Accepted: 15 March 2018

DOI: 10.1111/sms.13090

ORIGINAL ARTICLE

WILEY

Video analysis of acute injuries and referee decisions during the 24th Men's Handball World Championship 2015 in Qatar

S. H. Andersson[1] | M. Cardinale[2,3,4] | R. Whiteley[5] | N. Popovic[5] | C. Hansen[5] | F. S. Lopez[5,6] | T. Bere[7] | R. Bahr[1] | G. Myklebust[1]

[1]Oslo Sports Trauma Research Center, Department of Sports Medicine, Norwegian School of Sport Sciences, Oslo, Norway

[2]Department of Sports Science, Aspire Academy, Doha, Qatar

[3]Faculty of Sport and Health Sciences, University of St. Mark and St. John, Plymouth, UK

[4]Department of Computer Science and ISEH, University College London, London, UK

[5]Aspetar Orthopaedic and Sports Medicine Hospital, Doha, Qatar

[6]Qatar Handball Association, Doha, Qatar

[7]Division of Orthopaedic Surgery, Oslo University Hospital, Oslo, Norway

Correspondence
Stig Haugsboe Andersson, Oslo Sports Trauma Research Center, Department of Sports Medicine, Norwegian School of Sport Sciences, Oslo, Norway.
Email: s.h.andersson@nih.no

Funding information
Qatar 2015 Organising Committee funded the video analysis of all the games of the World Championship.

Although handball is a contact sport with a high risk of acute match injuries, their mechanisms have not yet been investigated. We aimed to describe the mechanisms of acute match injuries in elite male handball and evaluate referee performance in injury situations. Based on injury surveillance from the 24th Men′s Handball World Championship 2015 in Qatar, injury situations and the referee decisions were identified on video footage. A total of 55 injury situations and 37 referee decisions were included for analysis. The injury situations were analyzed individually by five handball experts, followed by a consensus meeting. An expert referee panel performed individual blinded evaluation of the referee decisions, followed by an online consensus meeting. Injuries were evenly distributed among attackers (n = 29) and defenders (n = 26). The most frequent injury cause was contact trauma due to a tackle (n = 27). At the time of injury, attackers were most frequently performing a jump shot (n = 9), while defenders were completing a tackle (n = 10). Defenders most commonly tackled the throwing arm (n = 7) or toward the head/face region (n = 6) of injured attackers, while attackers most frequently hit injured defenders with the knee during jump shots (n = 5). Agreement between the referees and the expert panel was weak (kappa: 0.22, 95% CI 0.07 to 0.36), with substantially more lenient rule interpretation by the referees. Our results suggest that stricter refereeing and rule amendments should be considered to prevent acute match injuries in elite handball, especially in relation to tackling episodes when an attacker is performing a jump shot.

KEYWORDS
handball, injury mechanisms, referee decisions, referee performance, risk factor

1 | INTRODUCTION

Handball is a team throwing sport characterized by frequent and rapid changes of movement, high-intensity running efforts, cutting, and jumping, as well as frequent physical contact between opponents and teammates during tackles and collisions.[1] Compared to other Olympic team sports, the risk of acute injuries in handball is high.[2,3] During the 24th Men′s Handball World Championship 2015 in Qatar, a total incidence of 104.5 match injuries per 1000 player-hour was reported, with about half leading to time loss.[4] Despite existing rules attempting to make the sport safe and fair,[5,6] the majority of injuries occurred during matches (92%), and 61% were reported as the result of contact between players, with only a few cases arising from foul play.[4]

When planning preventative measures aiming to reduce the rate of sports injuries, it is crucial to understand their causes.[7] This encompasses information regarding the risk

factors present for a particular player in a given situation and the specific mechanisms of injury. Bahr & Krosshaug,[8] expanding on previous epidemiological and biomechanical models, suggested that the description of the injury mechanisms should not only include details of the whole body and joint biomechanics at the time of injury, but also needs to account for the events leading to the injury situation, that is, the playing situation, as well as player and opponent behavior.[8-10]

The majority of intervention studies in sport injury prevention research have used such data to develop and assess the effect of programs on the risk of injuries, with only a minority investigating the effect of amendments and/or stricter interpretation of rules.[11] Despite these studies showing a great potential to reduce the rate of acute injuries through reduction of foul play, this remains unexplored in several sports, and research efforts are warranted.[12]

To successfully intervene through the rules and regulations governing sports, information on the events leading to injury is needed, including referee performance.[8] As there are no data on the events leading to injury in handball, and no previous studies have investigated referee decisions, the aims of this study were to describe the mechanisms of acute match injuries in elite male handball and evaluate referee performance in injury situations.

2 | METHODS

2.1 | Study design and video material

This was a prospective video analysis including acute injuries during the 24th Men′s Handball World Championship 2015 in Qatar. Throughout the event (January 15 to February 1, 2015), 122 match injuries were recorded by team medical staff, using the IOC injury and illness surveillance protocol. Detailed information regarding these injuries and the methods used is described in a previous publication.[4] Based on the injury reports, which also included the approximate timing of the match injuries, three operators accessed the videos of each game and identified the specific injury situations using video analysis software (ProzoneHANDBALL v.1.0.0.0.14, Prozone Sports, Leeds, UK). All events involving entry of medical team and playing situations leading to two-minute suspension, and red cards were coded to easily retrieve such events linked to injuries. In addition, players sustaining injuries were tracked over the course of the specific match reported to identify the key situation leading to injury. All videos were saved with a minimum of 5 s preceding and following the injury situation. A total of 55 videos, with visible acute injury situations, were identified and included in an individual analysis performed by a panel of handball experts June 2016, followed by a consensus meeting in July 2016 (Figure 1).

Following the injury consensus meeting, the operators re-accessed the videos to identify the decisions made by the referees in each injury situation (September to October 2016). Videos including non-contact traumas (n = 4) and videos not showing the referees and their decisions (n = 14) were excluded (Figure 1). The referee decisions in the remaining 37 videos were recorded according to the rules of the game.[5,6] An expert referee panel performed individual

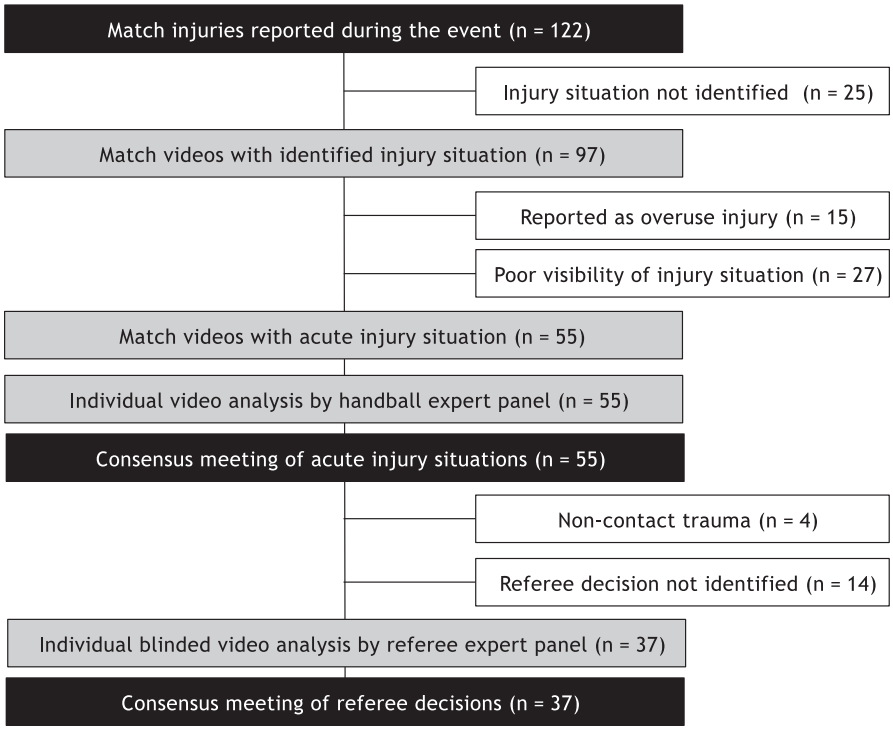

FIGURE 1 Study flowchart showing the number of match videos included in the analysis by the handball expert panel and by the referee expert panel

blinded evaluation of the same videos using the same evaluation criteria (November 2016), followed by an online consensus meeting.

2.2 | Analysis of acute injuries

An expert panel consisting of a handball coach employed by the Norwegian Handball Federation and four clinicians (two physicians and two physiotherapists) working with handball players nationally and internationally analyzed the 55 injury videos. A specific form, developed by the expert panel to describe the situation and mechanism leading to injury, was used for the analyses and included variables such as ball possession, playing position, court position, injury cause, action of attacker and defender, and localization of tackle or hit, with additional specific sections on injuries to the head/face, knee, and ankle (Appendix S1).

If the team had ball possession, injuries were classified as an acute injury to an attacking player, whereas if the opposing team had ball possession, injuries were classified as an injury to a defending player. The cause of injury was divided into contact trauma, landing trauma following contact and non-contact trauma. Contact trauma was defined as injuries due to direct contact with opponent (tackle), teammate (collision), static object (eg, post), or moving object (eg, handball). Landing trauma following contact was defined as injuries occurring during landing after contact with opponent (tackle) or teammate (collision). Non-contact trauma was defined as injuries occurring during running, cutting, jumping, or landing without any involvement from opponents or teammates.

At the time of injury, the action of both the attacking and defending player was analyzed. The action of the attacking player was divided into: cutting movement; shot on target from the ground, or while jumping; running toward the goal; receiving pass from teammate; passing to teammate from the ground or while jumping; or other. The action of the defending player was divided into: blocking or tackling, with specified body region of the tackle, for example, head/face, shoulder, throwing arm, ball, abdomen, hip, thigh, or other. In addition, whenever an attacking player sustained an injury due to contact with a defending player, the main body region used by the defender to tackle was noted: head, shoulder, arm(s) flexed or extended, elbow, hand(s), abdomen, hip, knee, leg, or foot. Whenever a defending player sustained an injury due to contact with an attacking player, the body region used by the attacker to hit the defender was noted: head, shoulder, throwing arm, elbow, hand, ball, abdomen, hip, thigh, knee, or foot.

Following the individual analysis of the acute injuries, a consensus meeting, including the five handball experts and a moderator, was performed at the Oslo Sports Trauma Research Center. A consensus was reached in all cases, defined as three of the five handball experts in the panel agreeing on all the variables related to an injury.

2.3 | Evaluation of referee performance

Three referees employed by the Norwegian Handball Federation, with extensive refereeing experience from international handball at the club and national team level, performed individual blinded evaluation of 37 videos of playing situations leading to injury. Blinding was accomplished by editing the video so that the decision of referees could not be seen. The evaluation criteria were identical to the ones used by the referees, that is no foul, free throw in favor of attacking (defensive foul) or defending team (offensive foul), and penalty throw in favor of attacking team (defensive foul). In addition, it was evaluated whether foul play led to the use of sanctions, that is a two-minute suspension, a yellow card (warning) or a red card (disqualification). In 25 of the 37 videos, a consensus could be reached, as at least two of three in the referee expert panel agreed. The 12 remaining videos were discussed in an online consensus meeting (Skype, Skype Communications SARL, Luxembourg city, Luxembourg) to ensure a majority agreement in all cases.

2.4 | Statistics

Descriptive statistics were used to present the results from the video analysis of acute injury situations and referee decisions. Kappa correlation coefficients were calculated to assess the agreement between the decisions made by the referees and the expert referee panel. All analyses were performed using SPSS statistical software (SPSS V.24, IBM Corporation, New York, USA).

3 | RESULTS

The acute injuries (n = 55) were evenly distributed between attackers (n = 29) and defenders (n = 26), but time-loss injuries (n = 22) were more common among attackers (n = 15). Of the 22 time-loss injuries, ten were reported as less severe injuries (estimated absence 1-2 days), ten were moderate injuries (estimated absence 3-4 days), and two were severe injuries (estimated absence >4 weeks). Injuries occurred most frequently between the 6- and 9-meter line on the handball court (n = 37), with back position as the most common playing position at the time of injury for attackers (n = 19) and mid-defense for defenders (n = 15).

As shown in Table 1, the most frequent acute injury cause was contact trauma (n = 42) due to direct contact with an opponent (n = 27) and landing trauma following contact (n = 9) with an opponent (n = 8). Irrespective of injury cause, a

TABLE 1 Causes observed for acute injuries (n = 55)

Acute injury causes	Descriptions	n (%)
Contact trauma	With opponent (tackle)	27 (49.1)
	With opponent (collision)	6 (10.9)
	With teammate (collision)	2 (3.6)
	With static object	1 (1.8)
	With moving object	6 (10.9)
Landing trauma following contact	With opponent (tackle)	8 (14.5)
	With opponent (collision)	1 (1.8)
Non-contact trauma	During running	3 (5.5)
	During landing	1 (1.8)

tackling episode between opponents was observed in the majority of injury situations (n = 35).

3.1 | Injury situations to the attacking players

Attacking players sustaining an acute injury (n = 29) were most frequently performing a shot on target (n = 11), while jumping (n = 9) or standing (n = 2). The defending opponent(s) most commonly tackled the attacker's throwing arm (n = 7) or toward the head/face region (n = 6), with arms extended (n = 6), while moving toward the attacker from the side (n = 11). Most often, one defender was involved in the injury situation (n = 13), followed by two defenders or more (n = 9).

3.2 | Injury situations to the defending players

When defending players sustained an acute injury (n = 26), they most commonly tackled the throwing arm of an attacker (n = 10) or performed a blocking attempt (n = 3), while moving directly toward the attacking player (n = 7) or from the side (n = 6). Most frequently, they were hit to the head/face region (n = 10), followed by the abdominal and thoracic region (n = 4). In the majority of the situations, the attacking player was performing a jump shot on target (n = 15) and hit the defender with the knee (n = 5), the elbow (n = 2), or the hand (n = 2). In five of the situations, the defending player was hit by the handball.

3.3 | Head/face injuries

All the acute injuries to the head/face region (n = 17) were classified as contact trauma. The most common injury situation was a tackling episode (n = 12), where six attacking players and six defending players sustained an injury. A straight blow to the front of the head/face was the most common injury mechanism (n = 10), followed by a blow to the side of the head/face (n = 5), resulting in nine contusions, four lacerations, and two concussions. A total of 11 head/face injuries required medical attention on the court. Four players had to leave the court, two on their own (one contusion and one laceration) and two with assistance from the medical team (concussions). The majority of the head/face injuries resulted in no absence from training and match play (n = 8), while one was classified as a less severe injury (contusion) and two as injuries with moderate severity (concussions).

3.4 | Ankle injuries

The six acute ankle injuries were evenly distributed between contact trauma, landing trauma following contact, and non-contact trauma. The two injuries classified as due to contact trauma were both less severe injuries (sprains) and occurred in relation to a direct blow to the ankle from the anterior side, one during collision with teammate and one during a tackle. Landing on the ground and landing on the opponent's foot were the two situations observed for the landing traumas following contact with opponent (tackle), both less severe injuries (sprains). The two non-contact traumas occurred during running without interception from teammates or opponents and were both moderately severe injuries (one sprain and one ligament tear). For the non-contact traumas and landing traumas following contact (n = 4), the injured ankle was observed to be in an inverted position at initial contact with either the ground or foot of an opponent in all cases. At initial contact, the ankle was also in plantar flexion in two cases and in relatively neutral flexion in two cases. Subsequently, the ankle moved toward dorsal flexion and inversion in all cases.

3.5 | Knee injuries

Of the four acute knee injuries, two were classified as contact trauma, one as landing trauma following contact and one as non-contact trauma. A direct blow to the anterior knee and from the lateral side was observed as the injury mechanisms for the two contact traumas, both occurring during a tackle. The anterior blow resulted in a less severe injury (contusion), while the lateral blow resulted in an injury with moderate severity (sprain). The landing trauma following contact (n = 1) was classified as a less severe injury (sprain) and occurred during a landing situation on the ground subsequent to a tackle, where the knee was flexed at initial contact and subsequently moved toward flexion and valgus. The non-contact trauma (n = 1) was classified as a less severe injury (sprain) and observed to occur during a cutting movement, with the knee flexed and in relatively valgus at initial contact with the ground, and subsequently moving toward flexion and valgus.

TABLE 2 Overall decisions made by the referees and in relation to possession of injured players (n = 37)

Referees decisions	Attacker injured (n = 22)	Defender injured (n = 15)	Total (n = 37)
No foul	6 (27.3)	8 (53.3)	14 (37.8)
Free throw in favor	10 (45.5)[a]	2 (13.3)[b]	12 (32.4)
Free throw against	1 (4.5)[b]	2 (13.3)[a]	3 (8.1)
Penalty throw	-	-	-
Yellow card	-	-	-
Two-min suspension[c]	5 (22.7)	3 (20.0)	8 (21.6)
Red card	-	-	-

Results are shown as n (%).
[a]Defensive foul.
[b]Offensive foul.
[c]All two-min suspensions resulted in a free throw in favor of the attacking team (defensive foul).

3.6 | Referee decisions

The overall decisions made by the referees and in relation to possession of the injured player are presented in Table 2. When assessing videos in relation to tackling episodes leading to an acute injury (n = 30), irrespective of possession, no foul was called in eight episodes, free throw in favor of the defending team (offensive foul) in two, and free throw in favor of the attacking team (defensive foul) in 20, with eight-two-minute suspensions of defenders. In situations where the attacker performed a shot on target (n = 10), the most common action when attackers sustained an injury, the referees called no foul in three cases, free throw against (offensive foul) in one, and free throw in favor (defensive foul) in six, with a two-minute suspension against the defender in two situations. In situations where the defender tackled the throwing arm of the attacker (n = 7), the most common action when an injury occurred to defenders, the referees called no foul in four situations and free throw against (defensive foul) in three, with a two-minute suspension against the injured defender in two episodes. When examining videos in relation to situations leading to an acute injury, with any degree of absence (n = 13), no foul was called in six situations, free throw in favor of the attacking player (defensive foul) in five, and free throw in favor of the defending players (offensive foul) in two. Only one of the situations qualified for the use of sanction, a two-minute suspension of the defending player.

3.7 | Evaluation of referee performance

As shown in Table 3, there was agreement between the referees and the expert panel in only 14 of the 37 acute injury situations (kappa: 0.22, 95% CI 0.07 to 0.36). The expert panel awarded two yellow cards and three-two-minute suspensions in relation to three free throws and two penalties, all in favor of the attacking team (defensive foul), in five situations in which the referees called no foul. In addition, the expert panel awarded a red card to an attacking player perpetrating an offensive foul (free throw defending team) in one situation in which the referees called no foul. When examining the overall use of sanctions, the expert panel awarded five yellow cards, 11 two-minute suspensions, and one red card in 17 situations in which the referees awarded no sanctions.

TABLE 3 The decisions made by the referees vs the decisions made by the expert referee panel for acute injury situations (n = 37)

	Referees					
Expert panel	No foul	Free throw[a]	Free throw[b]	Yellow card	Two-min suspension	Red card
No foul	8	1	1	-	-	-
Free throw[a]	-	2	-	-	-	-
Free throw[b]	-	-	-	-	-	-
Yellow card	2	3	-	-	1	-
Two-min suspension	3	6	2	-	4	-
Red card	1	0	-	-	3	-

The shaded cells denote agreement between the match referees and the expert panel.
[a]In favor of attacking team (defensive foul).
[b]In favor of defending team (offensive foul).

Assessment of decisions in relation to tackling episodes (n = 30) revealed that the expert panel called three free throws and one penalty in favor of the attacking team (defensive foul) in four situations in which the referees called no foul. Regarding use of sanctions, the expert panel awarded five yellow cards and 11 two-minute suspensions in 16 tackling episodes in which the referees awarded no sanction. In addition, the expert panel awarded three red cards in episodes in which the referees only awarded two-minute suspension.

When assessing decisions in the most frequent injury situations for attackers (performing a jump shot, n = 8) and defenders (tackling toward the throwing arm, n = 7), the expert panel called eleven free throws in favor of the attacking team (defensive foul), including seven-two-minute suspensions and one yellow card, in situations where the referees called no foul.

When examining decisions in situations leading to an injury with any degree of absence (n = 13), the expert panel called four free throws in favor of the attacking team (defensive foul) in four situations in which the referees called no foul. In addition, the expert panel awarded three yellow cards and five-two-minute suspensions, all to the defending player, in eight situations leading to a time-loss injury in which the referees refrained from the use of sanctions.

4 | DISCUSSION

This is the first prospective video analysis describing the mechanisms of acute injuries and evaluating referee performance in injury situations in elite handball. A tackle was the most frequent injury situation, with contact trauma and landing trauma after opponent contact as the main injury causes. The referees were substantially more lenient than the expert referee panel in their interpretation of rules and use of sanctions.

4.1 | Cause of acute injuries

Handball is considered a contact sport, where tackles and collisions are a natural part of the game.[1] Consequently, this puts players at risk of sustaining an injury, with contact highlighted as the main cause of injuries in epidemiological studies.[4,13-16] In fact, between 60% and 90% of all injuries has been reported as contact injuries during international male championships.[4,17,18] Based on player and medical reporting, contact injuries typically occur during high-speed movement, often involve several players, and can be caused by a direct blow to the body during a tackle or collision, or indirectly during landing, following a tackle, or a collision.[4] However, the causes of injury can be challenging to capture with data collection based on recall. Based on the current video analysis, we found that contact trauma due to a tackling episode between opponents was the most common acute injury cause, followed by landing trauma subsequent to a tackling episode. In fact, a tackling episode was the most frequent event observed preceding an acute injury situation.

4.2 | Possession and playing position

According to previous epidemiological studies in handball, the majority of injuries occur during attacking while having ball possession,[13-15] with back players in the most vulnerable playing position.[19,20] However, when adjusting for match exposure during an international tournament, players in the line position had the highest risk of injury.[4] In the current study, acute injuries were evenly distributed between attackers and defenders. At the time of injury, the back position was the most common playing position for attackers and mid-defense for defenders, with the majority of injuries occurring between the 6- and 9-m lines. A previous study conducted on the time motion analysis of the same event highlighted that majority of goals were scored from the back and line position.[21] Therefore, to reduce scoring chances, it is expected that the likelihood of collisions and contact is high between opponents in these positions. When comparing our results with previous studies, methodological differences should be kept in mind, as epidemiological studies are solely based on player and medical reporting, and may vary from observation of actual injury situations, that is, the playing position at the time of injury may vary from player's ordinary position and may be dependent on playing possession.

4.3 | Action of injured player and opponent

To our knowledge, no previous study has reported information regarding the action of the injured player and the opponent at the time of injury in handball. In the current study, we found that attacking players most often were performing a jump shot when sustaining an acute injury, while the defending opponent tackled toward the throwing arm or the head/face region of the attacker with arms extended, which is a violation of the rules.[5] Interestingly, the majority of injuries to defenders occurred in the same playing situation, that is, while defenders tackled toward the throwing arm of an attacker performing a jump shot and were hit by the attacker's knee, elbow, or hand. This indicates that tackling episodes occurring when attackers perform a jump shot should be targeted to prevent acute injuries among both attackers and defenders through development and appropriate interpretation of the rules of the games.

4.4 | Referee decisions and performance

We found that the referees called foul play in 62% of situations leading to injuries, with only a minority leading to the use of sanctions. All situations leading to foul play resulted in free throws, with the majority in favor of the attacking team (defensive foul), despite injuries being evenly distributed among attackers and defenders. None of the situations qualified for a penalty throw and no yellow or red cards were awarded.

In a previous epidemiological study, including match injuries from six international handball tournaments, 54% of the contact injuries were caused by foul play according to the medical team and the injured player. In contrast, only 32% of these injuries qualified for the use of sanctions by the referees.[18] These data are solely based on an injury-reporting system and vulnerable to both recall and information bias. In the current study, we found that the overall agreement between the referees and the expert panel in regard to calling foul play was weak, with substantially stricter interpretation of the rules in the expert panel. The referees were found to be substantially more lenient in their use of sanctions and calling foul play during tackling episodes and situations leading to time-loss injuries. Based on these results, we suggest that stricter refereeing and potentially also rule amendment should be considered to protect handball players from acute injuries, as previous studies have reported a preventative effect of such efforts in other sports.[22-25]

4.5 | Injury mechanisms of specific body regions

The analysis form used in the current study included specific sections regarding head/face, knee, and ankle, and aimed to describe the acute injury mechanisms to these body regions in detail. However, due to a limited number of cases, these results must be interpreted with caution.

All acute injuries to the head/face region were classified as contact trauma. The majority occurred during tackling episodes and was evenly distributed among attackers and defenders and should be targeted when aiming to prevent head/face injuries through referee′s interpretation of rules. A blow straight to the head/face or from the side was the most common injury mechanism. Interestingly, majority of players continued to play, despite more than half of the injuries requiring medical attention on the court. Only four players were withdrawn from play, and only two were classified as moderate injuries. Due to the high intensity in handball, it could be questioned if the severity of head/face injuries in handball is underestimated. Are the medical teams capturing the true extent of the problem? Do they use the sport concussion assessment tool when evaluating if a player should be withdrawn from play after a blow to the head/face? In July 2016, subsequent to the championship in Qatar, the International Handball Federation updated the rules regarding injured players during matches. In case of an injury, the referees may give permission to the medical team to enter the court to assist an injured player. However, if the preceding event does not involve foul play, the injured player must leave the court immediately after receiving medical attention and can only return following the third attack of his team.[26] This may provide the medical team with additional time to evaluate an injury. However, in situations where the referees are uncertain if the player requires medical attention on the court, the players should decide themselves.[26] This may stimulate players to neglect medical attention to avoid leaving the court. Consequently, this may inhibit the medical team in capturing a player with a concussion that should be withdrawn from play, and the new rules should be debated in a medical perspective. Rule amendments to consider include a three-minute full stop in play whenever the referees suspect a serious injury to the head, allowing a thorough assessment of the injured player on the court, with mandatory confirmation from the medical team before the player is allowed back in play, similar to the procedure introduced by the Union of European Football Associations Executive Committee in 2014, dealing with suspected concussions in football.[27]

According to previous kinematic case studies,[28-30] ankle inversion traumas occur in a neutral or dorsal flexed position. Recently, a systematic video analysis of ankle injuries in volleyball supported this, as landing-related injuries were reported to mostly result from inversion in neutral flexion without any substantial plantar flexion.[31] In the current study, we observed similar mechanisms for acute ankle injuries occurring while running or during landing situations on the ground or on an opponent's foot. However, when interpreting our results, it should be noted that we only included four ankle injuries classified as non-contact trauma or landing trauma following contact. A previous prevention study in handball,[19] including exercises to improve awareness and control of ankles during running, cutting, jumping, and landing, has reported a reduction in acute ankle injuries, and such exercises should be preferred when aiming to prevent ankle injuries. Regarding the ankle injuries due to contact trauma, there is no obvious aim for prevention, as this study only included two cases that both occurred during an involuntary blow to the ankle.

Two of the acute knee injuries were classified as contact trauma occurring during a tackle, with a direct blow anterior to the knee and from the lateral side as the observed injury mechanisms. Potentially, injury preventative measures should focus on referee's interpretation of rules in such situations. However, as there are only two cases in the current study, this remains unclear. The remaining two acute knee injuries in the video material were classified as one non-contact trauma and one landing trauma. In both injuries, the knee was

flexed at initial contact with the ground and subsequently moving toward increased flexion and valgus, similar to acute knee injury mechanisms previously reported in handball.[32] Prevention programs including balance exercises focusing on neuromuscular control, planting and landing skills, and lower extremity strength have been reported to reduce the risk of acute knee injuries in handball[19,33] and should be preferred when aiming to prevent such injuries.

4.6 | Methodological considerations

A major strength of this study was that we included a sample of real-time acute match injuries in elite handball, which were individually analyzed by five handball experts, before completing a consensus meeting. We also recruited an expert referee panel, with extensive referee experience from international handball, to perform individual blinded evaluation of the injury situations in regard to foul play, and compared this with the referee decisions. However, this study also has several limitations that need to be addressed.

When interpreting our results, it should be kept in mind that the time of injury was determined subjectively and may differ from real life, but was in most cases obvious according to the expert panel. As the video material consisted of limited camera angles and only included a minimum of 5 s preceding and following the injury situations, our ability to describe the injury mechanisms may have been affected. In addition, the external validity is limited due to a homogenous population and the low number of cases, especially for ankle and knee injuries.

Videos not showing the referees and their decisions were excluded, but it seems reasonable to assume that these would be random cases. When evaluating referee performance, the decisions made by the expert panel were used as the gold standard. However, we cannot be certain that their evaluations were correct. There are several differences between evaluating the situations live compared with on video. In ice hockey, it is reported that situational factors, such as crowd noise, influence from the coaches, and stress, can influence the refereeing.[34,35] These factors will also be present during international handball matches and may have influenced the referee's decision-making. In contrast, the expert panel will not have been exposed to these factors. Regarding visual view, the expert panel had access to two camera angles in most cases, that is, an overview of the situation, followed by a close up during the replay. Naturally, these angles will differ from the referees live viewing of the situations and may have lead to different observations. In addition, the expert panel had the opportunity to watch unlimited slow-motion replays, providing them with an advantage when evaluation the situations. It is also reported that hockey referees tend to use a stricter interpretation of rules when refereeing based on video compared with live.[36] This may be explained by the "advantage" rule, allowing referees not to interfere if they consider that the attacker is not obstructed and will benefit from continued play.[5] As the expert panel only had access to the specific injury situation with a limited timeframe, this may have affected their ability to take this rule into account. It should also be noted that the culture of handball and tradition of referring and adherence to existing rules might differ between the Norwegian referees in the expert panel and championship referees with an extensive international background. This may have affected our results and challenges the external validity of our findings.

5 | PERSPECTIVES

Rules and referee performance are important external risk factors to consider when planning injury preventative measures in sports and previous studies intervening on these factors have reported to successfully reduce the rate of injuries.[8,12,22-25] Based on our results, we recommend that rule amendments and stricter rule enforcement should be considered to prevent acute match injuries in elite male handball, especially in relation to tackling episodes when an attacker is performing a jump shot, as this was the most common playing situation observed when attackers and defenders sustained an acute injury. Measures to consider are delayed video review of matches with the possibility to retrospectively sanction players violating the rules,[37] as well as extensive referee education focusing on playing situations with injury potential, that is, defender use of extended arms during tackles and attacker use of knee, elbow, and hand during jump shots. These measures to reduce foul play should be communicated to the handball community on an organizational level and be addressed by future research to assess the effects on acute injury rates.

ACKNOWLEDGEMENTS

We would like to thank Tom Morten Svendsen for contributing to the video analysis of the acute injury situations and the referees in the expert panel; Øyvind Togstad, Øystein Pettersen, and Per Morten Sødal, for evaluating the playing situations leading to injury. Aspetar hospital, the International Handball Federation, the Aspire Zone Foundation Research Committee, the Medical and Scientific Commission, and the Organizing Committee of the Qatar 2015 World Championships which provided the approval and support for the project and the funding to conduct the analyses of the games. The Oslo Sports Trauma Research Center has been established at the Norwegian School of Sport Sciences through generous grants from the Royal Norwegian Ministry of Culture, the South-Eastern Norway Regional Health Authority, the International Olympic Committee,

the Norwegian Olympic and Paralympic Committee & Confederation of Sport, and Norsk Tipping AS.

AUTHORS' CONTRIBUTION

All authors contributed to the study design and data recording preparation. MC was responsible for developing the video software in collaboration with ProzoneSports. MC, CH, and FSL were responsible for preparation of the video material. SA, MC, NP, and GM performed the video analysis, and TB was responsible for the injury consensus meeting. SA was responsible for the referee consensus meeting. SA interpreted the data and wrote the first draft of the manuscript. All authors reviewed and approved the manuscript. SA and the main supervisor, GM, are responsible for the overall content as guarantors.

ETHICAL APPROVAL

The injury surveillance study was reviewed and approved by the Anti-Doping Lab Qatar (ADLQ), Doha, Qatar. The video analysis of the games was reviewed and approved by the Medical and Scientific Commission of the Qatar 2015 World Championships and by the Aspire Zone Foundation Research Committee.

TRANSPARENCY

The lead author (the manuscript's guarantor) affirms that the manuscript is an honest, accurate, and transparent account of the study being reported and that no important aspects of the study have been omitted.

DATA SHARING

All data are available upon request.

ORCID

S. H. Andersson http://orcid.org/0000-0002-2440-8399
C. Hansen http://orcid.org/0000-0003-4813-3868
G. Myklebust http://orcid.org/0000-0002-0692-7494

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

How to cite this article: Andersson SH, Cardinale M, Whiteley R, et al. Video analysis of acute injuries and referee decisions during the 24th Men's Handball World Championship 2015 in Qatar. *Scand J Med Sci Sports*. 2018;28:1837–1846. https://doi.org/10.1111/sms.13090