ARTICLE IN PRESS
JSAMS-02979; No of Pages 6
Journal of Science and Medicine in Sport xxx (xxxx) xxx–xxx
Contents lists available at ScienceDirect
Journal of Science and Medicine in Sport
journal homepage: www.elsevier.com/locate/jsams

Original research

Ankle sprain, concussion, and anterior cruciate ligament injuries are common and burdensome in sub-elite female Australian football players

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ARTICLE INFO

Article history:
Received 22 November 2023
Received in revised form 28 February 2024
Accepted 16 May 2024
Available online xxxx

Keywords:
Athletic training
Female athlete
Ligamentous injuries
Football, Australian
Head injuries

ABSTRACT

Objectives: To describe the epidemiology of injuries in sub-elite female Australian Football (AF).
Design: Prospective cohort.
Methods: 424 athletes were tracked across a 12-match season. Injury characteristics (location, severity, mechanism) were reported. Injury incidence (injuries per 1000 h) and injury burden (days absent per 1000 h) were calculated. Severity was considered as the number of days missed between injury onset and return to full training. Incidence was compared using incidence rate ratios, and severity using a Mann–Whitney *U* test.
Results: Total injury incidence was 10.8 (95 % confidence interval [CI] = 9.0, 12.8) injuries per 1000 h. Match incidence was 34.6 (95 % CI = 28.0, 42.4) injuries per 1000 h. Ankle sprain injuries (2.2 per 1000 h, 95 % CI = 1.4, 3.1) and concussion (1.6 per 1000 h, 95 % CI = 1.0, 2.5) injuries were the most frequent, followed by anterior cruciate ligament (ACL) injuries (0.9 per 1000 h, 95 % CI = 0.4, 1.6). ACL (40.4 days per 1000 h, 95 % CI = 36.9, 44.1), ankle sprain injuries (31.4 per 1000 h, 95 % CI = 28.4, 34.7), and concussion (19.9 per 1000 h, 95 % CI = 17.5, 22.5) injuries were also the most burdensome. There were 78 mild, 34 moderate, and 21 severe injuries. ACL injuries were the most severe injury (56.0 [77.0] in-season days missed).
Conclusions: This research describes the first large-scale injury profile of sub-elite female AF, reporting time-loss measures of incidence and burden for many injury types. Ankle sprain injuries, concussions, and ACL injuries are common and burdensome, and should be prioritised for prevention.

Practical implications

- Findings indicate that ankle sprain, concussion, and anterior cruciate ligament injuries are the most common and burdensome in sub-elite female AF and should be prioritised for prevention strategies.
- Female AF athletes present different injury profiles to male AF athletes, who are known to experience much higher rates of hamstring and calf muscle strains.
- Whilst the injury profiles of sub-elite and elite female AF athletes are similar, injury incidence appears much lower in sub-elite cohorts. This may be explained by elite female AF athletes requiring greater physical performance capabilities.
- Practitioners working with female AF athletes may need to consider targeted prevention strategies to reduce rates of concussion and anterior cruciate ligament injuries.
- Female AF league management could consider game rule modifications to reduce the incidence of contact injuries. Female AF coaches should consider developing efficient and safe tackle technique to reduce the risk of contact injuries occurring.

1. Introduction

The introduction of the Australian Football Leagues Women's (AFLW) competition in 2017 was a watershed moment for Australian Rules Football (AF), with registered women's football participation increasing from ~380,000 in 2016 to ~600,000 in 2022. Females now represent 31 % of all AF players nationally.[1,2] This increase in professionalism and participation has created greater need for coaches, practitioners, and medical staff to enhance player safety through injury reduction strategies. However, to date, research on injury profiles

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https://doi.org/10.1016/j.jsams.2024.05.008
1440-2440/

Please cite this article as: H. Bennett, J. Fuller, T. Debenedictis, et al., Ankle sprain, concussion, and anterior cruciate ligament injuries are common and burdensome in sub-elite female Australian..., Journal of Science and Medicine in Sport, https://doi.org/10.1016/j.jsams.2024.05.008

in female AF is sparse in comparison to well-established men's competitions.[3,4]

Injury surveillance is the first step towards reduced injury burden.[5] Identifying areas in greatest need of injury prevention efforts facilitates targeted strategies, maximising the potential for positive impact on player safety. There is a large body of research reporting on the injury epidemiology of male AF at the elite senior[3] and junior,[6] along with amateur adult[7] and youth,[8] competition levels. Across these competition levels, hamstring strains, shoulder sprains and dislocations, and ankle sprains are consistently the most common or burdensome injuries, whilst anterior cruciate ligament (ACL) injuries are consistently the most severe.[4] However, most research to date has been conducted in male athletes. Whilst this research is important to understand injury in AF, there are known sex differences in injury profiles in other field sports including rugby[9] and soccer.[10] Additionally, there are key differences in match demands of male and female competitions, whereby female AF is played with 16 players on the field (rather than 18 in the men's) and has shorter game duration than the men's competition. With these rule differences, there are also known differences in match play characteristics, with stoppages occurring 30 % more frequently in female AF, and female teams having more than twice as many contested possessions and tackles per minute of match-play than males.[11] Consequently, female AF athletes are likely to have different injury profiles than their male counterparts, suggesting that evidence from male AF may not translate appropriately to female AF.

To the authors' knowledge, five prior studies have explored injuries sustained by female AF athletes. However, these studies have methodological or generalisability limitations that create the need for further research. One study collected only self-reported injuries during a retrospective survey,[12] two focussed on only a single injury type,[13,14] and one examined only hospital admission data,[15] which biases towards severe injuries. Finally, whilst one study provided valuable insight using a prospective design of 257 sub-elite players, data were collected during the earlier years of competition (2017–2019).[16] Furthermore, it also used a non-time loss injury definition that included injuries causing an athlete to seek assessment and treatment, irrespective of whether it resulted in missing a training or game. Whilst non-time loss injury definitions can provide detailed information on minor injuries that may not impact an athlete's ability to train or play, that have been reported to be more prone to inconsistencies than time-loss injury definitions which require athletes to miss trainings or games to be considered injured.[17] Lastly, incidence and burden were only reported for broad body locations (e.g., lower extremity, head and spine, upper extremity, other), rather than for specific injury types, limiting the ability of findings to inform injury prevention practices. As time-loss incidence and burden of specific injuries (i.e., ankle sprains, concussions, hamstring strains) have not been reported in female AF, combined with the rapid growth and professionalism of female AF, there is a clear need for larger prospective surveillance research that reports on minor and major injuries using a standardised injury reporting methodology. Therefore, this study aimed to describe the epidemiology of injuries in sub-elite female AF athletes to determine injury prevention priorities.

2. Methods

2.1. Participants and recruitment

Every player ($n = 424$) from seven teams (of eight) participating in the sub-elite 2023 South Australian National Football League Women's (SANFLW) competition participated in this study. The sub-elite SANFLW competition is a feeder pathway competition to the elite senior AFLW competition. The regular season consisted of 12 rounds, whereby the league team (first team) played 12 matches and the development (reserves) team played 8 matches. Each week 21 players competed for each team, with 16 players on the field at any one time. Each league match consisted of four 20-minute quarters, whilst each development match consisted of four 17-minute quarters. All quarters were played continuously without additional time added after scoring or due to injury. Players were included in the study if they completed at least one training session during the 2023 season. All included clubs trained twice per week for the 2023 season, with an estimated average of 60 min engaged in football-specific activities per training session. The study was approved by the University of South Australia Research Ethics Committee (protocol number: 205303).

2.2. Data collection

Injury data were collected prospectively over the 2023 regular season (final matches were excluded). A standardised online injury report form (Qualtrics, Provo, UT) was completed by designated club medical personnel (physiotherapist or sports trainer) for every player who missed a regular season match or could not complete an unmodified training session during the regular season due to injury. The injury report form included information pertaining to injury type and mechanism, and replicated previous injury report forms used in prior AF injury research.[3] All injuries were diagnosed by club physiotherapists. Additionally, the participation in matches and trainings of all injured players was monitored using a Player Movement Record (PMR) completed by club medical staff. Each week, an injured player's non-participation in training or matches was recorded to identify the number of trainings and matches missed due to injury. In the instance where club staff did not update the PMR for a given week, they were contacted directly for that information by the research team. Injury severity was determined by the number of days missed between the date of injury onset and the date returned to full training or matches. In the instance where an athlete returned to full training but did not participate in the subsequent game, they would still be considered "no longer injured." When a player sustained concurrent injuries, injury severity was only accounted for once, indicated by the most days missed. To further categorise injury severity and provide insight into the most common injury severity-type, the following thresholds were applied: minor (1–7 days absence), moderate (8–28 days), and severe (≥29 days); based on established consensus in the field.[18]

2.3. Statistical analysis

Injury incidence (inclusive of new and recurring injuries) for training and matches, and total injury burden, were calculated for the regular season. Due to severity data being non-normally distributed and a notable number of injury types having an incidence of two or less, injury severity was presented as a median and range for each injury type. Injury incidence and burden were calculated as described by Sprouse et al.[19] via the following formulas, and presented with 95 % confidence intervals calculated using the Poisson distribution method:

$$\textit{Injury incidence per 1000 h} = (\textit{total number of injuries} \times 1000)/\textit{total exposure}$$

$$\textit{Injury burden per 1000 h} = (\textit{total number of days absent} \times 1000)/\textit{total exposure}$$

Total match exposure for the season for all included clubs was calculated as:

$$\textit{Total match exposure}(\textit{hours}) = \left(\textit{Number of minutes per match} * \textit{number of rounds} * \textit{number of players on field per team} * \textit{number of teams included in the study}\right)/60$$

Total training exposure was calculated as:

$$\textit{Total training exposure}(\textit{hours}) = ((\textit{training duration in hours} * \textit{trainings per week} * \textit{number of rounds}) * \textit{number of included players}) - \textit{number of training hours missed through injury}$$

Any injuries unrelated to AF participation were not considered when calculating injury outcomes, however, the trainings they missed were considered when calculating total training exposure for the cohort. The incidence rates of the most burdensome injuries were compared statistically using the "stir" function whilst the severity of those injuries was compared statistically using a Mann–Whitney *U* Test. The most burdensome injuries were determined by visual inspection of a plot with burden on the y-axis and injury diagnosis ordered from highest to lowest burden on the x-axis (supplementary digital content 1). Visual inspection determined the point whereby there was a notable plateau in injury burden from one injury diagnosis to the next most burdensome diagnosis. All injury diagnoses with burden above the plateau were considered for comparison. Analysis was conducted in Stata Statistical Software (release 18, College Station, TX).

3. Results

424 athletes (age 21.1 ± 4.9 years; height 168.9 ± 6.3 cm) from seven participating clubs were included. The total exposure time of the 12-week season period was 12,336 h (2807 match, 9529 training). There were 146 new injuries (97 matches, 36 training injuries). Thirteen injuries occurred outside training and matches and were unrelated to AF, and therefore were not considered when calculating injury incidence and burden. There were no recurrent or concurrent injuries, and no instance where an athlete returned to full training and did not participate in the subsequent game. A single injury had an unknown diagnosis, with clear diagnosis provided for the remaining 145 (99.3 %) injuries. The total injury incidence was 10.8 injuries per 1000 h of participation, with a match incidence of 34.6 injuries per 1000 match hours, and a training incidence of 3.8 injuries per 1000 training hours (Table 1).

After injury, there was a total of 2303 days missed before return to full training or competition, causing 647 missed trainings and 297 missed games. There were 58 (59.8 %) mild, 23 (23.7 %) moderate, and 16 (16.5 %) severe match injuries, and 20 (55.6 %) mild, 11 (30.6 %) moderate, and five (13.8 %) severe training injuries. Table 1 reports the average severity of all injury types. Fig. 1 highlights injury burden according to the incidence and severity of injury categories for this cohort.

Of the 146 injuries, a clear injury mechanism was established for 98 (match $n = 79$, training $n = 16$; Table 2), whilst 48 did not have a clear mechanism. Contact injuries made up 74.7 % of match injuries.

After visual examination of the burden plot (supplementary digital content 1), six injuries were identified to have notably high burden compared to other injury types. The six most burdensome injuries were ACL, ankle sprains, concussion, leg and foot fracture, forearm and wrist fractures, and other groin injuries, respectively (Table 1). Incidence rate comparison indicated that ankles were not statistically more frequent than concussions ($p = 0.312$), however they were significantly more frequent than the remaining four injury types analysed (all $p < 0.05$). Conversely, concussions were not more frequent than ACL injuries ($p = 0.110$) but were more frequent than the remaining three analysed injury types (all $p < 0.05$). Lastly, ACL incidence was statistically more frequent than leg and foot fractures ($p = 0.035$), but

Table 1
Injury incidence, average severity (combined training and match injuries), and total burden for all injury types.

	Training incidence	Match incidence	Combined incidence	Average severity	Total burden
Concussion	0.1 (0.0, 0.6)	6.8 (4.1, 10.6)	1.6 (1, 2.5)	7.0 (55.0)	19.9 (17.5, 22.5)
Facial fractures	0.0 (0.0, 0.4)	0.0 (0.0, 1.3)	0.0 (0.0, 0.3)	0.0 (0.0)	0.0 (0.0, 0.3)
Neck sprains	0.1 (0.0, 0.6)	0.7 (0.1, 2.6)	0.2 (0.0, 0.7)	4.0 (3.0)	1.2 (0.7, 2.0)
Other head/neck injuries	0.1 (0.0, 0.6)	1.1 (0.2, 3.1)	0.3 (0.1, 0.8)	4.0 (13.0)	1.8 (1.2, 2.8)
Head/neck total	0.3 (0.1, 0.9)	8.6 (5.5, 12.7)	2.2 (1.4, 3.2)	7.0 (55.0)	22.9 (20.3, 25.8)
Shoulder sprains and dislocations	0.0 (0.0, 0.4)	0.7 (0.1, 2.6)	0.2 (0.0, 0.6)	33.5 (53.0)	5.4 (4.2, 6.9)
AC joint injuries	0.1 (0.0, 0.6)	0.7 (0.1, 2.6)	0.2 (0.0, 0.7)	14.0 (7.0)	2.8 (1.9, 3.9)
Fractured clavicle	0.0 (0.0, 0.4)	0.4 (0.0, 2.0)	0.1 (0.0, 0.4)	35.0 (0.0)	2.8 (1.9, 3.9)
Elbow sprains or joint injuries	0.0 (0.0, 0.4)	0.0 (0.0, 1.3)	0.0 (0.0, 0.3)	0.0 (0.0)	0.0 (0.0, 0.3)
Other shoulder/arm/elbow injuries	0.0 (0.0, 0.4)	0.4 (0.0, 2.0)	0.1 (0, 0.4)	4.0 (0.0)	0.3 (0.1, 0.8)
Shoulder/arm/elbow total	0.1 (0.0, 0.6)	2.1 (0.8, 4.7)	0.6 (0.2, 1.2)	14.0 (56.0)	11.4 (9.6, 13.5)
Forearm/wrist/hand fractures	0.0 (0.0, 0.4)	1.4 (0.4, 3.6)	0.3 (0.1, 0.8)	26.5 (56.0)	10.0 (8.3, 11.9)
Other forearm/wrist/hand injuries	0.0 (0.0, 0.4)	1.1 (0.2, 3.1)	0.2 (0.0, 0.7)	4.0 (3.0)	1.0 (0.5, 1.7)
Forearm/wrist/hand total	0.0 (0.0, 0.4)	2.1 (0.8, 4.7)	0.5 (0.2, 1)	7.0 (59.0)	7.5 (6.1, 9.2)
Rib and chest wall injuries	0.1 (0.0, 0.6)	1.1 (0.2, 3.1)	0.3 (0.1, 0.8)	10.5 (21.0)	4.1 (3.0, 5.3)
Lumbar and thoracic spine injuries	0.3 (0.1, 0.9)	1.1 (0.2, 3.1)	0.5 (0.2, 1.0)	5.5 (7.0)	3.0 (2.1, 4.1)
Other trunk/back/buttock injuries	0.0 (0.0, 0.4)	0.4 (0.0, 2.0)	0.1 (0.0, 0.4)	7.0 (0.0)	0.6 (0.2, 1.2)
Trunk/back total	0.4 (0.1, 1.1)	2.5 (1, 5.1)	0.9 (0.4, 1.6)	7.0 (21.0)	7.6 (6.2, 9.3)
Groin strains/osteitis pubis	0.1 (0.0, 0.6)	1.1 (0.2, 3.1)	0.3 (0.1, 0.8)	25.0 (66.0)	5.8 (4.5, 7.3)
Hamstring strain	0.2 (0.0, 0.8)	0.4 (0.0, 2.0)	0.2 (0.0, 0.7)	4.0 (24.0)	2.4 (1.6, 3.4)
Quadriceps strain	0.4 (0.1, 1.1)	0.4 (0.0, 2.0)	0.4 (0.1, 0.9)	11.0 (7.0)	4.1 (3.0, 5.3)
Thigh and hip haematomas	0.0 (0.0, 0.4)	1.1 (0.2, 3.1)	0.2 (0.0, 0.7)	4.0 (0.0)	1.0 (0.5, 1.7)
Other groin/hip/thigh injuries	0.3 (0.1, 0.9)	1.1 (0.2, 3.1)	0.5 (0.2, 1.0)	11.0 (63.0)	8.4 (6.9, 10.2)
Hip/groin/thigh total	1.0 (0.5, 1.9)	3.9 (2, 7)	1.7 (1.1, 2.6)	7.0 (70.0)	21.3 (18.9, 24.1)
Knee ACL	0.2 (0.0, 0.8)	3.2 (1.5, 6.1)	0.9 (0.4, 1.6)	56.0 (77.0)	40.4 (36.9, 44.1)
Knee MCL	0.1 (0.0, 0.6)	0.0 (0.0, 1.3)	0.1 (0, 0.4)	28.0 (0.0)	2.2 (1.5, 3.2)
Knee PCL	0.0 (0.0, 0.4)	0.0 (0.0, 1.3)	0.0 (0.0, 0.3)	0.0 (0.0)	0.0 (0.0, 0.3)
Knee cartilage	0.0 (0.0, 0.4)	0.4 (0.0, 2.0)	0.1 (0.0, 0.4)	56.0 (0.0)	4.5 (3.4, 5.9)
Patella injuries	0.0 (0.0, 0.4)	0.7 (0.1, 2.6)	0.2 (0.0, 0.6)	4.0 (0.0)	0.6 (0.3, 1.3)
Knee tendon injuries	0.2 (0.0, 0.8)	0.0 (0.0, 1.3)	0.2 (0.0, 0.6)	7.0 (0.0)	1.1 (0.6, 1.9)
Other knee injuries	0.2 (0.0, 0.8)	1.8 (0.6, 4.2)	0.6 (0.2, 1.2)	4 (3)	2.5 (1.7, 3.5)
Knee total	0.7 (0.3, 1.5)	6.1 (3.5, 9.7)	1.9 (1.2, 2.9)	10.5 (80.0)	54.9 (50.8, 59.2)
Ankle sprains or joint injuries	0.7 (0.3, 1.5)	7.1 (4.4, 11)	2.2 (1.4, 3.2)	7.0 (73.0)	31.4 (28.4, 34.7)
Calf strain	0.2 (0.0, 0.8)	0.0 (0.0, 1.3)	0.2 (0.0, 0.6)	7.5 (7.0)	1.2 (0.7, 2.0)
Achilles tendon injuries	0.0 (0.0, 0.4)	0.0 (0.0, 1.3)	0.0 (0.0, 0.3)	0.0 (0.0)	0.0 (0.0, 0.3)
Leg and foot fractures	0.0 (0.0, 0.4)	1.1 (0.2, 3.1)	0.2 (0.0, 0.7)	56.0 (63.0)	10.8 (9, 12.8)
Leg and foot stress fractures	0.0 (0.0, 0.4)	0.0 (0.0, 1.3)	0.0 (0.0, 0.3)	0.0 (0.0)	0.0 (0.0, 0.3)
Other leg/foot/ankle injuries	0.0 (0.0, 0.4)	1.1 (0.2, 3.1)	0.3 (0.1, 0.8)	4.0 (35.0)	1.3 (0.7, 2.1)
Shin/ankle/foot total	1.0 (0.5, 1.9)	9.3 (6.1, 13.6)	2.9 (2.0, 4.0)	7.0 (73.0)	44.7 (41.1, 48.6)
Total	3.8 (2.6, 5.2)	34.6 (28.0, 42.2)	10.8 (9.0, 12.8)	7.0 (55.0)	171.1 (163.9, 178.6)

Incidence reported as injuries per 1000 h; burden reported as days until recovery per 1000 h; severity reported as median (range).
AC, acromioclavicular; ACL, anterior cruciate ligament; MCL, medial collateral ligament; PCL, posterior collateral ligament.

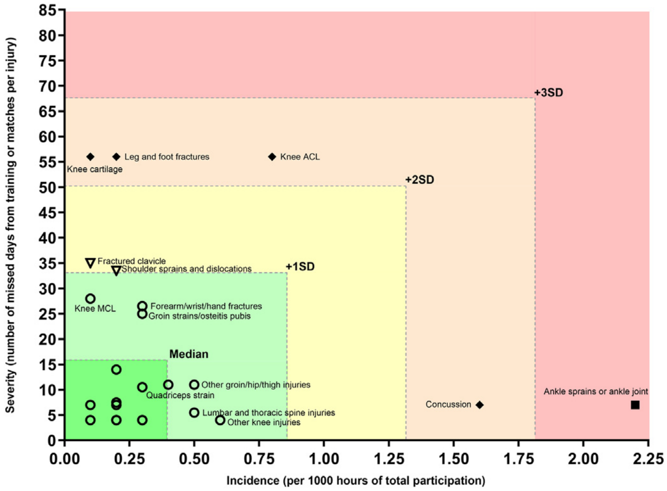

Fig. 1. The burden of injuries according to the incidence and median severity of injury categories for the cohort. Only injuries with a known diagnosis are included. Injury categories are listed if they were above the median for either incidence or severity. Dotted lines refer to the median incidence and severity of injury categories, and subsequently, +1SD, +2SD, or +3SD values above the median for incidence and severity. Injury categories include:
○ Injury categories that were <1 SD for both incidence and severity.
▽ Injury categories that were +1 SD for either incidence or severity
◆ Injury categories that were +2 SD for either incidence or severity.
■ Injury categories that were +3 SD for either incidence or severity.

not forearm and wrist injuries or other groin injuries ($p > 0.05$). ACL injuries were statistically more severe than all other analysed injury types (all $p < 0.05$). However, there were no significant differences in severity between ankle and concussion injuries ($p = 0.675$), or between ankle and concussion injuries and any other analysed injury type (all $p > 0.05$).

4. Discussion

This study provides a contemporary profile of female AF injuries, and the first description of time-loss incidence and burden for specific injury types in any female AF cohort. Injury incidence was nearly tenfold higher during matches than training. Over 70 % of match injuries had a contact mechanism, whilst almost all training injuries were non-contact. Ankle sprain, concussion, and ACL injuries were the most common and burdensome injuries. Injuries were typically mild in severity, but a meaningful number ($n = 21$ [14 %]) were classified as severe, including ACL injuries which were the third most common injury. These findings suggest that injury risk reduction strategies in modern female AF should target ankle sprain, concussion, and ACL injures which had the highest burden. The high number of contact injuries suggests that prevention strategies should also consider better physical preparation of female AF athletes for contact or minimising contact situations in matches through skill enhancement or rules changes.

Table 2
Mechanism of injuries.

	Mechanism	Training		Game		Combined	
		n	%	n	%	n	%
Contact	Collision with player[a]	1	6 %	32	41 %	34	35 %
	In a tackle	0	0 %	27	34 %	27	28 %
Total contact		1	6 %	59	75 %	61	62 %
Non-contact	Overuse	7	44 %	4	5 %	11	11 %
	Jumping	3	19 %	7	9 %	11	11 %
	Falling	0	0 %	0	0 %	0	0 %
	Slip/trip	2	13 %	3	4 %	5	5 %
	Over-extension	1	6 %	1	1 %	2	2 %
	Struck by ball	1	6 %	2	3 %	4	4 %
	Change of direction	1	6 %	3	4 %	4	4 %
Total non-contact		15	94 %	20	25 %	37	38 %

[a] Collision with a player includes all contact injuries not the result of a tackle. For example, engaging with a player in a marking contest, colliding with a team mate, getting bumped by an opposition player (or bumping an opposition player), and contacting an opposition player during contested match play.

The 10.8 injuries per 1000 h of participation observed is comparable to previous research in similar sub-elite female AF cohorts (9.6 injuries per 1000 h of participation), and markedly lower than the 27.4 and 42.4 injuries per 1000 h of participation previously reported in elite male[20] and female[16] AF, respectively. It is likely that elite female AF athletes are at a greater risk of injury compared to sub-elite athletes, which is supported by the most recent AFLW injury report (2022), where injury incidence was 23.7 injuries per 1000 h of participation.[21] Whilst the reason for this finding is uncertain, it could be explained by the physical performance characteristics of different female AF cohorts. Elite female AF athletes are generally faster than their sub-elite counterparts (3.41 ± 0.15 s vs 3.59 ± 0.30 s twenty metre sprint times, respectively),[22] which is a known risk factor for injury in AF.[23] It is also important to highlight that prior research used an injury definition that included any injury that required an athlete to seek assessment and treatment from medical staff, irrespective of whether it resulted in them missing a training or game.[16] This likely explains the difference between the elite cohorts in this prior study and recent AFLW injury reports which use a more narrow "missed match" injury definition.[21] Importantly, as injury incidence was similar between the present cohort and previously reported sub-elite AF athletes despite using a broader injury definition,[16] these findings may imply that injury incidence in sub-elite AF has increased since 2019 when that study was undertaken.

Of interest is the high rate of concussion and ACL injuries in this cohort. Concussion was the second most frequent injury, with a total incidence of 1.6 injuries per 1000 h, and a match incidence of 6.8 injuries per 1000 h. Recent injury reports in elite male AF have estimated a match injury incidence of 1.9 concussion per 1000 h,[24] whilst the most recently reported incidence in elite female AF was 6.3 concussion injuries per 1000 h of participation.[21] The discrepancies between the sexes could be due to a variety of reasons. Firstly, on average, females have smaller neck circumferences and lower neck strength than their male counterparts,[25] both of which have been shown associations with increased concussion risk.[26] Secondly, as female AF has more with stoppages, contested possessions, and tackles per minute of match-play than males, females may be more frequently involved in contact situations whereby concussions are likely to occur.[11] This is particularly relevant considering that 75 % of match injuries in this cohort occurred via a contact mechanism, suggesting that concussion-specific prevention strategies should focus on contact concussion injuries. Irrespective of the reason, female AF athletes appear at a greater risk of concussion compared to male AF athletes, a finding that has been observed in baseball, softball, basketball, volleyball, and soccer.[27] It is also important to note that the average severity of concussion was one week, which aligns with current Australian football return to play protocols, whereby the earliest a player can return to competitive matches is 12 days post-concussion. As such, it is highly likely that concussion burden is heavily impacted by sport-specific concussion guidelines.

Regarding ACL injuries, there was a total incidence of 0.9 injuries per 1000 h, and a match incidence of 3.2 injuries per 1000 h. Although this is lower than the most recent injury reports in elite female AF (2.8 ACL injuries per 1000 h of participation),[21] it is higher than elite male AF athletes (0.7 injuries per 1000 h of participation).[4,13] Some potential reasons for the high rates of ACL in female AF athletes may include biological factors thought to increase ACL injury risk, including females having both a smaller intercondylar notch width and greater joint laxity.[28] Another potential issue could be related to cultural factors, whereby there has historically been less access to consistent and rigorous AF training for females and less funding to implement injury prevention strategies,[29] both of which would influence the physical preparedness to tolerate the rigours of regular high-level competition. Like total injury incidence, it appears that elite female AF athletes are at a greater risk of ACL injury than those playing at a sub-elite level. This may be again explained by greater physical performance capabilities required of elite female AF athletes, which is conducive to performing cutting and landing tasks at faster speeds, with greater braking forces and knee joint loading. These kinetic factors are known contributors to ACL injury.[30]

Interestingly, there was a relatively low incidence of muscle strains and sprains compared to other injuries. This contrasts with male AF, where hamstring strains are consistently one of the most common injuries.[4] This may be related to game style differences, whereby female AF is more congested than male AF,[11] and therefore results in less high speed running. Supporting this suggestion, a recent review indicated that elite male AF athletes record substantially larger high speed running distances (≥50 %) than elite female AF athletes.[31] Findings from the present study highlight that the prevention of contact injuries is a priority for female AF athletes, with 62 % of all injuries (and 75 % of match injuries) being contact in nature. This may suggest a need for injury prevention strategies that focus on tackling, falling, and landing technique,[8] as well as the development of upper and lower body strength[32] to help prevent contact injuries from occurring as frequently, whilst an increased focus on skill training may help reduce congested match play. It may also indicate a need to explore rule changes that could make the game less congested, reducing the opportunity for contact injuries to occur.

Some limitations should be considered. Firstly, data were only collected during the competitive regular season. Previous research indicates that training injury incidence may be highest in pre-season periods,[16] where training loads are higher than in-season. Secondly, some players may have missed training sessions due to non-injury reasons. Since we did not capture that information, this may have resulted in some overestimation of training exposure and underestimation of training injury incidence. Thirdly, whilst all diagnoses were made by qualified physiotherapists, they did not have to be confirmed using a radiological diagnosis. As such, there is the possibility that a small number of injuries could have been misdiagnosed. Fourthly, the time loss injury definition used in the present study biases towards slightly more serious injuries. As such, if any athletes suffered an injury that did not require missing or modifying a training session or game, they were not reported as injured. Lastly, despite ACL injuries having the highest injury severity, missed days were only calculated for the season in which the injury occurred (with a maximum number of 84 days available to be missed). As such, this data underreports the true severity of ACL injuries in this population, which would have resulted in missed days in the following season.

5. Conclusions

This study provides the first large-scale league profile of the injuries sustained by contemporary sub-elite female AF players, reporting on time-loss measures of injury incidence and burden for many injury types. Ankle sprains, concussions, and ACL injuries were both the most common and most burdensome injuries and should be prioritised for injury prevention strategies. The notably high incidence of concussion and ACL injuries, combined with the low incidence of muscle strains, provides further evidence that female AF athletes have different injury profiles to their male counterparts, and may therefore require different intervention practices to help reduce the incidence of the most common and burdensome injuries.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsams.2024.05.008.

Funding information

The authors received no funding from an external source.

Confirmation of ethical compliance

This study was approved by an institutional Review Board (protocol: 205303), and participants consented to participate in the study.

CRediT authorship contribution statement

Hunter Bennett: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Joel Fuller:** Methodology, Formal analysis, Investigation, Writing – review & editing, Visualization, Project administration. **Thomas Debenedictis:** Conceptualization, Methodology, Resources, Writing – original draft, Writing – review & editing, Visualization. **Samuel Chalmers:** Methodology, Investigation, Resources, Data curation, Writing – review & editing, Visualization, Project administration.

Declaration of interest statement

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.

Acknowledgements

The authors would like to acknowledge the support of the South Australian National Football League, and all participating clubs for facilitating the collection of this data.

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