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Research article

Injuries in Male and Female Elite Aquatic Sports Athletes: An 8-Year Prospective, Epidemiological Study

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Abstract

This study aimed to determine the injury patterns associated with training activities in elite South Korean aquatic sports athletes training for the Olympic Games. From 2012 to 2019, we prospectively collected data on elite aquatic sports athletes at the Korea National Training Center. The athletes were assessed by four sports medicine doctors, and data were stratified according to sex, aquatic style, injury body location, and injury severity. Chi-square tests were used to compare groups. Injury rates was expressed as rate ratios with 95% confidence intervals. Annually, the center hosts an average of 42 elite aquatic athletes spread over four aquatic styles. We recorded 797 injuries in total (annual average: 2.37 injuries/athlete), during training sessions, 57.1% of which were mild injuries. For all athletes, most injuries occurred in the upper limb (35.9%), followed by the lower limb (31.0%), the trunk (24.5%), and the head and neck (8.7%). Aquatic style significantly influenced injury body location and severity for both male and female athletes (injury body location: $p < 0.001$ and $p < 0.010$, respectively; injury severity: $p = 0.027$ and $p < 0.001$, respectively). In general, male and female athletes experienced a comparable risk of injury (rate ratio: 1.15; 95% confidence intervals: 0.53-2.46). Among the male and female South Korean elite aquatic athletes training for the Olympic Games, most injuries were mild and occurred in the upper limb, and aquatic style influenced injury body location and severity.

Key words: Sports injury, aquatic sports, South Korea, body region, sex differences

Introduction

Aquatic sports have been part of the Olympic Games since the 1896 Athens Games (FINA, 2020). In 1908, the International Amateur Swimming Federation was established to provide a much-needed structure to the competitive aquatics program (FINA, 2020).

South Korea as the host of the Gwangju 2019 FINA World Championships (FINA, 2020), the popularity of aquatic sports and the expectations regarding the athletic performance of South Koreans at international aquatic sports competitions have been increasing.

Elite South Korean aquatic sports athletes undergo intensive training involving high-intensity exercise for long durations. Although the increased activity is critical for maximizing athletic performance (McGuine, 2006), it significantly increases the risk of sports injury (Park and Brian, 2017). Aquatic sports athletes are matched according to aquatic style, leading to entirely different styles of play, traits, and tactics (International Olympic Committee, 2020). It is unknown whether this also leads to a difference in the injury rate and nature of sports injuries.

According to epidemiological studies carried out during the Olympics, aquatic sports have been associated with lower injury rates compared to combat sports (Junge et al., 2009; Engebretsen et al., 2012). However, every part of the human body is vulnerable to injury in aquatic sports (Caine et al., 2010). Although several reports on aquatic sports injuries have been published (Annett et al., 2000; Badman and Rectine, 2004; Bak and Fauno, 1997; Capaci et al., 2002), few studies have examined injuries during training or competition for these sports.

Furthermore, most studies involve short-term follow-ups (typically no longer than 1 year) and are focused around special sports events. For example, Engebretsen et al. (2013) only addressed the injury rate of sports damage during the London Olympics. Furthermore, the injury profile for aquatic sports is unclear, and most studies evaluating aquatic sports injuries are retrospective and do not account for exposure when determining injury rates. Therefore, their study showed the highest injury rate of artistic swimming injury (Engebretsen et al. 2013). The Charter of the International Olympic Committee (IOC) aims to develop programs to prevent sports injuries and help enhance the performance of Olympic athletes (International Olympic Committee, 2019). To collect data on the circumstances in which injuries of different severity occur, a prospective surveillance program was initiated at the National Training Center in South Korea, which hosts the training of elite athletes who are expected to represent South Korea at international sporting events.

In this study, we analyzed sports injury data prospectively recorded during the 8-year period following the initiation of the surveillance program. We aimed to analyze the specific patterns (injury rate, body region, site, type, and severity) of injury for each of the main aquatic styles (swimming, diving, water polo, and artistic swimming) and to investigate potential sex-specific differences in aquatic injuries.

Methods

Study population

This study included elite aquatic athletes participating in top-level international competitions who trained at the Korea National Training Center between January 2012 and December 2019. The study design was approved by the Korea Training Center, and the study was conducted

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ethically according to the principles of the Declaration of Helsinki. The requirement for informed for informed consent was waived by the ethics committee.

Annually, the center hosts an average of 42 elite aquatic athletes grouped according to four aquatic styles (swimming: 5 men, 5 women; diving: 5 men, 5 women; water polo: 12 men; artistic swimming: 10 women) (Table 1). All athletes who trained in this facility for a duration ranging from at least one year were included in this study. South Korean aquatic athletes compete for national team selection every year; therefore, only selected athletes train at the National Training Center. During the research period, some athletes were selected for the national team for only 1 year, while others were selected for multiple years. The longest an athlete spent on the national team was 8 years.

Data collection

Training details (aquatic style and date), athlete characteristics (sex and name), and injury characteristics (injury rate, body region, site, type, and severity) were recorded using daily injury report forms issued by the IOC (Bahret al. 2020). During the study, the athletes were assessed by one of four sports medicine doctors who completed the daily injury report forms on-site before referring the athletes to the training center clinic.

Operational definitions

A sports injury was defined as any acute or chronic musculoskeletal signs or symptoms occurring due to aquatic activities during training sessions (Goldberg et al., 2007). Multiple injuries in a single athlete were classified according to the affected body region. However, acute and overuse injuries were not distinguished. Bahret al. (2020) Calculated as the number of days of failing to participate in training due to sports injury, the Injury severity was classified as level I (mild injury, requiring 1–3 days of time loss), lever II (moderate injury, requiring 4–7 days of time loss), and lever III (severe injury, requiring ≥8 days of time loss) (Park and Brian, 2017; Park et al., 2019). The injury body location and injury type was classified based on an IOC consensus statement (Bahret al. 2020). We defined affected body regions and type of injury as the head and neck, upper limb (shoulder, upper arms, elbow, forearm, wrist, hand), trunk (chest, thoracic, lumbosacral, abdomen), and lower limb (hip/groin, thigh, knee, lower leg, ankle, foot). Muscle/Tendon, Nervous, Bone, Cartilage/Synovium/Bursa, Ligament/Joint capsule, Superficial tissues/skin, Vessels, Stump, Internal organs and Non-specific (Bahret al. 2020).

Statistical analysis

The examined variables included sex, aquatic style, injury body location (body region and specific site of injury), injury severity and injury rates. Descriptive statistics were used to examine injury patterns. We used chi-square tests to compare injury severity and body location between groups based on aquatic style or sex. Injury rates were expressed as the number of injuries per year, the number of injuries per 1000 hours of training, and the number of injuries per 1000 athlete exposures (AEs). The total number of training hours was calculated based on the total time that athlete spent at the training center. One AE was defined as participation in one training session. The annual hours and AEs were calculated by excluding hours and exposure of not participating in training due to injury. The calculations of the injury rate per 1,000 hours and 1,000 AEs were calculated as follows: (total injury/the total training hours or total AEs of all athletes × 1000). To compare the relative risk of injury between sexes, the injury rate ratio (RR) was determined with 95% confidence intervals (CIs). All statistical analyses were performed using SPSS version 24.0 for Windows (IBM Corp., Armonk, NY, USA), and the significance level was set at $p < 0.05$.

Results

In total, 241 athletes were included in the study. They trained an average of 4.5 h/day, 5 days/week. For 1 year, the athletes were present at the training center for 9.5 months (41.25 weeks). Swimmers and divers trained 4 h/day, 5 days/week, for 9 months (39 weeks); water polo players and artistic swimmers trained 5 h/day, 5 days/week, for 10 months (43.5 weeks). Overall, athletes participated in nine training sessions for each two-week period (4.5 training sessions per week). In total, 797 injuries (including acute and overuse injuries) were recorded during the study period.

Injury rates

In total, 241 athletes were 2.37 injuries/year. For 61 swimming, 56 diving, 73 water polo, and 51 artistic swimming training, the annual injury rates were 3.19 (30 men: 2.90; 31 women: 3.48), 2.20 (32 men:1.88; 24 women: 2.53), 2.10, and 2.05 injuries/year, respectively.

When normalized to training hours, the overall injury rate was 2.74 (95% CI = 2.55–2.93) injuries/1000 hours of training. For swimming, the injury rate was 4.60 (95% CI = 4.04 - 5.17) injuries/1000 hours of training, with

Table 1. General characteristics of the subjects. Data are means (±SD).

	Swimming		Diving		Water polo	Artistic Swimming
	Men	Women	Men	Women	Men	Women
N	30	31	32	24	73	51
Hours of training	28272	27120	28688	27136	98176	81896
Athlete exposures	6654	6510	6706	6512	18014	15022
Age (years)	24.4 (4.4)	23.7 (2.6)	23.6 (4.0)	22.8 (1.7)	24.4 (3.4)	19.1 (1.9)
Height (m)	1.84 (0.03)	1.71 (0.02)	1.67 (0.05)	1.56 (0.04)	1.82 (0.05)	1.63 (0.03)
Weight (kg)	78.9 (5.6)	63.4 (1.3)	62.0 (4.1)	52.3 (0.9)	86.5 (9.2)	53.13 (4.0)
BMI ($kg \cdot m^{-2}$)	23.3 (1.0)	21.6 (0.6)	22.3 (0.2)	21.4 (1.1)	26.0 (2.8)	19.83 (1.1)

lower rates observed in men than in women, but the difference was not significant (4.10 vs. 5.13 injuries/1000 hours of training; RR = 1.25, 95% CI = 0.34 - 4.57). For diving, the injury rate was 3.15 (95% CI = 2.69 - 3.62) injuries/1000 hours of training, with lower rates observed in men than in women, but the difference was not significant (2.61 vs. 3.72 injuries/1000 hours of training; RR = 1.43, 95% CI = 0.29 - 6.92). For water polo and artistic swimming, the injury rates were 2.06 (95% CI = 1.77 - 2.34) and 2.00 (95% CI = 1.70 - 2.31) injuries/1000 hours of training (Table 2), respectively.

When normalized to AEs, the overall injury rate was 13.41 (95% CI = 12.48 - 14.34) injuries/1000 AEs. For swimming, it was 19.37 (95% CI = 16.99 - 21.75) injuries/1000 AEs, with lower rates observed in men than in women, but the difference was not significant (17.43 vs. 21.35 injuries/1000 AEs; RR = 1.22, 95% CI = 0.65 - 2.29). For diving, it was 13.32 (95% CI = 11.35 - 15.28) injuries/1000 AEs, with lower rates observed in men than in women, but the difference was not significant (11.18 vs. 15.51 injuries; RR = 1.39, 95% CI = 0.65 - 2.98). For water polo and artistic swimming, rates were 11.21 (95% CI = 9.67 - 12.76) and 10.92 (95% CI = 9.25 - 12.59) injuries/1000 AEs (Table 2), respectively.

In men, swimming was associated with a higher injury rate compared to diving (RR = 1.54, 95% CI = 0.73 - 3.23) and water polo (RR = 1.55, 95% CI = 0.74 - 3.28), but the differences were not significant, whereas water polo and diving had similar injury rates (RR = 1.01, 95% CI = 0.45 - 2.30). In women, swimming was associated with a higher injury rate compared to diving (RR = 1.38, 95% CI = 0.72 - 2.63), but the difference was not significant. Swimming was associated with a higher injury rate than artistic swimming (RR = 1.96, 95% CI = 0.95 - 4.03), and diving was associated with a higher injury rate than artistic swimming (RR = 1.42, 95% CI = 0.66 - 3.07), but the difference was not significant.

Injury body location and type of injury

The body regions in which most injuries occurred were the upper limb (35.9%), followed by the lower limb (31.0%), the trunk (24.5%), and the head and neck (8.7%). The distribution of affected body regions was similar in male and female athletes ($p = 0.377$). However, across all athletes, we observed significant differences in affected body regions between aquatic style categories ($p < 0.001$). Similarly, when men and women were examined separately, we observed significant differences in affected body regions between aquatic style categories ($p < 0.001$ and $p = 0.010$ for men and women, respectively). The shoulder, lumbosacral, neck, knee, ankle, and elbow were the most common specific sites of injury (Table 3). The most common injury was Muscle/Tendon (44.7%), followed by Ligament/Joint capsule (33.4) and Cartilage/Synovium/Bursa (20.6%) (Table 4).

Injury severity

For all athletes included in the study, 57.1% of injuries were classified as level I, 26.2% as level III, and 16.7% as level II. We observed significant differences in injury severity between men and women ($p = 0.018$). Overall, we found that males had more level I and level II injuries, while females had more III injuries. For all athletes, we observed significant differences in injury severity between aquatic style categories ($p < 0.001$). Similarly, when men and women were examined separately, we also observed significant differences in injury severity between aquatic style categories ($p = 0.027$ and $p < 0.001$ for men and women, respectively). Across all athletes, we did not observe significant differences in injury severity between affected body regions ($p = 0.165$). When men and women were examined separately, injury severity was not significantly influenced by body region ($p = 0.223$ and $p = 0.459$ for men and women, respectively). However, in swimmers and divers, injury severity was significantly influenced by body region ($p = 0.019$ and $p = 0.021$ for swimmers and divers, respectively) (Table 5).

Discussion

We aimed to better understand the pattern of sports injuries among elite Korean aquatic athletes by assessing how injury rate, body location, and severity were associated with sex and aquatic style category. Previous prospective studies conducted in Korean athletes only examined the difference between male and female injury rates and did not consider aquatic style or injury severity (Kim and Kim, 2014; Yoon et al., 2018).

Although differences in study design preclude a direct comparison between our results and those of previous studies, there are apparent differences in overall injury rate (this study: 13.41 total injuries/1000 AEs; Kim and Kim (2014): 34.1 total injuries/1000 AEs) and sex-specific injury rates (this study: men 50.69 vs women 49.31; Yoon

Table 2 During 8 years of elite Korean aquatic athletes practice.

Aquatic style	Injury Rates.		
1000h	**Men IR (95CI)**	**Women IR (95CI)**	**RR (95%CI)**
Swimming,	4.10 (3.36-4.85)	5.13 (4.27-5.98)	1.25 (0.34-4.57)
Diving,	2.61 (2.02-3.21)	3.72 (3.00-4.45	1.43 (0.29-6.92)
Water polo	2.06 (1.77-2.34)	-	-
Artistic swimming	-	2 (1.70-2.31)	-
Total	2.53 (2.28-2.78)	2.97 (2.68-3.26)	1.17 (0.22-6.26)
1000AE	**Men IR (95CI)**	**Women IR (95CI)**	**RR (95%CI)**
Swimming,	17.43 (14.26-20.61)	21.35 (17.80-24.90	1.22 (0.65-2.29)
Diving,	11.18 (8.65-13.72	15.51 (12.48-18.53	1.39 (0.65-2.98
Water polo	11.21 (9.67-12.76)	-	-
Artistic swimming	-	10.92 (9.25-12.59	-
Total	12.53 (11.29-13.76)	14.41 (13.00-15.81)	1.15 (0.54-2.44)

IR: Injury rate CI: confidence interval RR: Rate ratio

Table 3. Injury location (body region and site) in elite Korean aquatic athletes.

Site	Frequency and Proportion (%)					
	Swimming		Diving		Water polo	Artistic Swimming
	Men	Women	Men	Women	Men	Women
Head	-	-	-	1 (1.0)	1 (0.5)	-
Neck	14 (12.1)	8 (5.8)	4 (5.3)	8 (7.9)	18 (8.9)	15 (9.1)
Head and neck	**14** (12.1)	**8** (5.8)	**4** (5.3)	**9** (8.9)	**19** (9.4)	**15** (9.1)
Shoulder	23 (19.8)	28 (20.1)	11 (14.7)	10 (9.9)	51 (25.2)	30 (18.3)
Upper arms	4 (3.4)	4 (2.9)	2 (2.7)	2 (2.0)	5 (2.5)	3 (1.8)
Elbow	5 (4.3)	8 (5.8)	-	1 (1.0)	22 (10.9)	13 (7.9)
Forearm	-	2 (1.4)	1 (1.3)	4 (4.0)	2 (1.0)	2 (1.2)
Wrist	1 (0.9)	-	3 (4.0)	12 (11.9)	8 (4.0)	11 (6.7)
Hand	-	1 (0.7)	1 (1.3)	4 (4.0)	9 (4.5)	3 (1.8)
Upper extremity	**33** (28.4)	**43** (30.9)	**18** (24.0)	**33** (32.7)	**97** (48.0)	**62** (37.8)
Chest	2 (1.7)	2 (1.4)	1 (1.3)	2 (2.0)	2 (1.0)	1 (0.6)
Thoracic spine	6 (5.2)	8 (5.8)	6 (8.0)	10 (9.9)	13 (6.4)	5 (3.0)
Lumbosacral	26 (22.4)	28 (20.2)	12 (16.0)	23 (22.8)	29 (14.4)	19 (11.6)
Abdomen	-	-	-	-	-	-
Trunk	**34** (29.3)	**38** (27.3)	**19** (25.3)	**35** (34.7)	**44** (21.8)	**25** (15.2)
Hip/groin	-	5 (3.6)	3 (43)	-	3 (1.5)	3 (1.8)
Thigh	7 (6.0)	7 (5.0)	9 (12.0)	4 (4.0)	7 (3.5)	13 (7.9)
Knee	11 (9.5)	13 (9.4)	7 (9.3)	3 (3.0)	17 (8.4)	12 (7.3)
Lower Leg	3 (2.6)	5 (3.6)	6 (8.0)	9 (8.9)	8 (4.0)	5 (3.0)
Ankle	13 (11.2)	13 (9.4)	8 (10.7)	5 (5.0)	6 (3.0)	21 (12.8)
Foot	1 (0.9)	7 (5.0)	1 (1.3)	3 (3.0)	1 (0.5)	8 (4.9)
Lower extremity	**35** (30.2)	**50** (36.0)	**34** (45.3)	**24** (23.8)	**42** (20.8)	**62** (37.8)
Total	116 (100.0)	139 (100.0)	75 (100.0)	101 (100.0)	202 (100.0)	164 (100.0)

Table 4. Injury of type in elite Korean aquatic athletes

Tissue	Pathology type	Frequency and Proportion (%)					
		Swimming		Diving		Water polo	Artistic Swimming
		Men	Women	Men	Women	Men	Women
Muscle/Tendon	Muscle injury	35 (30.2)	41(29.5)	24 (32.0)	33 (32.7)	57 (28.2)	53 (32.3)
	Muscle contusion	-	-	2 (2.7)	3 (3.0)	7 (3.5)	-
	Tendinopathy	16 (13.8)	18 (12.9)	8 (10.7)	12 (11.9)	29 (14.4)	18 (11.0)
	Tendon rupture	-	-	-	-	2 (1.0)	-
Bone	Bone stress injury	-	-	2 (2.7)	3 (3.0)	-	-
	Bone contusion	-	-	-	-	3 (1.5)	-
Cartilage/ Synovium/ Bursa	Cartilage injury	7 (6.0)	10 (7.2)	5 (6.7)	6 (6.0)	12 (5.9)	9 (5.5)
	Arthritis	9 (7.8)	7 (5.0)	3 (4.0)	5 (5)	9 (4.5)	11 (6.7)
	Synovitis/Capsulitis	4 (3.4)	9 (6.5)	4 (5.3)	3 (3.0)	10 (5.0)	9 (5.5)
	Bursitis	4 (3.4)	6 (4.3)	2 (2.7)	3 (3.0)	9 (4.5)	8 (4.9)
Ligament/ Joint capsule	Joint sprain (ligament tear or acute instability episode)	41 (35.3)	48 (34.5)	25 (33.3)	33 (32.7)	63 (31.2)	56 (34.1)
Stump	Stump injury	-	-	-	-	1 (0.5)	-

et al. (2018): men 36.36 vs women 63.64). These differences in injury rates are most likely due to different training and competition. For example, during training, unskilled skills and tactical exercises are performed (Powell and Barber-Foss, 1999). However, physical contact is allowed during the competition (water polo), which increases the injury rates (Mountjoy et al., 2019). In addition, Richardson (1999) found that injury rates are high in the water during the competition (swimmers). Anderson and Rubin (1994) found that injury rates are high on impact with water during the competition (divers). Other possible reasons include differences in the rigor and level of coaching (Sallis et al., 2001).

Injury body location and type of injury

We determined that injuries usually occurred in the upper limb, followed by the lower limb, trunk, and head and neck. Previous studies have examined injuries in aquatic athletes from the Turkish (swimming) (Capaci et al., 2002), American (diving) (Anderson et al., 1993), and Canadian championships (artistic swimming) (Kirkley, 1991) and the 2004 Olympic Games (water polo) (Junge et al., 2006). Although differences in study design preclude a direct comparison between the results of previous studies and those of the current study, it appears that the regions of the body injured by divers and artistic swimmers were similar (Kirkley, 1991; Anderson et al., 1993). Conversely, the regions of the body injured during swimming and water polo varied between our study and the aforementioned studies. Capaci et al. (2002) reported that, in swimmers, upper limb injuries were common and lower limb injuries were rare. However, in this study, upper limb injuries were less

Table 5. Statistics results of injury in elite Korean aquatic athletes.

Injury	Frequency and Proportion (%)					
	Level I	Level II	Level III	df	chi-square	p value
Men	231 (58.8)	75 (19.1)	87 (22.1)	2	7.992	0.018
Women	224 (55.4)	58 (14.4)	122 (30.2)			
Swimming	164 (64.3)	45 (17.6)	46 (18.0)	6	31.306	<0.001
Diving	81 (46.0)	25 (14.2)	70 (39.8)			
Water polo	111 (55.0)	43 (21.3)	48 (23.8)			
Artistic Swimming	99 (60.4)	20 (12.2)	45 (27.4)			
Men						
Swimming	81 (69.8)	19 (16.4)	16 (13.8)	4	10.932	0.27
Diving	39 (52.0)	13 (17.3)	23 (30.7)			
Water polo	111 (55.0)	43 (21.3)	48 (23.8)			
Women						
Swimming	83 (59.7)	26 (18.7)	30 (21.6)	4	20.224	<0.000
Diving	42 (41.6)	12 (11.9)	47 (46.5)			
Artistic Swimming	99 (60.4)	20 (12.2)	45 (27.4)			
Swimming						
Head and neck	20 (90.9)	1 (4.5)	1 (4.5)	6	15.206	0.019
Upper extremity	45 (59.2)	10 (13.2)	21 (27.6)			
Trunk	48 (66.7)	13 (18.1)	11 (15.3)			
Lower extremity	51 (60.0)	21 (24.7)	13 (15.3)			
Diving						
Head and neck	5 (38.5)	2 (15.4)	6 (46.2)	6	14.559	0.024
Upper extremity	23 (45.1)	5 (9.8)	23 (45.1)			
Trunk	22 (40.7)	4 (7.4)	28 (51.9)			
Lower extremity	31 (53.4)	14 (24.1)	13 (22.4)			

common than lower limb injuries (this study: 29.8% and 33.3%; Capaci et al. (2002): 56.5% and 13%, for the upper and lower limb injuries, respectively). Junge et al. (2006) reported that, in water polo athletes, head and neck injuries were less common than upper limb injuries. However, in this study, upper limb injuries were less common than head and neck injuries (this study: 9.4% and 48%; Junge et al. (2006): 53% and 30% for upper limb and head and neck injuries, respectively). Most injuries from aquatic sports are inherently chronic and involve repetitive movements (e.g., eggbeater kicking in water or arm cycles in swimming). However, the onset may vary depending on anatomical location and the mechanism of the injury (Caine et al., 2010). In swimming athletes, the dolphin kick has been increasing in popularity in both research and competition due to the apparent advantage conferred by successfully performing dolphin kick sequences following starts and turns (Atkison et al., 2014). The underwater dolphin kick is performed using the lower limb joints (hip, knee, and ankle) (Nakashima, 2009). This is most likely the reason why these athletes develop lower limb injuries. In water polo athletes, head and neck injuries often occur due to contact with other players during a competition (Junge et al., 2006). However, the upper limb injuries developed by these athletes may be associated with repetitive shooting during practice. A study by Wheeler et al. (2013) found that shoulder pain directly correlated with the volume of goal shooting and inversely correlated with rest time between shots.

The most common injury was Muscle/Tendon, followed by Ligament/Joint capsule and Cartilage/Synovium/Bursa. Although differences in study design preclude a direct comparison between the results of previous studies and those of the current study, it appears that the regions of the type of injury were similar (Anderson et al., 1993; Capaci et al., 2002; Junge et al., 2006; Kirkley, 1991).

Injury severity

A previous study noted that most aquatic sports injuries were not serious, but it did not specifically define severe and very severe injuries (Richardson, 1999). In this study, aquatic style significantly influenced injury severity when subjects were stratified by sex (Table 5). However, our findings could not be compared with previous observations since previous studies did not examine the influence of aquatic style on injury severity. Herein, we assessed injury severity according to time loss from training. Anderson and Rubin (1994) and Rubin et al. (1993) found that acute injuries were common in diving due to impact with the water, whereas chronic injuries were common in swimmers due to the highly repetitive motions associated with such activities (i.e., arm cycles in swimming or treading in water polo). This may have contributed to differences in injury distribution that may be explained by the differences in the sex distribution of athletes involved in each aquatic style. Swimmers and divers were both male and female, whereas water polo athletes were only male, and artistic swimmers were exclusively female. Swimmers and divers differed significantly in terms of injury distribution and severity of injuries to different body regions. However, water polo players and artistic swimmers were similar in terms of injury distribution and severity of injuries to different body regions.

Sex-specific differences in injury patterns

Kim and Kim (2014) reported that the injury rate of sports injuries differed between women and men. Our study also noted that men displayed a higher annual injury rate than women, most likely due to the tendency of the athletes to adapt their strategy and use different skill sets according to

their physical build and strength (Sterkowicz et al., 2013). Another reason may be neuromuscular differences between men and women. Neuromuscular impairments can change the pattern of movement and increase the risk of injury (Dutton, 2013). However, certain injuries occur more frequently in women than in men, and a large contributing factor to this difference is the lack of neuromuscular control (Dutton, 2013).

Men and women differed significantly in terms of injury severity. Overall, we found that men had more level I and II injuries, whereas women had more level III injuries. A primary reason underlying this difference may be differences in responses to growth hormones. Longobardi et al. (2000) administered exogenous growth hormones to both sexes and found that males exhibited an increase in bone formation markers that was nearly threefold greater than that in females. Since males demonstrate a greater capacity to activate bone growth, this may serve to increase their healing rate and allow them to return to sport sooner (Tran et al., 2009).

Strengths and limitations

This study has several strengths. First, a large number of athletes were observed closely for 9.5 months (41.25 weeks). Second, a detailed analysis of the severity (which we defined based on the time lost from training), injury rate, and body location of injuries was performed with an extremely high inclusion rate. Third, every injury that occurred at the training facility was reported and handled within the on-site facilities, ensuring consistent data gathering. Finally, the number of injuries was analyzed according to subcategories to address novel research questions that are relevant to other fields of sports medicine. This indicates that the rate of injury, body location, and injury severity during training sessions differ depending on sex and detailed events, even in the same event. This should also be considered when developing and training injury prevention programs.

Our study also has some limitations. We did not present any information regarding the mechanism(s) of injury (training load, injury type, or cause of injury). Our data were collected from daily injury report forms, which were completed on site as soon as an athlete reported injury symptoms. These forms only included the results of the initial assessment, before the athlete was referred to the clinic; therefore, the forms did not specify the athlete's final diagnosis. We were not able to include athletes who left the center mid-season because of a severe injury or for personal reasons. However, every injury that occurred at the training facility had to be reported and handled within the on-site facilities, which helped ensure consistent data gathering.

Conclusion

This is the first study to examine the epidemiology of injuries in elite South Korean aquatic sports athletes. In this study, the athletes were observed over a relatively extended time period. Moreover, a detailed analysis regarding the injury rate, body location, and severity of the injuries was performed. Further analyses also considered the influence of aquatic style category, which is expected to be relevant to the risk assessment of sports injuries and to the development of preventive measures. More than half of all injuries observed among elite South Korean aquatic sports athletes were considered to be minor since athletes were able to return to training after simple treatment and taping. When we compared aquatic style categories, swimmers had the highest injury rates. Moreover, women had higher injury rates than men. Aquatic style influenced injury severity in both male and female elite athletes and the region of the body that was injured. This study indicates the need for conceptualization and implementation of injury-prevention strategies. The findings of this study may be useful when developing future programs that aim to prevent sports injuries in aquatic athletes.

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Key points

- Injury patterns associated with training activities in elite aquatic sports athletes training for the Olympic Games have not been fully elucidated.
- Aquatic style significantly influenced injury body location and severity for both male and female athletes.
- Conceptualization and implementation of injury-prevention strategies are needed to prevent sports injuries in aquatic athletes.

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