

Video Analysis of Pectoralis Major Injuries in Professional Australian Football Players

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Background: There is little evidence regarding the mechanisms of pectoralis major (PM) injury and player outcomes in Australian Football League (AFL) players.

Purposes/Hypothesis: The study aims were to investigate (1) the mechanisms of PM muscle injury in elite AFL players via video analysis and (2) the player profile, method of management, and clinical outcomes of the PM injuries sustained. We hypothesized that the majority of PM tears would occur in outer-range PM positions (hyperextension of the glenohumeral joint).

Study Design: Case series; Level of evidence, 4.

Methods: We analyzed video of the precipitating event for traumatic PM injuries during AFL competition or training over a 20-year period (2002-2021). The footage was analyzed by 4 experienced assessors, and the following were evaluated: mechanism of injury, injury variables (arm position, initial contact point, visual awareness, and use of taping), player characteristics (age at the time of injury, hand dominance, and history of injury), injury profile (location and size of tear), method of management (operative vs nonoperative), patient outcomes (time to return to full senior training/match play), and complication rates.

Results: The mean \pm standard deviation age of the players was 26.5 ± 3.1 years (range, 21-32 years). Overall, 22 PM injuries were identified in the AFL injury database for a rate of 1.1 per year; 16 of these injuries had accompanying video footage. We identified 3 mechanisms for PM injury: horizontal hyperextension (62.5%), hyperflexion-abduction (25.0%), and horizontal adduction (sustained tackling; 12.5%). The most common site of the tear was the insertion point of the sternocostal head (91.0%). Twenty players (91.0%) required surgical repair, with 75% undergoing surgery within 1 week (range, 0-26 weeks). The mean return to competition for the surgical repair group was 11.1 weeks (range, 8-15 weeks). The rerupture rate was 5.0% (1 repair; <4 weeks postoperatively in 2004).

Conclusion: PM tears in elite male AFL players were due to 1 of 3 distinct mechanisms: horizontal hyperextension, hyperflexion-abduction, and horizontal adduction (sustained tackling). Players returned to play on average 11 weeks after injury. Knowledge regarding mechanisms of injury, player profile, and return-to-sport timelines is important for appropriate medical management and provides potential areas to target for prevention of PM injuries.

Keywords: injury mechanisms; video analysis; muscle injuries; shoulder; AFL

The pectoralis major (PM) muscle serves as a powerful internal rotator and adductor of the humerus. The PM provides tackling strength and dynamic stability to the anterior shoulder and is therefore imperative in contact activities and overhead movements in sports. The use of the PM muscle is high in Australian Rules football, a physically demanding type of football that requires the use of the shoulder and arm for ball-handling skills (many overhead), tackling, and shepherding (legally pushing, bumping, and blocking opposing players).²⁶ Unique to Australia and the highest level of competition, the Australian Football League (AFL) runs from March to the end of September

and is played with 18 players per side over approximately 100 minutes (4 terms, 20 minutes, with additional stoppage time). There are 18 clubs in total, each with a list size of 40 players, and 23 competition rounds are played.

Although PM rupture is a relatively uncommon sports injury, its incidence has increased over the past 30 years in professional and amateur athletes.^{6,30,32} In the AFL, 5 PM injuries were reported between 2002 and 2011 and 17 between 2012 and 2021, a 3-fold increase.² The increasing incidence of shoulder injuries in the AFL and the codes of rugby have been linked to increases in the speed of the game,^{12,18,19} player position,^{11,30} and tackling techniques (ie, sling tackle or shoulder charge),^{11,25} which have prompted changes to rules of the game to limit or outlaw these tackling techniques.^{11,20} However, the specific rationale regarding the rise in PM tears in the elite AFL has not

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Figure 1. The position commonly reported in the literature in which pectoralis major injuries occur: hyperextension, abduction, and external rotation.

been explored. Knowledge regarding the cause of PM tears could lead to better prevention and management of these injuries at elite and community levels of Australian Rules football and other contact and collision sports.

While PM ruptures are most often seen in weight lifters during the eccentric phase of a bench press,^{7,22} they have been reported in contact codes of football (rugby league and American football)^{25,30} where high contact forces are sustained during tackling. Collisions in football codes can occur at high velocities (eg, >20 km/h) and at a force of almost 2000 N.^{13,22,23,29} Previous studies have identified the arm in a position of horizontal hyperextension at the time of injury, specifically in abduction and external rotation (Figure 1).^{5,22} However, a recent study of shoulder injury mechanisms in AFL players indicated that some PM injuries occurred in positions yet to be described in other collision sports.²⁷ A case study of 3 rugby league players found that a distal arm point of contact on the injured player may contribute to PM injuries sustained in hyperextension arm positions when tackling.²⁵ Currently, no longitudinal study has assessed the specific mechanisms of injury for PM muscle tears in professional Australian Rules football players.

Although nonoperative treatment may be appropriate for partial- or full-thickness tears in noncontact athletes, the role of the PM muscle in contact sports that require strength and power is such that surgical management post-injury is preferred to assist the athlete in returning to the

previous level of competition.^{5,7,8,22,30} Long delays between injury and surgery have a detrimental effect on postsurgical outcomes owing to scarring and retraction of the tendon.^{1,5} Return to the previous level of sport after a repair varies between 4 and 7 months.^{7,9,22,32} This time frame is based on injuries sustained in a variety of sports (weight lifting, wrestling, rugby, American football) with the majority in recreational-level athletes. No prior study has investigated the return-to-sport time frames after PM muscle injury in AFL players. In addition, it is unknown if the size or location of the tear or if the mechanism of injury contributes to return-to-sport time frames.

A greater understanding of the mechanisms of PM tears sustained in Australian Rules football has the potential to improve the link between mechanism and injury, the use of injury prevention measures (eg, shoulder taping, strength, and conditioning practices), and return-to-sport timelines. The primary aim of this study was to determine the mechanism of injury and position of the arm during injury of the PM muscle in AFL players. Secondary aims were to investigate player characteristics (age, arm dominance, and injury history), injury profile (location and size of tear), method of management (surgery vs nonoperative; timing of surgery), and player outcomes (return to full training and competition timelines; complication rates) for PM muscle injuries. It was hypothesized that the majority of PM tears would occur in outer-range PM positions (hyperextension of the glenohumeral joint).

METHODS

This study was approved by our institutional review board and the AFL Research Board. Professional male Australian Rules football players who had sustained a PM injury during an AFL match or AFL training (field or strength and conditioning) were included in this study. A database of PM injuries between March 2002 and September 2021 was compiled using annual AFL injury reports and online searches. Players who had a previous PM tear to the same side of the body and pectoralis minor muscle tears were excluded. Participant characteristics such as age, hand dominance (dominant handball arm), and history of shoulder injury (ipsilateral or contralateral) were described for all cases.

Further examination of injury variables via video analysis was undertaken for the 16 cases in which video footage was available. The mechanism of injury was

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Ethical approval for this study was obtained from Ramsay Health (project No. 266).

TABLE 1
Mechanisms of Shoulder Injury in AFL Players^a

Mechanism	Definition
Anterior contact	A posteriorly directed force applied to the anterior aspect of the shoulder joint complex
Lateral contact	A medially directed force applied to the lateral aspect of the shoulder joint complex
Hyperflexion-abduction	Arm is forced beyond end-of-range flexion and/or overhead abduction
Horizontal hyperextension	Tackler's arm is forced beyond end-of-range shoulder extension, below shoulder height (<90° of flexion)
Horizontal adduction ^b	Attempts to restrain an opponent in possession of the ball with the injured player's arms in horizontal adduction, flexion, and internal rotation (a sustained tackling position)
Force through elbow	A force applied to a flexed elbow and transmitted along the shaft of the humerus toward the shoulder complex

^aDefinitions based on video analysis of specific mechanisms of shoulder injury in AFL players. Reproduced with permission Schwab et al.²⁷ AFL, Australian Football League.

^bMechanism-of-injury term was modified from "sustained tackling" to reflect the injury terminology used in other types of football.

investigated for all cases with adequate video footage (≥ 2 camera angles of each injury). Video footage included at least 5 seconds before the inciting event and at least 2 to 3 seconds after the event to assess the match-specific context. Analysis of the video footage was undertaken by 4 independent assessors: 2 orthopaedic shoulder surgeons (R.Z., S.H.) and 2 sports physical therapists (L.S., K.D.) with >10 years of experience in sports medicine. Assessors independently viewed all available footage in real time and frame by frame to estimate the precipitating event index frame using QuickTime Player (Version 10.4; Apple Inc). Assessors were taught how to differentiate the index frame (injury time point) from the time of initial contact (first time that the player comes into contact with the opposing player) as described by Montgomery et al.¹⁶ To gain consensus, assessors were permitted to discuss the findings with each other after independently reviewing the footage of the injury event. If consensus was not reached, an independent rater was consulted (the club physical therapist of the injured player). Consensus was defined as at least 3 of 4 agreeing on the index frame. The mean absolute deviations of the analysts regarding the index frame were 16 milliseconds (4 video footage frames).

Afterward, all videos were characterized using a systematic approach^{3,10,16} (Appendix Figure A1) to determine categorical variables, including the 6 potential shoulder injury mechanisms previously described by Schwab et al²⁷ (Table 1). Video footage could be paused at the index frame to determine if there was shoulder rotation involved (external or internal) at the time of injury. The following were also recorded: the initial contact point on the body (trunk, upper arm, or lower arm including the hand), the situational activity the player was executing in the 5 seconds before the injury (handballing, marking, tackling, spoiling the ball, ball in dispute, or tackled to the ground and running), visual awareness of impending contact (yes/no), if the player was wearing shoulder tape (yes/no), and the head and neck position (cervical flexion, extension, rotation, lateral flexion, or neutral) at the time of injury.

Magnetic resonance imaging and surgical reports were utilized to determine the characteristics of the PM injury and any additional injuries sustained. The location of the tear (tendon insertion vs intrasubstance) and the size of the

tear (percentage of tendon involved) were evaluated. In addition, the method of management (surgical vs nonoperative) and the timing to surgery were evaluated by reviewing orthopaedic surgeon correspondence and surgical reports. Delayed surgery was defined as >4 weeks after injury.

Patient-focused outcomes included return to sport (full-contact training) and return to competition (number of weeks). Only players who were injured and returned in season were analyzed for return-to-play timelines, as patients out of season may have significantly skewed the results and misrepresented the return-to-sport times given the long off-season period.²¹ The context of any complications was also reported (ie, postsurgical complications, reinjury). The mean follow-up time for rerupture of the PM muscle was determined by the player's return-to-sport date until the end of data collection (September 30, 2021).

Data for each assessor were analyzed retrospectively using SPSS Statistics for Mac (Version 26.0; IBM Corp). Descriptive statistics (counts, means, averages, ranges, and percentages) were used to summarize all participant characteristics, injury profile variables, methods of management, and patient outcome variables. Variables from video analysis (arm position, initial contact point, visual awareness, and use of taping) were also reported descriptively (counts, percentages, visual estimation of angles, and ranges). The mean difference of the index frame selected by the 4 assessors was calculated. Post hoc analysis of return to play was undertaken to investigate whether there was a difference in the number of games missed between players who sustained an isolated PM tear and players with a PM tear with secondary muscle involvement (subscapularis), using an independent *t* test. Statistical significance was set at $P < .05$.

RESULTS

A total of 23 AFL PM ruptures were identified from our database search (March 2002–September 2021). One athlete was excluded for an isolated pectoralis minor rupture. Therefore, 22 AFL athletes were included in this study for an injury rate of 1.1 per year (0.5 per year 2002-2011; 1.7 per year 2012-2021). The mean (\pm SD) age at time of injury was 26.5 ± 3.1 years (range, 21-32 years). Fifteen players



Figure 2. Mechanisms of pectoralis major injury in elite Australian Football League players (arrows): (A) horizontal hyperextension, (B) hyperflexion-abduction, and (C) horizontal adduction (sustained tackling).

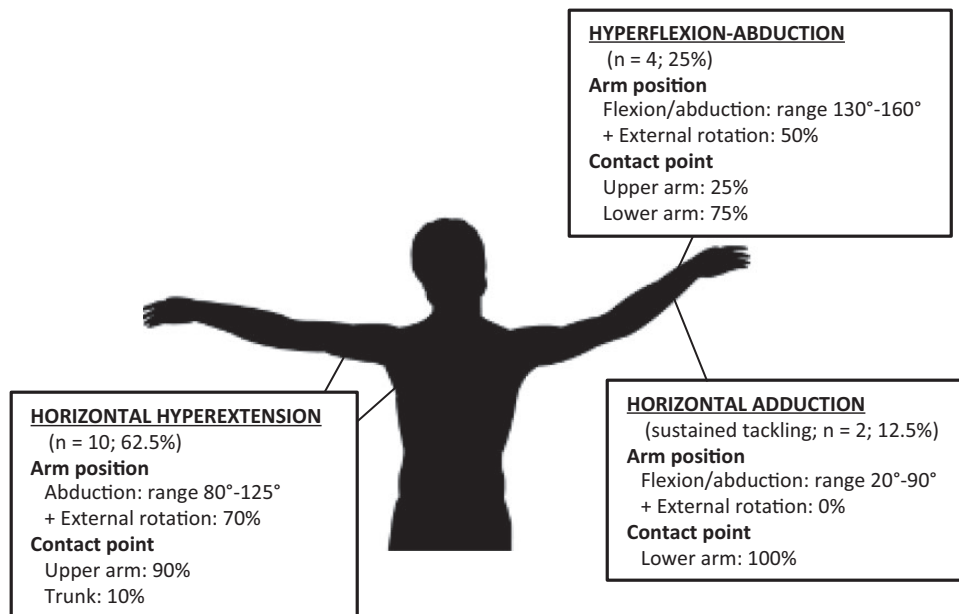


Figure 3. Position of the arm (degrees of flexion, abduction, external rotation) and initial contact point on the player's body at the time of the inciting event.

(68.2%) were right arm dominant, and 5 players had a history of any injury to the ipsilateral shoulder (22.7%). Two players had a past PM tear to the contralateral shoulder. Twenty injuries were traumatic and sustained during competition, while the remaining 2 cases occurred while strength training (ie, bench press). Video footage was available for 16 of 20 traumatic PM injuries and was not available for either of the strength training injuries (n = 2). Four injuries had no available footage because they occurred during preseason matches with no video (n = 1) or because the injury event was unable to be determined from the available video (n = 3). Players were followed for a mean (\pm SD) 6.65 \pm 4.5 years after the PM tear injury.

The most common mechanism of injury was horizontal hyperextension (n = 10; 62.5%) (Figure 2A), followed by hyperflexion-abduction (n = 4; 25.0%) (Figure 2B) and horizontal adduction when sustaining a tackle (n = 2; 12.5%) (Figure 2C). In addition, the arm was externally rotated in 56.3% of cases (n = 9), internally rotated in 25.0% (n = 4), and neutral in 18.8% (n = 3). The initial point of contact on the injured player was the upper arm (n = 10), lower arm (or hand; n = 5), or trunk (n = 1). The arm position angle at the time of injury and the contact point for the 3 mechanisms are described in Figure 3. Before injury, the majority of players were either tackling another player (n = 14) or spoiling the ball (deflecting the ball from the opposition

player; $n = 2$); hence, all players were visually aware of the impending contact. Head position was neutral ($n = 11$), extended ($n = 1$), ipsilaterally rotated ($n = 1$), contralaterally rotated ($n = 2$), or laterally flexed ($n = 1$) at the time of PM injury. Only 2 athletes were taped at the time of injury.

Twenty PM ruptures were tendinous avulsions involving the sternocostal head ($n = 18$, full-thickness tears; $n = 2$, partial-thickness tears [75%-90% of the tendon thickness]) reported on magnetic resonance imaging or ultrasound. The remaining 2 injuries were intrasubstance tears occurring at the myotendinous junction. Five players had a concomitant partial tear of the subscapularis tendon. The majority of injuries ($n = 20$; 91.0%) were managed surgically (19 tendinous avulsions and 1 intrasubstance tear). Only 1 tendinous avulsion of the sternocostal head and 1 intrasubstance tear were treated nonoperatively. Surgery was most often performed within a week of the injury ($n = 15$; 75.0%) but was delayed >4 weeks in 5 cases (25.0%) either because the team made the finals ($n = 3$) or for unknown reasons ($n = 2$). These players continued to play games with the shoulder taped until surgery was performed at the end of the playing season.

The surgical procedure involved reattachment of the tendon or muscle unit via whipstitch sutures to the lateral edge of the bicipital groove, most commonly using Arthrex pectoral button or Mitek G2 anchors. Concomitant subscapularis tears were also repaired during surgery. Shoulders were protected in a sling worn across the body for 4 to 6 weeks, with minor pendulum work allowed. Active movement commenced from 4 weeks and resistance and strengthening work from 6 weeks onward. Players were cleared to join contact training after the surgeon and club high-performance team (team doctor, physical therapist, and strength and conditioning professionals) had assessed strength and pain levels, and this was usually at 8 to 10 weeks postoperatively.

All players returned to professional AFL competition after rehabilitation. In the operative group, the mean time of return to play was 11.1 weeks ($n = 14$; range, 8-15 weeks) for players who returned during the season. Players returned to full training at a minimum 7 weeks. The 2 players with nonoperatively managed PM ruptures returned to play at 4 and 9 weeks. There was no statistically significant difference in return-to-sport timelines with an isolated PM tear (11.5 ± 2.8 weeks) as compared with a PM tear with secondary subscapularis involvement (10.6 ± 1.9 weeks; $P = .6$). There was 1 complication (5.0%) where the player required further surgery attributed to rerupture in the first month after their surgery in 2004. The player who had a retear reinjured the muscle innocuously while sleeping in the sling at 1 month postinjury.

DISCUSSION

Video analysis has confirmed that most PM injuries in elite AFL players were sustained in a hyperextended shoulder position during the act of a player tackling another player. The study has also described the athlete characteristics,

mechanisms of injury, management, and outcomes for PM muscle tear injuries in elite Australian Rules football players.

The study results supported our first hypothesis. Analysis of the mechanisms of PM muscle injury via video footage established that most tears (63%) were sustained in horizontal hyperextension of the glenohumeral joint. However, the study identified PM injuries from other mechanisms: hyperflexion-abduction and horizontal adduction (sustained tackling with both arms in front of the torso), which have not been widely reported in collision athletes. It is likely, though, that the PM is contracted and that the additional force of hyperextension, abduction, and external rotation results in an eccentric muscle contraction. While case numbers for the 2 alternative mechanisms of injury were small, these mechanisms may reflect the specific rules and physical intensity of AFL match play, such as spoiling (deflecting) the ball overhead and tackling from multiple directions. Likewise, the arm-blocking motion (bench press-like fending action) used by offensive linemen in American football to prevent a player from tackling the ball carrier has been reported to be a specific mechanism of PM injury unique to American football.²⁸

Previous studies of contact PM injuries have described the mechanism of injury as involving an externally rotated arm.²⁵ Surprisingly, the arm of the injured player in the current study was not externally rotated in almost half of all cases (Figure 2C). Moreover, all tackling mechanism injuries to the PM and most hyperflexion-abduction ones (ie, spoiling the ball) commonly occurred with a distal arm contact point. The resulting long-lever counterforce sustained by the glenohumeral joint during a maximal eccentric contraction of the muscle may contribute to these overhead PM injuries. The study's findings are supported by Sartori and Whiteley,²⁵ who reported that suboptimal tackling techniques (eg, initiating the tackle with the lower arm instead of close to the body) were a common pattern in PM injuries in a rugby league case series. Therefore, tackling technique may serve as an impetus for injury prevention research in PM tears and ruptures. Athletes may require coaching input or biomechanical analysis of their current tackling techniques, which in turn may reduce the risk of PM injuries (ie, tackling closer to the body).²⁵ Likewise, the arm of most PM injuries sustained in hyperextension was in a similar position of shoulder abduction (ie, 80° - 125° ; outer muscle ranges); as such, strength and conditioning training in these ranges that injuries are occurring and using the specific types of contractions (ie, eccentric breaking of forces) may assist in decreasing the number of injuries sustained. There were no trends identified in the current study, though, that associated head position or shoulder taping at the time of the PM injury with tear size or location.

The mean time for return to competition for elite AFL players who had surgery and returned to play in the same season was 11 weeks (range, 8-15 weeks). In a systematic review, Yu et al³² stated that 90% of patients (134/149) undergoing PM surgical repair successfully returned to sport at a mean 6.1 ± 1.7 months postoperatively. In the National Football League (American football), a mean return-to-sport time of 16 to 21 weeks has been reported

postsurgery.^{24,28} Even though the overall demands of AFL game play are considered high with direct multidirectional shoulder contact and often ferocious tackling,³¹ participants in the current study returned to sport relatively early as compared with in the literature^{24,28} and other professional contact sports without reporting high reinjury rates over the duration of the study. Therefore, this finding may challenge and advance future return-to-sport protocols. Fortunately, the complication rate of surgical repairs of PM tears in this study was low (<5%; 1 reinjury in 2004), and all players returned to elite-level competition.

One myotendinous junction tear and 1 tendinous avulsion were managed nonoperatively in season. One rationale for delaying surgical management would be for players whose teams make finals competition. Extraneous variables, such as out-of-contract players trying to return to play quickly to improve future prospects, may be another reason for trying nonoperative management. However, results of a recent systematic review with meta-analysis by Bodendorfer et al⁷ that reported superior functional (range of motion, strength, and return to play), cosmetic, and pain outcomes with acute surgical management may warrant consideration when choosing to delay surgery in future cases of PM injury.

Interestingly, an increase in the frequency of PM muscle tears in the AFL has been observed over the past 10 years (1.7 vs 0.5 injuries per year; 2002-2011). Increases to the speed of the game, the time spent on field training, the size of players, and therefore the contact forces experienced during tackling may explain these findings.^{14,31} In addition, the number of allowed player rotations during games has decreased, but the number of tackles that an AFL player makes during a match has almost doubled over the past 20 years.^{4,14} This may result in increased fatigue of surrounding shoulder muscles and reduced neuromuscular control during match play.¹⁷ This phenomenon may result in an increase in the incidence of muscle strain injuries.¹⁵ While the increase in injuries over the past 10 years may be due to superior reporting now that PM injuries have their own category in the AFL injury report, injuries before 2016 in the “other shoulder injury” category of all yearly reports were manually checked to avoid missing any PM injuries with in-season time loss.

Limitations

There were some limitations to our research findings. We acknowledge that the sample size was relatively small (N = 22), that video footage was not available for all traumatic injury events, and that no case-controls were used for comparison. Despite our scanning hours of broadcast footage, club footage, and all social media portals, not all injury events had available video. The comparison of return to play for PM tears versus PM tears with concomitant subscapularis involvement should also be interpreted with caution, as the group number is small and may be underpowered. Nonetheless, anecdotally our results have identified similar return-to-sport timelines for injuries with multiple-muscle involvement surrounding the shoulder after PM injuries. We additionally acknowledge the

differences in PM surgical fixation methods used and the evolution of surgical techniques over the past 20 years to repair PM injuries, when interpreting reinjury rates and return-to-sport findings (repair techniques from 2004 no longer utilised).

A major strength of this study was the long duration of PM injury capture (2 decades) and that it was the first study of its kind to systematically analyze the mechanisms of injury of traumatic PM tears sustained by AFL players. This study is also the largest video analysis of traumatic PM injuries, as the previous largest review involved analysis of 3 cases only.²⁵ Future video analysis studies involving other codes of football (American football, rugby league, rugby union) would strengthen our knowledge regarding all mechanisms of PM injury and player characteristics. Reporting injury characteristics, such as the type of muscle contraction (isometric, eccentric, concentric) and the force intensity of the injury event (high/low), and including strength testing results of the PM muscle over the rehabilitation timeline may provide more rationale for our methods of management, injury prevention strategies, and return-to-sport guidelines.

CONCLUSION

PM tears in elite Australian Rules football players have been shown to predominantly occur with horizontal hyperextension of the arm during tackling, and players return to sport at approximately 11 weeks postinjury after surgical repair. This study provides increased knowledge regarding the mechanisms of injury, profile, management, and outcomes when players sustain PM tears. This information may be invaluable to coaches, club medical and performance staff, and orthopaedic sports or shoulder surgeons involved in interventions and rehabilitation of these injuries. The data may also guide clinicians regarding areas to target for the prevention of these injuries (ie, strength and conditioning training; tackle technique coaching) or challenge return-to-play guidelines.

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APPENDIX

Primary Field	Secondary Field	Descriptors
ID		Player name
Playing scenario prior to contact (5 second lead up)	Game situation	Ball in dispute Spoiling Marking Running Tackling Tackled to ground Handballing
	Player taping	Yes No
	Player visual awareness of impending contact (subjective)	Yes No
Detailed description of contact situation	Mechanism of injury (Schwab et al. 2019)	Lateral contact to the glenohumeral joint Anterior contact to the glenohumeral joint Hyperflexion/ abduction Horizontal hyperextension Horizontal adduction (sustained tackling) Force through elbow
	Head/ neck position at contact	Neutral Flexion Extension Lateral flexion (ipsi/contralateral) Rotation (ipsi/ contralateral)
	Arm position at initiation of injury (index frame) Nearest 5 degrees	Flexion/abduction/extension angle Abduction- Yes/No External rotation- Yes/No
	Point of contact on player	Trunk Upper arm Forearm/ hand

Figure A1. Assessor protocol for the systematic video analysis of pectoralis major injuries in elite Australian Rules football players.