athletes. The latest injury data for diving in big competition events is absent, and there is a strong expectation for more new injury surveillance data to be published in the future. Additionally, the specific injury pattern, prevention strategy, and rehabilitation training plan for diving injury are severely deficient in the current literature.

1. Introduction

Competitive diving has not only gained popularity with a large number of participants around the world but has also evolved significantly in terms of complexity and difficulty over the past 30 years [1–3]. Competitive diving demands exceptional strength, flexibility, proprioception, and kinesthetic sense [4]. These attributes enable competitive divers to execute intricate acrobatic maneuvers throughout their dives and enter the water with the goal of as little splash as possible to maximize the score of the performance. During the slamming stage, while the body impacts and penetrates the water surface, there is a dramatic instant increase in the dynamic impact force, contributing to a great value of impulsive force which is impossible to be absorbed by the human musculoskeletal system, consequently leading to severe injuries [5]. It has been demonstrated that a diver jumping from a 10-m height accelerates velocity to reach about 14.16 m/s before impacting the water and decelerates to 9.16 m/s, amounting to approximately 400 N of force upon impact with the water [6]. Therefore, it is not surprising that diving has the highest frequency of injuries when compared to other aquatic sports.

The epidemiology of diving has been studied through case series and retrospective surveys in international competition events, such as the World Aquatics Championships (known as the FINA World Championships until 2022) and the National Collegiate Athletic Association (NCAA) have implemented injury surveillance programs in aquatic sports. Of the most recent published data, Boltz et al. looked at NCAA men's diving from the academic years 2014–2015 to 2018–2019, they reported an injury rate of 1.52 per 1000 athlete-exposures (AEs). The highest proportion of injuries occurred in the shoulder (23.3 %) and trunk (23.3 %) [7]. Meanwhile, Chandran et al. found a women's diving injury rate of 2.49/AEs during the same period, with the majority of injuries affecting the head or face (29.4 %) and trunk (20.2 %) [8]. Furthermore, Prien et al. compared results from three World Aquatics in

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2009, 2013, and 2015, revealing that diving athletes accounted for the highest injury rates, and all reported injuries have progressively increased over the years [9]. All those mentioned studies can reach a consensus that most injuries in competitive divers were attributed to overuse. It has been noted that competitive divers spend more than 50 % of training time doing intensive training to enhance their performance, which could inevitability increase the overuse injury rate [10]. The out-of-competition surveillance was recommended for athletes to develop prevention strategies for overuse injury [9].

There are four published narrative reviews on competitive diving. The earliest one, by Rubin in 1999, primarily focused on describing the pathomechanics of diving injuries related to specific body parts [11]. In 2009, Mountjoy concentrated on injuries and medical concerns specifically in synchronized divers [12]. In 2017, researchers presented a summary of general competitive diving principles and diving-specific injuries [4]. In the latest study, Day et al. provide a narrative review with injury data in competitive diving being analyzed and discussed, but it lacks a systematic evaluation of the quality of the included study, which may introduce bias [13]. Overall, despite diving having the highest injury rate in aquatic sports, it has received less attention compared to other sports. To address this gap, there is a need to update the scientific evidence on the epidemiology of injuries in competitive divers and to facilitate the development of injury prevention strategies. Therefore, the objective of this research is to conduct a systematic review by collecting injury data, case studies, and information on medical and treatment concerns related to competitive diving injuries, to contribute valuable information for injury prevention strategies.

2. Methods and materials

2.1. Search strategy

This systematic review was carried out based on the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and PRISMA in Exercise, Rehabilitation, Sport Medicine, and Sport Science (PERSiST) [14,15]. The potential studies were determined by a combination search process. The following four online bibliographical databases were consulted: Google Scholar, PubMed, Scops, and Web of Science from their inception until December 6, 2023. The search terms were used for all databases: “competitive diving”, “diving injury”, “aquatic sports injury”, “epidemiology diving”, and “injury survey” alone or combined. Also, the relevant studies in the reference list of selected studies were hand searched to identify potential eligible studies. Titles and abstracts then full-text studies were independently screened by two reviewers (XW and MZW) to determine studies that meet the eligible criteria. A third reviewer (MZ) was consulted to resolve any discrepancy in the screening process.

2.2. Eligibility criteria and data extraction

The inclusion criteria of selected studies are as follows: (1) the study must be published in a peer-reviewed journal in the English language; (2) divers had to compete in a high-level competition which held at national or international events; (3) studies report injury incidence or injury data in competitive divers; (4) studies provide any medical concerns and treatment strategies for competitive divers. Studies were excluded if there was no injury data related to competitive diving or the outcome data could not be retrieved from those other sports.

In terms of data extraction and analyses in the selected papers, the study characteristics were extracted from all selected studies by two reviewers (XW and MZW), which involved publications details (author and year), sample size, competition event, level of athlete, study design, injury type, injury location, and mechanism of injury. In terms of the case study, extra details of diagnosed symptoms, assessment methods, and treatment strategies were included.

2.3. Quality assessment

The methodological quality of the selected studies was assessed using two separate scales. The first one was an adapted version of the “Strengthening the Reporting of Observation Studies in Epidemiology (STROBE)” statement, which is recommended as a suitable scale for assessing the quality of the observational study [16]. This scale consists of an 11-item checklist to guide the study appraisal; each item was scored as follows: “yes” = 1, “no” = 0, “not able to determine” = 0. The risk of bias was determined by counting scores for each item, classifying a study as having a low risk of bias (high quality) if the score ≥7 or a high risk of bias (low quality) if the score ≤6. The second part of the quality assessment focused on case studies and employed a 10-point checklist based on the Joanna Briggs Institute (JBI) critical appraisal scale, which addresses the internal validity, risk of bias in study design, and importance of clear reporting [17]. For the second scale, the high quality is defined as score ≥6, and the low quality is defined as score ≤5. Two reviewers independently (XW and MZW) assessed the methodological quality of all selected studies using both scales, any discrepancies were resolved through discussion with a third reviewer (MZ) when necessary.

3. Results

3.1. Search results and selection

The electronic database search obtained 807 studies, and additional 12 studies were identified through reference list, of which 682 studies remained after removing duplicates. Then 586 studies were excluded based on the title and abstract screening, leaving 96 studies for a comprehensive review. After screening these studies, 81 studies were excluded for not meeting specific inclusion criteria, thus 15 studies were selected in the present review. The selection process is illustrated in Fig. 1.

3.2. Quality of the selected studies

In terms of the methodology quality of the selected studies, scores on the risk bias scale of STROBE quality scale ranged from 6 to 10 out of 11, high quality and low bias in most of the studies, only one study identified as a low quality and high bias with score ≤6. Items 1, 2, and 3 received the highest scores, and item 9 related to the “Describes injury history” displayed the lowest scores. The scores of the STROBE scale can be found in Table 1. Regarding the JBI scale for the case study, all studies would be identified as high quality with scores ranging from 7 to 8 out of 10. Items 2, 4, 5, 6, 7, 8, and 9 have the highest scores, and item 1 related to “were there clear criteria for inclusion in the case series” received the lowest scores. The scores of the JBI scale are displayed in Table 2.

3.3. Descriptive characteristics of the studies

The main details of all selected studies are presented in Table 3. There are a total of 15 studies, consisting 11 describe studies and 4 case studies. In terms of the participant sample's country and origins of injury data, six studies were carried out in the USA based on the injury database of The National Collegiate Athletic Associate (NCAA) Injury Surveillance Program (ISP). Another six studies included participants sample from multiple countries who have attended international competition events. This includes three studies that collected data from the World Aquatics Championships and three studies that analyzed injury data from the Summer Olympic Games. Also, a limited number of studies were conducted in Japan and Sweden.

3.4. Injury incidence

11 studies have reported injury numbers and incidence values of competitive divers [7–9,18–25]. However, the presented values differ

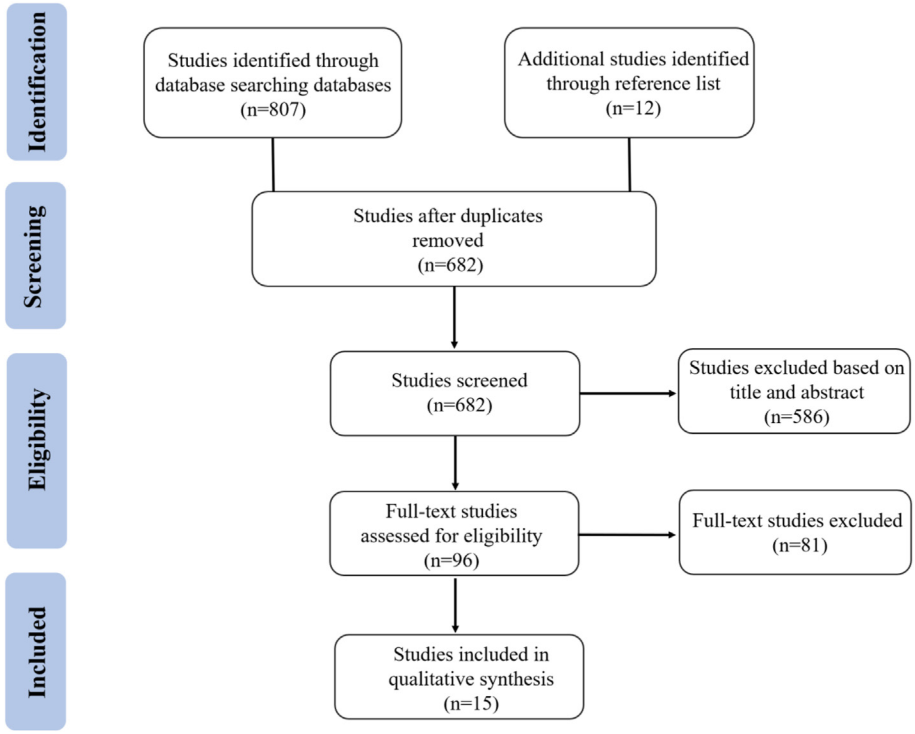

Fig. 1. Flow chart of the selection of studies in the systematic review.

Table 1
The methodological quality assessment of selected studies (observational study).

Num	Study	1	2	3	4	5	6	7	8	9	10	11	Score
1	Boltz et al., 2021 [7]	1	1	1	1	0	1	0	1	1	0	1	8
2	Chandran et al., 2021 [8]	1	1	1	1	0	1	0	0	1	0	1	7
3	Prien et al., 2016 [9]	1	1	1	1	0	1	0	1	1	0	0	7
4	Kerr et al., 2015 [21]	1	1	1	1	0	1	1	1	1	0	1	9
5	Mountjoy et al., 2014 [23]	1	1	1	1	0	1	0	1	1	0	1	8
6	Mountjoy et al., 2010 [22]	1	1	1	1	0	1	1	0	1	0	1	8
7	Engebretsen et al., 2013 [19]	1	1	1	0	0	1	1	1	1	0	1	8
8	Junge et al., 2009 [20]	1	1	1	0	0	1	1	1	0	0	0	6
9	Wasserman et at. 2018 [25]	1	1	1	0	0	1	1	1	1	0	0	7
10	Baranto et al., 2006 [18]	1	1	1	0	0	1	1	1	1	1	1	9
11	Grant et al., 2017 [24]	1	1	1	1	0	1	1	1	1	0	0	8

The numbers of the columns corresponded to the following items of the STROBE scale.
1. Describes the setting or participating locations; 2. Describes relevant dates (period of recruitment, exposure, follow-up, data collection); 3. Provides statement concerning institutional review board approval and consent; 4. Gives the inclusion and exclusion criteria; 5. Describes injury history; 6. Describes methods of follow-up, data sources/measurement; 7. Provides a definition of injury; 8. Verifies injury by an independent medical professional; 9. Classifies injury (severity, location, and type of injury); 10. Indicates the number of participants with missing data and explain how this was addressed; 11. Measures and presents exposure data.

across studies due to variations in period, competition events, participant samples, model of data collection, and definitions of injury used in the selected studies. Therefore, we aim to provide a clear display of injury data based on the same competition event. In the context of the NCAA competition level, injury and exposure data collected from the NCAA ISP involve injury incidence during both practice and competition periods. During the 2009–2010 through 2013–2014 athlete seasons, Kerr et al., reported a total of 62 injuries with the rate of 1.94/1000 AEs in male and 2.49/1000 AEs in female divers [21]. Boltz et al. and Chandran et al. indicated 43 diving injuries with a rate of 1.52/1000AEs in the males, and 109 injuries with a rate of 2.49/1000AEs in the females during the 2014–2015 through 2018–2019 athletic seasons [7,8].

In terms of the World Aquatics competition level, studies indicated divers have the highest injury rate among the aquatic sports. For instance, in the World Aquatics 2015 report, 46 injuries (injury rate: 49.5 %) were documented in high-diving athletes, and 15 injuries (injury rate: 57.7 %) were recorded in diving athletes [9]. In FINA 2013 and 2009, 26 injuries (injury rate: 29.5 %) and 63 injuries (injury rate: 52.5 %) were recorded, respectively [22,23]. Looking at the Summer Olympic Games, in 2008 Beijing reported 3 injuries (injury rate: 2.1 %) [20], in 2012 London reported 11 injuries (injury rate: 8.1 %) [19], and in 2016 Rio reported 12 injuries (injuries rate: 9 %), along with 16 cases of illness in divers (illness incidence: 12 %) [24]. Moreover, during the 2016 Rio Olympics, a spine MRI assessment was conducted for athletes, revealing that 4 divers had moderate to severe spine pathology, marking the highest sport-specific rate of 3 % in spinal pathology [25].

3.5. Injury location

Four studies have investigated injury locations in competitive divers (Table 4), with three focusing on injury data collected within the NACC ISP. Among male participants, the weighted average percentages from two studies were 27.7 % in the shoulder/clavicle, 21.7 % in the trunk, 9.8 % in the hand/wrist, and 5.4 % in the head/face [7,21]. Female

Table 2
The methodological quality assessment of selected studies (case study).

Study	1	2	3	4	5	6	7	8	9	10	Score
Hosey et al., 2006 [26]	U	Y	Y	Y	Y	Y	Y	Y	Y	NA	8
Berkoff and Boggess. 2011 [27]	U	Y	Y	Y	Y	Y	Y	Y	Y	NA	8
Badman et al., 2004 [28]	U	Y	U	Y	Y	Y	Y	Y	Y	NA	7
Asai et al., 2021 [29]	U	Y	Y	Y	Y	Y	Y	Y	Y	NA	8

Y = Yes; N=No; U = Unclear; Not Applicable = NA.
The numbers of the columns corresponded to the following items of the JBI scale: 1. Were there clear criteria for inclusion in the case series; 2. Was the condition measured in a standard, reliable way for all participants included in the case series; 3. Were valid methods used for identification of the condition for all participants included in the case series; 4. Did the case series have consecutive inclusion of participants; 5. Did the case series have complete inclusion of participants; 6. Was there clear reporting of the demographics of the participants in the study; 7. Was there clear reporting of clinical information of the participants; 8. Were the outcomes or follow-up results of cases clearly reported; 9. Was there clear reporting of the presenting sites'/clinics' demographic information; 10. Was statistical analysis appropriate.

Table 3
Study characteristics for all selected studies.

Reference	Country of Sample	Competition Event	Design (Type of study/ data collection/Weeks of Follow-up)	Number of Samples	Level of athlete	Prevalence of injuries (number of injury/injury rate)	Injury characteristic description	Diving injury surveillance
Boltz et al., 2021 [7]	USA	NCAA: 2014–2015 through 2018–2019	Retrospective study/ NACC ISP/5 years	Male (number was not provided)	Elite	43	Yes	Yes (a)
Chandran et al., 2021 [8]	USA	NCAA: 2014–2015 through 2018–2019	Retrospective study/ NACC ISP/5 years	Female (number was not provided)	Elite	109	Yes	Yes (a)
Prien et al., 2016 [9]	Multiple Countries	2015 FINA World Championships	Retrospective and Prospective survey/ questionnaire survey and LOC's report/-	278 (male: 157 and female: 121) High diving: 93 Diving: 26	Elite	High diving: 46/ 49.5 % Diving: 15/57.7 %	Yes	Yes (b)
Kerr et al., 2015 [21]	USA	NCAA: 2009–2010 through 2013–2014	Retrospective study/ NACC ISP/5 years	Female and male (number was not provided)	Elite	Male: 25/16.8 % Female: 37/17.8 %	Yes	Yes (a)
Mountjoy et al., 2014 [23]	Multiple Countries	2013 FINA World Championships	Retrospective and prospective survey/ questionnaire survey and IOC' ISS/5 weeks	High diving: 17 Diving:88	Elite	High diving: 1/ 5.8 % Diving: 26/29.5 %	Yes	Yes (b)
Mountjoy et al., 2010 [22]	Multiple Countries	2009 FINA World Championships	Prospective study/IOC ISS/1–2 weeks	Male: 118 Female: 82	Elite	63/52.5 %	Yes	Yes (b)
Grant et al., 2017 [24]	Multiple Countries	2016 Rio Summer Olympic Games	Prospective study/IOC ISS/32days	135	Elite	Injury: 12/8.9 % Illness: 16/12 %	–	Yes (c)
Wasserman et at. 2018 [25]	Multiple Countries	2016 Rio Summer Olympic Games	Retrospective study/ clinical assessment by MRI/32days	135	Elite	43.0 %	Yes (only spine injury was assessed)	Yes (c)
Engebretsen et al., 2013 [19]	Multiple Countries	2012 London Summer Olympic Games	Prospective study/IOC ISS/-	136 (Male: 68 Female: 68)	Elite	Female: 4/5.9 % Male: 5/7.4 % 11/8.1 %	Yes	Yes (c)
Junge et al., 2009 [20]	Multiple Countries	2008 Beijing Summer Olympic Games	Prospective survey/IOC ISS/-	145 (male and female)	Elite	3/2.1 %	NO	Yes (c)
Baranto et al., 2006 [18]	Sweden	–	Longitudinal study/ clinical assessment and questionnaire survey/5 years	18; 10-21-year-old	Elite	16	Yes (only spine injury was assessed)	Not provided
Asai et al., 2021 [29]	Japan	–	Case study/clinical assessment/4 weeks	1 female; 16-year-old	Elite	1	Yes (only shoulder injury was assessed)	Not Provide
Berkoff and Boggess 2011 [27]	USA	–	Case study/Clinical assessment/2-3weeks	1 male; 15-year-old	Elite	1	Yes (only wrist injury was assessed)	Not Provide
Hosey et al., 2006 [26]	USA	–	Case study/clinical assessment/Not provide	1 female; 13-year-old	Not provided	1	Yes (only wrist injury was assessed)	Not Provide
Badman et al., 2004 [28]	USA	–	Case study/Clinical assessment/Not provide	1 female; 19-year-old	Elite	1	Yes (only spinal injury was assessed)	Not Provide

LOC: local organizing committee; IOC: The international Olympic committee; ISS: Injury surveillance system; NCAA: The national Collegiate Athletic Association; MRI: Magnetic Resonance Imaging; Olympic Committee; LOCOG: London Organizing Committee of the Olympic and Paralympic Games; ISP: Injury surveillance program.
(a) The national Collegiate Athletic Association Injury Surveillance Program [lunwen 3].
(b) Consensus statement on the methodology of injury and illness surveillance in FINA (aquatic sports) [lunwen cankao 1 de (a).
(c) Injury surveillance in multi-sport events: the International Olympic Committee approach [lunwen cankao 1 de (b)].

Table 4
Injury characteristics in the selected studies.

References	Location of injury (number of injury/injury rate)		Type of injury (number of injury/injury rate)		Athlete Exposures (AEs)	Mechanism of Injury
	Male (M)	Female (F)	Male (M)	Female (F)		
Boltz et al., 2021 [7]	Shoulder: 10/23.3 % Trunk: 10/23.3 % Hand/wrist: 5/11.63 % Head/face; Knee/Lower leg: 3/6.98 % Hip/groin; Foot: 2/4.65 % Neck; Thigh; Ankle: 1/2.33 %	–	Strain: 8/18.6 % Inflammatory condition: 7/16.3 % Sprain: 4/9.3 % Concussion; Dislocation; Entrapment; Spasm: 3/7 % Fracture: 2/4.7 %		M: 1.52/1000 AEs	Male only: Overuse injury: 9/20.9 %; Noncontact injury: 13/30.2 %; Surface Contact: 14/32.6 %
Chandran et al., 2021 [8]	–	Head/face: 32/29.36 % Trunk: 22/20.18 % Knee: 10/9.17 % Shoulder: 9/8.26 % Hand/wrist; Hip/groin: 5/4.59 % Neck; Lower leg; Foot: 4/3.67 % Ankle: 3/2.75 %	–	Concussion: 15/13.8 % Illness/infection: 12/11.01 % Strain/Contusion: 7/6.42 % Sprain: 6/5.5 % Spasm; Inflammatory: 5/4.59 % Fracture: 4/3.67 %	F: 2.49/1000 AEs	Female only: Surface contact: 34/31.19 % Noncontact: 16/14.68 % Overuse: 26/23.85 %
Kerr et al., 2015 [21]	Shoulder/clavicle: 8/32.0 % Trunk: 5/20.0 % Neck; Ankle; hand/wrist: 2/8.0 % Head/face; Arm; Elbow; Hip/groin; Thigh; Knee; Lower leg: 1/4.0 %	Trunk: 14/37.8 % Hand/wrist: 6/16.2 % Head/face: 5/13.5 % Neck: 3/8.1 % Shoulder/clavicle; Ankle: 2/5.4 % Arm/elbow/knee/lower leg/foot: 1/2.7 %	Strain: 5/20 % Sprain/Spasm/: 3/12 % Contusion; Inflammation; Sacroiliac joint dysfunction; Tendonitis: 2/8.0 %	Strain: 6/16.2 % Spasm: 5/13.5 % Sprain: 4/10.8 % Concussion/contusion: 3/8.1 % Fracture; Sacroiliac joint dysfunction: 2/5.4 %	M: 1.94/1000 AEs F: 2.49/1000 AEs	Overuse injury: 24 % (male), 21.6 % (female) Noncontact injury: 28 % male, 27 % female Surface contact: 32 % in male; 16.2 % in female
Mountjoy et al., 2010 [22]	Both genders: Ankle: 9 Low back; Wrist/hand: 5 Cervical; Knee: 4 Spine; Neck; Arm; Elbow: 3 Thigh; Lower leg): 2		–	–	M: 2.68/1000 AEs F: 2.26/1000 AEs	–

divers exhibited weighted averages of 29 % in the trunk, 21.5 % in the head/face, and 10.4 % in the hand/wrist, and 6.8 % in the shoulder/-clavicle [8,21]. Other reported injury locations included the neck, arm/elbow, knee, hip/groin, foot, and ankle. Additionally, based on injury data collected in World Aquatics 2009 for both male and female divers, Mountjoy et al. reported the highest injury proportion occurred in the ankle at a rate of 14.2 %, followed by 4.2 % in the trunk/lower back [22].

In a longitudinal study conducted by Baranto et al. they specifically examined spine health in young elite divers through a 5-year follow-up MRI assessment. Among the 18 investigated divers, it was reported that 89 % experienced back pain symptoms, 65 % showed abnormalities in the thoraco-lumbar spine, and 53 % experienced deterioration [18].

3.6. Injury type and injury mechanism

Three studies reported on the types of injuries and injury mechanisms in both male and female divers (Tabel 4). In the male divers, the average percentage weighted by two studies showed 19.3 % in the strain, 12.1 % in the inflammation, 10.7 % in the sprain, 9.5 % in the spasm, and 7.5 % in the concussion [7,8]. Among female divers, the weighted averages were 11.3 % for strains, 11 % for concussions, 9 % for spasms, 8.1 % for sprains, and 4.6 % for fractures [8,21].

Furthermore, injuries were most commonly attributed to the mechanism of overuse, noncontact, and surface contact. According to the two reported studies, the weighted average was 22.5 % for overuse, 29.1 % for noncontact injury, and 32.3 % for surface contact in male divers [7,21]. Regarding females, with weighted average was 26.4 % for overuse, 20.9 % for noncontact, and 20 % for surface contact [8,21].

3.7. Injury in case studies

Four case studies evaluated the specific injury in competitive divers with various symptoms in the shoulder, wrist, and spine (Table 5). Specifically, two studies focused on wrist injuries: one was diagnosed with a scaphoid stress fracture treated with internal fixation surgery [26], while the other reported contiguous contusions on the dorsal wrist and received conservative therapy with a custom-molded rigid extension brace [27]. Badman et al. demonstrated a spinal injury in which a patient with C5–C6 ligamentous instability, was treated with posterior arthrodesis surgery [28]. In the most recent case study, a diver injury case was reported with traumatic growth injury in the shoulder, applied rehabilitation training for 4 weeks [29].

4. Discussion

Competitive diving injuries receive less attention than those in other aquatic sports. This study aims to systematically review the scientific evidence on injury incidence in competitive divers, highlight prevalent injury patterns, and aid in developing prevention strategies. This systematic review identified the trunk, shoulder, head/face, and hand/wrist as the main locations of injuries. Regarding the type of injury, it appears that strain, sprain, spasm, and concussion are the most common. These injuries are often associated with mechanisms such as overuse and surface contact [21].

4.1. Injury incidence

Diving injury data collection from various competition events based on different injury surveillance systems, has resulted in disparate rates,

Table 5
Injury characteristics in the selected studies (case study).

Reference	Diving Event	Injury Location	Diagnosed Symptom	Assessment Method	Treatment Strategy
Hosey et al., 2006 [26]	–	Wrist	Scaphoid stress fracture	MRI	Surgery: internal fixation
Berkoff and Boggess 2011 [27]	10 m platform and 3 m springboard	Wrist	Contiguous contusions on the dorsal wrist	MRI	Conservative therapy: custom-molded rigid extension brac; 2–3 weeks
Badman et al., 2004 [28]	3 m spring board	Spinal	Patient with C5–C6 ligamentous instability	Radiograph	Surgery: posterior C5–C6 arthrodesis
Asai et al., 2021 [29]	7.5 m platform	Shoulder	Traumatic growth injury	MRI	Conservative therapy: muscle training, active ROM exercise; 4 weeks

making it difficult to contextualize these findings. At NCAA competition levels, researchers have described the epidemiology of diving injury among college-level student-athletes, using data collected by the NCAA ISP. Across ten seasons spanning from 2009/2010 to 2018/2019, the injury rate remained stable at 2.49/1000 AEs in the female divers [8,21]. Notably, there was a decrease in the injury rate of 1.94/AEs to 1.52/AEs in male divers [7,21]. However, summarizing potential trends in male injuries in NCAA events proves challenging based solely on the currently recorded data, as the injury rate can be influenced by multiple factors during data collection.

Additionally, the 2008, 2012, and 2016 Summer Olympic Games showed that injury rate of 2.1 %, 8.1 %, and 9 %, respectively [19,20,24]. Furthermore, in the World Aquatics Championships 2009, 2013, and 2015, the highest injury rate was reported in high diving with rate of 12.6/100 athletes, 11.4/100 athletes, and approximately rate of 36/100 athletes, respectively [9,22,23]. Overall, there has been an observable increase in injury rates over the years. One possible explanation is the accumulation of injury history among athletes, as it has been reported that two-thirds of athletes experienced symptoms before competing [30]. The accumulation of injury history not only hinders diving performance by compromising physical capabilities but also increases the risk of recurrent and similar injuries in the future. Another contributing factor could be the improved compliance and response rates of medical staff in the injury surveillance system over the years, leading to a higher number of reported injuries.

Additionally, the injury rate in female divers is significantly higher than males across the recorded sports seasons at the NCAA level. Also, in World Aquatics 2013, Mountjoy et al. indicated that significantly more females (36.7 %) reported injury than males (28.6 %) in all aquatics [23]. Previous studies have analyzed the differences between genders in anatomical, physiological, and psychological aspects, which could be potential factors leading to a higher injury risk in female athletes [30]. Further investigation into the specific causes of the high injury rate in female divers is warranted, as it could provide targeted healthcare for females to reduce the injury incidence in female divers.

The reported incidence of diving injuries could be even higher in reality than the reported data, possibly due to the limitations of ISP and moderate athlete response in the retrospective survey. Within the sports culture, some mild symptoms such as chronic pain in the wrist, shoulder, and lower back are considered normal and expected to be tolerated [21]. For example, one study investigating attitudes toward shoulder pain among 102 adolescent swimmers, found that 95 % of them believed mild and moderate shoulder pain to be normal and should be endured [31]. Regarding the injury surveillance system, only when the athletes disclose the pain or the athlete's trainer notices is the injury recorded. On the other hand, swimming and diving are typically treated as one team, yet they inherently pose different levels of injury risk, as diving involves performing highly technique aerial movement and presents a distinct set of challenges and risks compared to swimming [32,33]. Consequently, AEs in diving injury may be underestimated based on the roster size, which is far from ideal.

4.2. Injury location, type, and mechanism

The selected studies have identified shoulder, trunk/lumbar spine, head/face, hand/wrist as the most common locations for injuries. Diagnoses covered a wide spectrum, with strain, sprain, spasm, concussion, and inflammation being the most prevalent type in both male and female athletes. Also, the common injury mechanism was identified in competitive diver involving overuse, noncontact, and surface contact, with overuse being the most contributions. In this part, three injury characteristics were discussed in combination.

4.2.1. Shoulder

Shoulder injury showed the highest injury rate in the male divers at the NCAA level, accounting for 32 %–23.3 % of all injuries over five academic seasons [7,21]. Similarly, World Aquatics 2009, 2013, and 2015, indicated that the most common injured body part was the shoulder, even though these studies did not differentiate between divers and swimmers [9,22,23]. Technically, diver's shoulders are often abducted and flexed in a vulnerable position, exposing them to impact forces during water entry. And this vulnerability is exacerbated by the repetitive nature of competitive sport throughout the training sessions. The most identified shoulder injury symptoms have been suggested as glenohumeral instability, overuse, and tendinopathy [11].

A recent case report highlighted a growth plate injury in the proximal humerus of a 16-year-old female elite diver [29]. The injury occurred during a 7.5 m platform diving practice, presenting initially with symptoms of shoulder tenderness and limited movement in the left shoulder, diagnosed with traumatic growth plate injury caused by a single external force, and received conservative therapy for five weeks before restarting the diving practice. The case report also emphasized the significant role of magnetic resonance imaging (MRI) in identifying epiphyseal injuries, which may be challenging to recognize through conventional X-ray imaging.

4.2.2. Hand and wrist

The injury rate of hand/wrist accounted for 5.5 %–16.2 % in NCAA level divers in the academic season from 2009/2010 to 2018/2019. Interestingly, no hand/wrist injuries were reported in the Olympic Games. This could be assumed that hand/wrist injuries in divers are likely attributable to overuse, given that the injury data are derived from the NCAA ISP, where symptoms may appear over an extended period of practice and competition. All successful dives ended with hand entry first, breaking the surface tension of the water, and handstand dives with full weight bearing on the hands are required in the 10 m platform. A similar pattern is evident in gymnastic athletes who spend extensive hours performing handstand activities, with a majority of reported occurring in the hand/wrist [34].

There are two case studies reported wrist injuries in competitive divers. In one case, a 13-year-old elite female diver with the symptom of insidious onset right wrist pain for two months, was diagnosed with a scaphoid stress fracture using MRI, and treated with a thumb spica cover

[26]. Another case identified a carpal contusion in a 15-year-old male elite diver, who participated in the 10 m platform and 3 m springboard events, with symptoms of his right wrist discomfort for 2–3 months, MRI showed contiguous contusions on the carpal and generalized ligament laxity, treated with rigid bracing and taping for 2–3 weeks [27]. Furthermore, it is noteworthy that in chronic overuse injuries, patients often become aware of symptoms only after they appear, or minor symptoms are ignored until they become intolerable. This condition is universally acknowledged among athletes [31]. In those two cases, patients sustain discomfort for 2–3 months before visiting a doctor. Therefore, health education and a more sophisticated ISP could be provided to athletes and their trainers to enhance injury response efficiency.

4.2.3. Spine

The vulnerability of the spinal column to injury in diving athletes is an unfortunate and well-established reality, as evidenced by Baranto et al.'s study published in 2006 [18]. They conducted a long-term longitudinal assessment of the throraco-lumbar spine health in 20 elite divers (aged from 10 to 21 years) for 5-years in Sweden [18]. Staggeringly, 65 % of divers had spine abnormalities already at baseline which were diagnosed by MRI, and 89 % had back pain history. Over the course of the study, 53 % of divers showed a deterioration in existing abnormalities, and the number of abnormalities increased by 29 %. In addition to this compelling evidence, other injury data collected from the ISP in the big competition events further underscore this concern. In the selected study, trunk injury rates were notably high, with a weighted percentage of 29 % in females and 21.7 % in males. This injury rate is considered among the highest in all diving-related injuries. Lower back pain and disc degeneration are thought to be the most common symptoms of spine injury among divers [35–38]. Biomechanically, divers subject their spine to axial loading, shearing, and torsional stresses while performing a series of complex movements involving extension, rotation, and flexion in the trunk, as well described in the previous studies [11,39].

The lumbar pain could easily occur at an early age in the diver, who is at high risk during the pubertal growth spurt [18]. However, most of them persist in this pain during daily training without realizing its severity. The Baranto et al.'s five years follow-up study revealed no improvements in baseline abnormalities [18]. Therefore, developing a specific prevention plan, especially for young divers becomes quite important for their athletic career. Narita et al. investigated intrinsic factors in low back pain development among 83 elite junior divers, suggesting that shoulder flexibility plays a crucial role in low back pain [40]. But sports injuries typically result from multiple factors, such as age, body mass index, muscle strength, motion technique, etc. Thus, more investigations are needed to determine the injury factors and develop effective prevention strategies.

4.2.4. Head/face and neck

The injury rate in the head/face and neck is relatively lower compared to the described injuries above. However, among female colligated divers, head/face injury showed a high injury rate, with an average weighted percentage of 21.5 % in NCAA academic seasons [8, 21]. No head/face injury cases were reported at World Aquatics events, this can be assumed that this injury commonly occurs during training seasons. It has been suggested that head/face injuries were often caused by surface contact mechanisms (with water), leading to abrasion/laceration and concussion [8]. In contrast, head/face injuries are significantly lower in male collegiate divers, with a weighted percentage of 5.4 %. The reason for this gender difference remains inadequately studied; therefore, obtaining additional information from the ISP during athlete training is essential for further exploration in order to develop effective prevention strategies specifically targeting female divers to reduce the risk of head/face injuries.

In terms of neck injuries, the incidence is also relatively lower than other types of injuries. At the NCAA level, the weighted percentage was 5.5 % in males and 5.9 % in females [7,8,21]. Additionally, four neck injury cases were reported in World Aquatics events [22]. However, in contrast to competitive divers, recreational divers frequently report neck injuries, commonly in the form of bursts and/or compression fractures resulting from flexion-compression forces on the cervical spine. Most fractures occur at the C5–C7 vertebral level [41–43]. Regrettably, even professional divers cannot escape from such tragedies, as they have to pose their necks in a flexed posture rather than a natural alignment when entering the water, subjecting the cervical spine to high axial loading which increases the injury risk. This was highlighted by a case report of a neck injury in a 19-year-old female elite diver, with symptoms of pain around the neck and arm for about 9 weeks, diagnosed cervical C5–C6 ligamentous instability, and treated with operative stabilization using allograft and plating, and the pain around her neck and arm resolved after one year [28].

4.3. Limitations and future work

In this research, the injury mechanism of competitive diving injury from the aspects of overuse, noncontact, and surface contact, are not thoroughly discussed here. Although it is well-known that overuse injury can be a main culprit for diving injury, given the nature of the competitive sport, including countless repetitive training over the long term, exploring the specific injury mechanism is still critical for establishing an effective injury prevention plan. Additionally, the injury mechanism in the competitive diver is quite a big topic that needs more detailed injury data gathered during both training and competition, this further emphasizes the necessity for designing and implementing an injury survey protocol among divers.

Moreover, the availability of diver injury data from major competition events is limited to the 2015 World Aquatics, 2016 Olympic Games, and 2018/2019 NCAA. Some research used a retrospective survey, which may lead to a bias in the collected data and compromise accuracy. Therefore, a strong appeal is made for the publication of more recent data in the future, and new data can be incorporated into this research for comparison. Also, the perspective survey is recommended for injury surveillance in further investigation.

5. Conclusion

This systematic review examined retrospective, prospective, and case surveys related to injuries in competitive diving. In comparison to other aquatic sports, diving has received less attention, despite a high incidence of injuries occurring in divers during both training and competition. In this systematic review, we highlighted that the upper body, including the shoulder, spine, hand/wrist, head/face, and neck, was the most frequently affected body part in competitive divers, aligning with previous research. We believe that the injury rate could be even higher in reality than reported; multiple factors can be taken into consideration, such as the limitations of the injury surveillance system, the weakness of health awareness in athletes, and the absence of effective prevention strategies, etc.

CRediT authorship contribution statement

Xin Wang: Writing – original draft. **Meizi Wang:** Writing – original draft. **Ming Zhang:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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