Journal of Science and Medicine in Sport 22 (2019) 987–991

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Mechanisms of traumatic injury to the shoulder girdle in the Australian Football League

Laura M. Schwab[a,*], Tim McGrath[b,c], Melinda M. Franettovich Smith[d], M. Dilani Mendis[a], Deirdre McGhee[e], Julie Hides[a]

[a] Griffith University, School of Allied Health, Australia
[b] St George Illawarra Dragons, Australia
[c] Elite Rehab & Sports Physiotherapy, Australia
[d] The University of Queensland, School of Physiotherapy, Australia
[e] University of Wollongong, School of Medicine, Australia

ARTICLE INFO

Article history:
Received 3 November 2018
Received in revised form 4 May 2019
Accepted 30 May 2019
Available online 7 June 2019

Keywords:
Injury prevention
Video analysis
Shoulder complex
Elite sport
AFL
Injury mechanism

ABSTRACT

Objective: To investigate mechanisms of shoulder girdle injuries and their impact on players from the Australian Football League (AFL).
Design: Retrospective video analysis.
Methods: Two experienced sports physiotherapists (>10 years) examined video footage of shoulder complex injuries that occurred in the 2015 premiership season. Information obtained from video footage included activity prior to injury; mechanism of injury; arm, head and neck position and point of body contact at the time of injury. Player demographics and injury characteristics were obtained from club and media data.
Results: The most common mechanism of injury was lateral contact (34.6%) followed by hyperflexion/abduction of the shoulder (19.2%). Glenohumeral joint (GHJ) dislocations and subluxations were the most frequent diagnosis for all mechanisms of injury, and occurred in a variety of shoulder positions. Over 80% of injuries occurred with the arm below 100° of shoulder flexion or abduction. The most common activity prior to injury was 'ball in dispute' (34.6%). Lateral contact injuries had the highest overall severity (two-thirds of players missed >3 games) and over 50% of shoulder injuries required surgery. Players missed on average 5.1 season games due to shoulder injury.
Conclusion: The lateral contact mechanism was the most common and severe mechanism of shoulder injury. Improved understanding of shoulder girdle injury mechanisms can help guide the use of preventative strategies and injury management programs in elite AFL players.

Practical implications

- The importance of training preparation for lateral contact and shoulder impact forces at game intensities (e.g. contact sessions using bump bags or player contests to replicate common shoulder injury mechanisms and ball in dispute scenarios).
- Consideration regarding which shoulder movements are limited by taping in AFL players in relation to the positions of injury (e.g. horizontal hyperextension, hyperflexion/abduction and external rotation).
- The importance of incorporating shoulder strengthening and proprioception exercises in the ranges of common injuries (e.g. below 100° flexion/ abduction), outer ranges (horizontal hyperextension) and sustained tackle positions (pectoral muscles tears) to increase the capacity of shoulder muscles to withstand loading in these positions.
- Consideration of injury data collection by clubs to include additional information such as mechanism of shoulder injury and individual injury severity (player games missed).

1. Introduction

Australian Rules football is a fast-paced and physically demanding contact sport that places high stresses on the shoulder joint complex due to the demands of overhead playing and multi-

* Corresponding author.
E-mail address: laura.schwab@griffithuni.edu.au (L.M. Schwab).
Twitter: @laura_physio (L.M. Schwab).

https://doi.org/10.1016/j.jsams.2019.05.019
1440-2440/

directional tackling. In the elite Australian Football League (AFL) competition, the incidence of shoulder injuries and the resultant number of games missed has increased over the past two decades (1992–2012; AFL injury report).[1] Glenohumeral joint (GHJ) dislocations & sprain injuries have been ranked as one of the top four most severe AFL injuries (in terms of games missed),[1] with players missing, on average, 11.5 games per club due to these injuries in the 2015 playing season alone.[2] The severity of shoulder injuries is reported to be greater when surgery is required (27.1–29.3 weeks off play),[3] which negatively impacts both player availability and team ranking.[4] Recurrence rates of shoulder injuries have also been reported to be as high as 52% (2014 AFL Injury Report),[2,5] making shoulder injuries an important issue for the players, coaches and medical staff.

Despite the negative impact of shoulder injuries in AFL, there has been a paucity of research investigating the mechanism of these injuries. Previous investigations of the mechanisms of other commonly occurring injuries in AFL have resulted in rule changes, such as posterior cruciate ligament injuries in the knee, which have reduced injury rates.[6] Video analysis has been found to be an effective method for investigating the mechanisms of other injuries in elite AFL players.[7] In other sports such as rugby league and rugby union, video analysis of the mechanisms of shoulder injury has found that sustaining a direct force to the shoulder (front-on or lateral) from another player or the ground to be a primary mechanism of injury.[8,9] A player tackling another player causing hyperextension of their arm and the 'try scorer' position (with the player's arms overhead) are other rugby specific mechanisms of shoulder injury.[8,10] Shoulder injuries sustained from direct force to the shoulder have resulted mainly in acromioclavicular joint (ACJ) injuries,[8,9,11] with impact forces as high as 2000 Newtons (N) reported in rugby union.[12] Investigators using video analysis of shoulder injuries in football (soccer) have reported the position of the shoulder joint to be related to shoulder joint dislocations, with the end of range of shoulder abduction and external rotation frequently associated with this injury.[13] However, direct comparison of injury mechanisms in rugby and football (soccer) with Australian Rules football may not be appropriate due to differences in player size,[14,15] tackling frequency,[16,17] tackling forces[12,18] and ball handling between the football codes. For example, the traditional 'hip and shoulder' method employed to displace an opposition player is a unique and legal technique in AFL play that applies lateral contact force to the shoulder, but is not permitted in the rugby codes.

The mechanisms of shoulder injuries in AFL are yet to be investigated using video analysis. AFL is different to other football codes. Greater understanding of the mechanisms of shoulder injuries specific to AFL has the potential to improve; the link between mechanism and injury, the use of injury prevention measures (e.g. shoulder taping, strength and conditioning) and club injury management. Therefore, the aim of this study was to investigate via video analysis the mechanisms of shoulder girdle injury (type of injury, primary mechanism of injury, situational activity and awareness prior to injury, position of arm, head and neck at time of injury and severity of injury) in elite male AFL players.

2. Methods

Twenty-four professional male AFL players who sustained one or multiple shoulder injuries during the 2015 playing season were included in the study. Participant characteristics such as player age, height, weight, body mass index (BMI), years of playing professional football, history of previous shoulder injury and recurrence of previous shoulder injury were obtained from player profiles on club websites. Inclusion criteria consisted of shoulder girdle injuries that resulted in missed matches, sustained by listed AFL players with publicly available video footage. Information about injuries was obtained from club websites, social media portals (Twitter and Instagram), newspaper articles and game replays. The 2015 AFL Injury Survey data[2] and club physiotherapists were used to verify and cross-reference injury incidents to the shoulder girdle: GHJ, ACJ, Sternoclavicular Joint (SCJ), scapula and muscles attached to the region, against publicly available information. Participants represented 11 of the 18 AFL clubs in the competition. Six clubs did not have video footage of injuries that occurred either in the reserve grades or at training and one club reported no shoulder injuries. Ethics approval for this study was granted by the Griffith University Human Research Ethics Board (GU2018/619).

Table 1
Definitions of mechanism of shoulder injury[8–10].

Mechanism	Definition
Anterior contact[8,†]	A posteriorly directed force applied to the anterior aspect of the shoulder joint complex
Lateral contact[8,†]	A medially directed force applied to the lateral aspect of the shoulder joint complex
Hyperflexion/ abduction[8,‡]	Arm is forced beyond end of range flexion and/ or overhead abduction
Horizontal hyperextension[8,10]	Tackler's arm is forced beyond end of range shoulder extension, below shoulder height (<90° flexion)
Tackling[§]	Tackler attempts to restrain an opponent in possession of the ball with the injured player's arms in horizontal adduction, flexion and internal rotation
Force through elbow[9,10]	A force applied to a flexed elbow and transmitted along the shaft of the humerus towards the shoulder complex

† Modified from one category (direct force) into two categories to reflect the multi-directional nature of the AFL game.
‡ Modified from the try scorer mechanism in rugby union to reflect AFL game actions e.g. marking, spoiling.
§ Definition based on preliminary analysis of AFL specific mechanisms of shoulder injury.

Mechanism of injury was investigated via analysis of video footage by two experienced assessors (titled sports physiotherapists). Criteria assessed included the mechanism of injury, the position of the arm, head and neck at the time of injury and the situational activity the player was executing in the 5 s prior to the injury (Appendix A.1, Supplementary data). Assessors independently viewed all available footage on QuickTime Player (v10.4, Apple, Cupertino, CA, USA) as many times as necessary and at the appropriate speed to determine when the injury occurred (index frame on video footage), which could be at initial contact or during secondary impact points. In order to gain consensus, assessors were allowed to discuss the findings with each other after reviewing the footage. If consensus was not reached, a third rater was consulted to make the final decision (required in 2 cases). Once agreement was reached regarding the time point of the inciting event, each variable (Appendix A.1) was recorded independently. Inter-rater reliability of shoulder injury mechanism and visual estimation of arm position (flexion/abduction angle in degrees) were examined for the 26 injuries using percentage agreement and ICC (2,1). Inter-rater agreement was 69.2% for assessment of video footage prior to discussion between assessors. Reliability of independent visual estimation of arm range measures prior to comparing results was high, (ICC = 0.95, 95 CI% 0.89–0.98).

The observed injuries were categorised into six potential mechanisms. These are defined in Table 1 and follow the classification of previous investigations used in other sports,[8,9,19] as well as the observations of AFL game play. The situational activity of the player in the 5 s prior to the shoulder injury was categorised into seven common AFL specific activities (handballing, marking, tackling, spoiling the ball, ball in dispute, tackled to the ground and run-

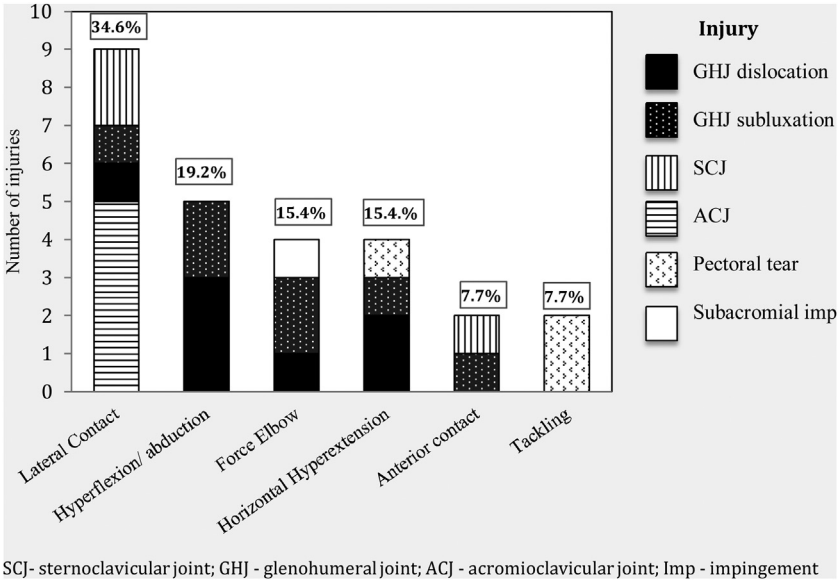

Fig. 1. Mechanisms of shoulder injury and the diagnosis (n = 26).

ning). Assessors subjectively rated whether the player was visually aware of impending contact (yes/no), and the position of the arm (degrees of flexion/abduction/external rotation to the nearest 10°), and head/ neck (cervical flexion, extension, rotation, lateral flexion, neutral) at the time of injury. Two criteria were used to determine the severity of the injury: time lost due to the injury (calculated by tallying the number of in-season games missed based on the AFL Injury Report definition of injury),1 and whether the injury required surgery. A severe injury was defined as missing >3 games (based on the Australian Sports Injury Data Dictionary definition of severity).[20] The need for surgery was verified by club physiotherapists or injury updates (yes/no) and classified as immediate or delayed. Data for each assessor were analysed using IBM SPSS Statistics for Mac, (v25.0, IBM Corp, Armonk, N.Y., USA). Descriptive statistics (counts, averages, percentages) were used to summarise all of the shoulder injury variables. Independent t-tests were used to investigate the differences between the player's head and neck position at contact ('neutral' or 'other') or visual awareness of impending contact ('yes' or 'no') and player injury severity (number of games missed) with statistical significance set at $p < 0.05$.

3. Results

Video footage of 26 shoulder injuries (from 24 players) was available in the public domain and included in the study. The mean (SD) and (range) of player age, height, weight, BMI and years of playing elite sport were: 23.4 (3.2) (range 18–30) years; 185.7 (7.5) (range 173–201) cm; 85.5 (9.2) (range 71–102) kg; 24.9 (1.1) (range 22–27); 5.5 (3.7) (range 0–14) years). The sample represents 50% of the 52 new shoulder injuries reported in the 2015 AFL Injury Survey.[2] Compared to shoulder injuries sustained with no available video footage, the frequencies of traumatic injuries, games missed and surgery rates were similar (Appendix A.2). The most common types of shoulder complex injuries observed were GHJ dislocations/ subluxations (14/26, 53.8%; Fig. 1). Lateral contact to the shoulder from another player or the ground was the most frequent mechanism of injury (34.6%, Fig. 1); and primarily resulted in ACJ injuries. Also, the lateral contact mechanism resulted in the most severe injuries with two-thirds of players missing at least four games. Commonly, a distal contact point on the arm (9/26) or elbow region (7/26), indirectly resulted in GHJ dislocations or subluxations and pectoral muscle injuries of the shoulder girdle.

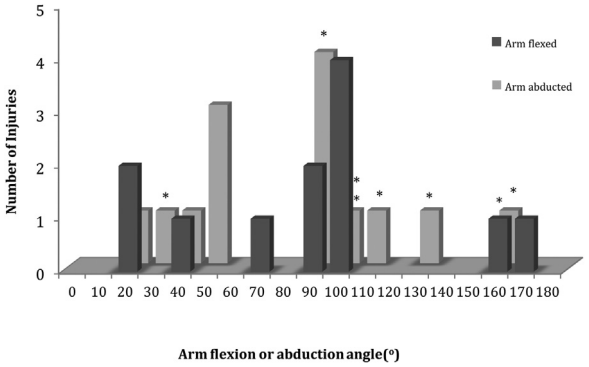

Fig. 2. Arm position at time of shoulder injury, flexion or abduction angle.

A proximal contact point, on the lateral (8/26), anterior (1/26) or superior (1/26) GHJ resulted predominantly in ACJ and SCJ injuries.

The most common situational activity prior to shoulder injury was ball in dispute (9, 34.6%) followed by spoiling (6, 23.1%), marking the ball (4, 15.4%) and then tackling (the tackler; 2, 7.7%). Appendix A.3 in Supplementary material describes all situational activities prior to injury and injury demographics. Most players (69.2%) appeared visually aware of impending contact, however, there were no significant differences in severity of injury between the players who were perceived to be visually aware and those who were not (5.2 vs. 6.4 games missed: $p > 0.05$). Seven players had a history of previous shoulder injury (7/26, 26.9%) and of these players; six were taped on the side of past injury and one bilaterally at the time of the inciting event. The reoccurrence rate of shoulder injuries (during the AFL player's professional career and not limited to the current playing season) was 30.8% in this study.

The position of the arm at the time of injury is displayed in Fig. 2. Eighty-one percent were assessed to be in 100° or less of flexion or abduction of the arm at the time of injury, with GHJ subluxation/ dislocation injuries occurring 64.3% of the time. The shoulder position varied from 20° to 100° at the time of contact for all the ACJ injuries. The head and neck position was neutral for the majority of the injuries (18/26, 69.2%) and for all (100%, n = 7) of the recurring shoulder injuries. No relationship was observed between head

position at contact (neutral vs. all other positions) and player injury severity (5.4 vs. 5.9 games missed; $p > 0.05$).

The average number of games missed was highest for GHJ dislocations (mean 6.6, SD 5.65), pectoral tears 6.3 games (SD 2.1) and ACJ injuries 5.4 games (SD 3.4). Overall, 53.8% of players required surgery, and of these 78.6% required immediate surgery. All shoulder dislocation injuries (100%) received surgery (57.1% immediately; 42.8% delayed) and all injured players included in the study returned to playing elite level AFL. Appendix A.4 in Supplementary material provides further details regarding the severity of injury.

4. Discussion

This is the first study to link the mechanisms of injury, diagnosis and the associated severity of shoulder injuries in elite male AFL players using video analysis. The results provide evidence that could be used to contribute to the scientific basis for prophylactic measures and injury management strategies.

The most common mechanism of shoulder injuries in elite AFL players was found to be lateral contact, which resulted in primarily ACJ injuries. This mechanism may be attributed to the unique nature of AFL whereby body contact can occur from all directions, no offside rules exist and lateral body contact through a hip and shoulder 'bump' to an opposition player is permissible. Contrary to previous research on ACJ injuries[21] in other sports, where the shoulder position has been reported to be by the players side (0° flexion or abduction) at the time of lateral contact, the current study found that the player's shoulder joint position ranged from 20° to 100° flexion or abduction at the time of lateral contact. Another interesting finding from this study was that pectoral injuries did not always occur in overstretched positions in AFL.[22] Traditionally, taping techniques for AFL players have focused on limiting end of range external rotation,[23] but our results suggest that taping should also target positions such as hyperflexion/abduction and horizontal hyperextension as all of these recurring injuries occurred despite the presence of tape. Although, it is also acknowledged that there is limited evidence currently available regarding the efficacy of shoulder taping for injury prevention.[23] Future research could investigate the use of protective equipment (taping, padding or bracing) that have the potential to dampen these impact forces[24] and consider both the magnitude of the forces and the position of the shoulder associated with these injuries. However, conflicting evidence exists regarding the benefit of shoulder padding in other football codes where contact impact forces are high.[12,24,25]

Contrary to previous rugby union research,[8,9] tackling a player was not the most common activity associated with shoulder injury in AFL players. This difference may be attributed to the lower tackling frequency (68.4 per team per game)[26] compared with rugby league (316.4 per team per game),[17] tackling technique differences between AFL and rugby codes as well as AFL rule changes in recent years that banned various types of tackles, such as the sling tackle. These differences may have limited the tackling opportunities for AFL players. It should be noted however that tackling frequency in AFL games has almost doubled since 2001. The additional data on the activity prior to injury provides important insight into the lead up to mechanisms of shoulder injuries in the AFL. The ball in dispute scenario, where no player has clean possession of the ball, was the most common situational activity in the 5-second lead-up to shoulder injury. Training sessions that include unpredictable shoulder contact (e.g. using bump pads), specifically in ball in dispute situations, could possibly improve the player's ability to cope with in game contact forces.

A variety of mechanisms were associated with anterior shoulder joint subluxations and dislocations in the current study (Fig. 1). Previous research on other sports has reported that these injuries usually occur in combined end of range positions (shoulder flexion/abduction/external rotation).[27] The majority of all injuries (80.7%) and GHJ subluxation/ dislocation injuries (9/14, 64.3%) occurred at less than 100°(flexion/abduction) in this study. Only half of GHJ subluxations/ dislocations occurred in any degree of shoulder external rotation (Fig. 2). These results for AFL players could be related to the higher peak running velocities,[28,29] whereby a player can experience impacts from multiple directions compared with other football codes. The speed could increase the magnitude of the peak contact force, which may be sufficient to dislocate the GHJ in almost any joint position. Consequently, shoulder impact forces in AFL players could be even greater than the forces reported in contact studies (2000 N) in rugby union.[12] Preventative exercise prescription incorporating shoulder strengthening and proprioception exercises in ranges where AFL players are more commonly injured (i.e. below 100°) may help to decrease the occurrence of shoulder subluxations and dislocations. Training should also address game specific force vectors and intensities in order to adequately prepare elite AFL players to sustain such forces.

Shoulder dislocation injuries resulted in the highest severity of injury, in terms of games missed (mean of 6.6 games) and need for surgery (100%, n = 7, Appendix A.4). Pectoral muscle injuries which are classified as 'other shoulder injuries' in AFL surveillance reporting, 2 however, resulted in a similar number of games missed (6.3 games missed, SD 2.1) and need for surgery 66% (n = 2; Appendix A.4). Shoulder surgery was delayed until the end of season in 21.4% of cases (all were GHJ dislocation injuries) and therefore the true severity of shoulder injuries is likely under-estimated by a 'games missed' definition of injury. These delayed surgeries may also have flow-on effects where the pre-season training load after their surgery is reduced as a consequence of the surgery. This may increase the risk of further injuries in the coming season due to decreased preparation in terms of strength and training load.[30] A suggested approach to future injury surveillance of shoulder injuries is to represent severity in terms of games missed per player instead of the current method, games missed per club. At a club level this may help to plan injury rehabilitation programs and to set realistic time frames for return to play per injury diagnosis; therefore limiting the risk of re-injury (30.8%).

A limitation of this study was that only 50% of footage of the injuries was accessed, which may have led to bias towards the most severe incidents being assessed, as the media may tend to only report more severe injury incidents publicly (Appendix A.2). Determining the exact time point of injury (first contact or subsequent impact) is also limited by the subjective interpretation by the assessor as well as the available viewing angles and is therefore another weakness of video analysis research. Only shoulder injuries that did not happen in the field of play or occurred at reserve level games without video footage were not evaluated. Improved video coverage of training and reserve level games from multiple angles is therefore recommended to the increase the amount, and quality of data obtained for future systematic video analysis research. Furthermore, future research of contact shoulder injuries could also investigate the magnitude of the forces involved in lateral contact shoulder injuries to increase the understanding of strategies to reduce these injuries.

5. Conclusion

Shoulder injury mechanisms in AFL players are related to the demands and the rules of the football code. Lateral contact was the most common and severe mechanism of shoulder complex injury, which suggests that it should be addressed in training for injury prevention. Our results may direct the refinement of currently used

preventative strategies, such as taping or shoulder strengthening to ensure that they are informed by both the mechanisms of shoulder injury and the ranges of motion in which they occur in this sport.

Funding

LS is the recipient of a Griffith University Postgraduate Research Scholarship. MS is supported by a University of Queensland Post-doctoral Research Fellowship (UQFEL1832429).

Acknowledgements

The authors would like to sincerely thank Anthony Schache from the AFL Research Board and Felix Leung for assisting with this project.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jsams.2019.05.019.

References

1. Orchard JW, Seward H, Orchard JJ. Results of 2 decades of injury surveillance and public release of data in the Australian Football League. *Am J Sports Med* 2013; 41(4):734–741.
2. Australian Football League. *AFL Injury Survey 2015. Melbourne, Victoria, Australia*, 2015 https://www.afl.com.au/staticfile/AFLTenant/AFL/Files/2015-AFL-Injury-Report.pdf.
3. Bonacci J, Manson B, Bowe SJ et al. Operative shoulder instability injury management in Australian Football League players: a case series. *J Sci Med Sport* 2018; 21(8):760–764.
4. Hagglund M, Walden M, Magnusson H et al. Injuries affect team performance negatively in professional football: an 11-year follow-up of the UEFA Champions League injury study. *Br J Sports Med* 2013; 47(12):738–742.
5. Orchard JW, Seward H, Orchard JJ [Accessed 22 June 2017]. *2014 AFL Injury Report*, 2015 http://s.afl.com.au/staticfile/AFLTenant/AFL/Files/2014-AFL-Injury-Report.pdf.
6. Orchard JW, Seward H. Decreased incidence of knee posterior cruciate ligament injury in Australian Football League after ruck rule change. *Br J Sports Med* 2009; 43(13):1026–1030.
7. Cochrane JL, Lloyd DG, Buttfield A, Seward H, McGivern J. Characteristics of anterior cruciate ligament injuries in Australian football. *J Sci Med Sport* 2007; 10(2):96–104.
8. Crichton J, Jones DR, Funk L. Mechanisms of traumatic shoulder injury in elite rugby players. *Br J Sports Med* 2012; 46(7):538–542.
9. Usman J, McIntosh AS, Quarrie K, Targett S. Shoulder injuries in elite rugby union football matches: Epidemiology and mechanisms. *J Sci Med Sport* 2015; 18(5):529–533.
10. Longo UG, Huijsmans PE, Maffulli N, Denaro V, De Beer JF. Video analysis of the mechanisms of shoulder dislocation in four elite rugby players. *J Orthop Sci* 2011; 16(4):389–397.
11. Headey J, Brooks JH, Kemp SP. The epidemiology of shoulder injuries in English professional rugby union. *Am J Sports Med* 2007; 35(9):1537–1543.
12. Usman J, McIntosh AS, Frechede B. An investigation of shoulder forces in active shoulder tackles in rugby union football. *J Sci Med Sport* 2011; 14(6):547–552.
13. Hart D, Funk L. Serious shoulder injuries in professional soccer: return to participation after surgery. *Knee Surg Sports Traumatol Arthrosc* 2015; 23(7):2123–2129.
14. Veale JP, Pearce AJ, Buttifant D, Carlson JS. Anthropometric profiling of elite junior and senior Australian football players. *Int J Sports Physiol Perform* 2010; 5(4):509–520.
15. Reilly T, Bangsbo J, Franks A. Anthropometric and physiological predispositions for elite soccer. *J Sports Sci* 2000; 18(9):669–683.
16. Dawson B, Hopkinson R, Appleby B, Stewart G, Roberts C. Player movement patterns and game activities in the Australian Football League. *J Sci Med Sport* 2004; 7(3):278–291.
17. National Rugby League. *NRL Player and team stats*, 2017 http://www.nrlpro.com/.
18. Duprey S, Bruyere K, Verriest JP. Human shoulder response to side impacts: a finite element study. *Comput Methods Biomech Biomed Eng* 2007; 10(5):361–370.
19. Andersen TE, Larsen O, Tenga A, Engebretsen L, Bahr R. Football incident analysis: a new video based method to describe injury mechanisms in professional football. *Br J Sports Med* 2003; 37(3):226–232.
20. Australian Sports Injury Data Working Party. *Australian sports injury data dictionary*, 1998 http://sma.org.au/resources-advice/sports-injuries/sports-injury-data-dictionary/.
21. Mazzocca AD, Arciero RA, Bicos J. Evaluation and treatment of acromioclavicular joint injuries. *Am J Sports Med* 2007; 35(2):316–329.
22. Haley CA, Zacchilli MA. Pectoralis major injuries: evaluation and treatment. *Clin Sports Med* 2014; 33(4):739–756.
23. Bradley T, Baldwick C, Fischer D, Murrell GA. Effect of taping on the shoulders of Australian football players. *Br J Sports Med* 2009; 43(10):735–738.
24. Pain MT, Tsui F, Cove S. In vivo determination of the effect of shoulder pads on tackling forces in rugby. *J Sports Sci* 2008; 26(8):855–862.
25. Harris DA, Spears IR. The effect of rugby shoulder padding on peak impact force attenuation. *Br J Sports Med* 2010; 44(3):200–203.
26. Australian Football League. *Player and match statistics 2017*, 2017 http://www.afl.com.au/stats.
27. Wilk KE, Obma P, Simpson CD et al. Shoulder injuries in the overhead athlete. *J Orthop Sports Phys Ther* 2009; 39(2):38–54.
28. Varley MC, Gabbett T, Aughey RJ. Activity profiles of professional soccer, rugby league and Australian football match play. *J Sports Sci* 2014; 32(20):1858–1866.
29. Wisbey B, Montgomery PG, Pyne DB, Rattray B. Quantifying movement demands of AFL football using GPS tracking. *J Sci Med Sport* 2010; 13(5):531–536.
30. Colby MJ, Dawson B, Heasman J et al. Preseason workload volume and high-risk periods for noncontact injury across multiple australian football league seasons. *J Strength Cond Res* 2017; 31(7):1821–1829.