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Direction of the load on the elbow of the ball blocking handball goalie

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Abstract Elbow problems in goalkeepers in team handball "handball goalie's elbow" is common. The accepted mechanism in the common injuries is hyperextension of the elbow. The purpose of this study was to describe the elbow position at the time of impact of the ball on the hand. This study is based on video-analysis. Fifteen handball goalies (ten females and five males) who had been playing handball for a mean time of 6.5 years were used in the study. The participants were not aware of the details of the study. A national team member attacker performed repetitive shots toward the right side of each goalkeeper. The goalkeepers blocked the ball with their own usual style. Each block was videotaped with three digital cameras (one side view, one superior view, and one frontal view). The captured shots were later evaluated by three analysts as to the elbow position at the time of the impact. Seventy-eight out of 101 shots (77%) were valgus or mostly valgus load producing shots. The remaining 23 (23%) were hyperextension or mostly hyperextension load producing shots. This study shows that the elbows of the handball goalkeepers experience valgus loads at the time of ball blockade during the penalty shoot-out. A detailed understanding of the mechanism of the loads on the handball goalkeepers' elbow will help in defining ways to prevent and to treat handball goalie's elbow.

Keywords Handball goalkeeper · Elbow · Valgus load · Hyperextension · Injury mechanism · Video analysis

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Introduction

The International Handball Federation (IHF) has more than 123 member countries and has around 12 million registered players worldwide. Team handball is played by six court players (three backcourt, two wing, and one line player or circle runner) and a goalie on each side, with two 30-min halves, on a court measuring 20×40 m^2. One goal (2-m high $\times$ 3-m wide) is located at each end of the court, enclosed by a 6-m "goal area" line; all shots on goal must occur outside the line. The 9-m, or free throw, line is used for minor penalties, whereas the 7-m, or penalty, line is used for penalty shots, much like penalty kicks in soccer. Players may dribble the ball, although the game is not dribble oriented like basketball. The offensive player usually attempts to score by a jump shot, side-arm shot, set shot, or bounce shot past the goalie. The defense attempts to stop the offense from scoring by blocking the opponent's throw, either by holding up hands to reject the shot or by making controlled contact with the player's shooting arm in an effort to stop the shot.

Although a few previous studies have evaluated the injuries specific to handball [2, 4, 12], they are few in contrast to other more popular sports such as football, basketball, volleyball or baseball. Handball is a contact sport with a high potential of injury caused by body-to-body collision, requirement of instantaneous direction changes, the speed of the ball, the rigidity of the surface an possibly also by high shoe-surface friction. In a prospective study covering 16 German handball clubs, Seil et al. [9] concluded that 0.6 injuries occurred per 1,000 player-hours in practice and 14.3 injuries occurred per 1,000 player-hours in games. Several researchers have evaluated the significant number of elbow injuries, specifically among goalies [10, 11]. The goalkeeper can touch the ball with any extremity in the goal area, can avoid body-to-body contact and not infrequently faces penalty shots. Their main function during the game is to save or block shots usually using fully extended arms. In an extensive study done by Tyrdal et al. [12], 45% of goalkeepers were reported by their coaches to have current or to have had previous problems with one or both elbows, whereas only 4% of field players were reported by their coaches to have current or to have had previous problems with one or both elbows.

The diagnosis of "handball goalie's elbow" covers symptoms seen in the elbow of the goalkeepers; pain, weakness, reduced range of motion, apprehension, numbness, swelling, clicking, locking, and instability [12]. The serial studies done by Tyrdal [11, 12] and the study done by Popovic and Lemaire [6] have suggested that the mechanism underlying the problem of handball goalkeepers' elbow is increased load in hyperextension.

Current video-analysis study was undertaken to define the position of the handball goalie's elbow at the time of the impact of the ball on the hand.

Materials and methods

Fifteen handball goalkeepers from four different teams were used in this study. They have all been playing in the national handball league at varying levels. There were ten female, five male players and had been playing handball as a goalkeeper for a mean time of 6.8 (3–12) years. All of the goalies were considered to be healthy by their coaches and played at the national level. The goalkeepers were informed that with this video-analysis study one of their upper extremity joint's position at the time of ball reception was being investigated withholding the information that it was an elbow study. The individuality of the players were respected; the results of the study were first delivered to them as they were anxious, all of the players consented with the use of their pictures in a medical journal if necessary and they were also presented with the information that during the study although the risks of injury would not be as much as it is in a game, they still existed. A consent form containing these important issues and those required by the initial authors' institution's ethical approval committee was individually signed by the players. The study was approved by the initial author's School of Medicine Medical Ethics Committee. Before the analysis was performed all the participants were interviewed regarding their age, sex, and active handball playing years (Table 1). A thorough examination of the goalkeepers were done including the presence of gross skeletal deformity, joint range of motion including dominant elbow, non-dominant elbow, dominant shoulder, and non-dominant shoulder (Table 2).

All of the goalkeepers were asked to warm up as if they were preparing for a league game by a first level team coach. Same striker was used for shooting to all the goalkeepers. The striker was a 23-year-old male who was a current national team member who had been playing handball for the last 11 years. He was informed of the study and was asked to shoot at the predestinated spots marked behind the goalkeepers' right side on the wall. The shots were taken at the regular penalty shooting point and the goalkeeper did not know which spot the striker was aiming at. The only limitation the goalkeeper had, was not to move his/her feet so he/she would be within the frames of the cameras.

Each block was captured with three digital cameras. Side view was captured with a digital video camera (Sony DCR-PC10E PAL) situated to the right of the goalkeeper placed on a stable tripod. Superior view was captured by another digital video camera (Sony DCR-PC3E PAL) used by an investigator placed right above the studied elbow.

Table 1 Demographic information of the players

Goalie	Sex	Years played	Age
EB	F	9	19
IT	M	12	22
BK	F	8	25
DN	F	8	20
SS	F	11	22
CA	F	3	16
HC	F	6	16
GT	F	7	16
EA	F	6	15
FP	F	5	13
SA	F	3	14
BK	M	4	14
ASM	M	6	17
BB	M	5	15
CT	M	10	33

Table 2 Range of motion of the upper extremity joints

Goalie	DEF	DEE	NDEF	NDEE	DFS	DFP	NDFS	NDFP	DSIR	DSER	NDSIR	NDSER
EB	140	–5	140	0	85	75	85	75	75	95	95	90
IT	150	0	145	0	85	80	85	80	80	100	90	90
BK	135	10	135	10	85	75	85	75	85	80	100	75
DN	150	10	150	10	90	75	85	80	70	90	90	80
SS	135	0	135	0	90	75	80	75	50	80	80	60
CA	150	13	150	5	80	70	85	75	70	80	100	70
HC	140	0	140	5	85	70	85	70	60	80	90	70
GT	145	0	150	–5	90	75	90	70	70	80	90	60
EA	160	–10	155	0	85	75	85	75	80	80	90	70
FP	135	0	140	0	95	70	90	70	90	40	90	80
SA	135	0	135	0	85	75	85	75	70	90	90	60
BK	150	0	150	5	90	75	90	80	85	90	85	90
ASM	135	5	135	0	85	75	85	75	85	90	90	95
BB	130	0	130	0	85	75	85	75	85	85	90	85
CT	140	5	140	5	85	75	85	75	90	85	90	80
Mean results	142	1.87	142	2.33	86.6	74.3	85.6	75	76.33	83	90.67	77

Values are given in degrees

DEF dominant elbow flexion, *DEE* dominant elbow extension, *NDEF* non-dominant elbow flexion, *NDEE* non-dominant elbow extension, *DFS* dominant forearm supination, *DFP* dominant forearm pronation, *NDFS* non-dominant forearm supination, *NDFP* non-dominant forearm pronation, *DSIR* dominant shoulder internal rotation, *DSER* dominant shoulder external rotation, *NDSIR* non-dominant shoulder internal rotation, *NDSER* non-dominant shoulder external rotation

The investigator was positioned on the frames of a basket located above the handball goal. The frontal view was captured by a high-speed digital camera (Canon EOS D30) behind the striker placed on a tripod (Fig. 1). The cameras were started with a remote control device which prevented image distortion.

Video analysis

Three standard cameras capable of capturing 30 frames/s were used in the study. The captured sequences were digitized and enhanced by creating still, slow motion and enlarged picture sequences to clearly show the elbow position at the time of the loading. A video editing program (Adobe Premiere 6.5®, Adobe Systems Incorporated, San Jose, CA, USA) was used to process the original videotapes and transfer them to a hard disk. Three individuals (an orthopedic surgeon specialized in sports trauma, a general orthopedic surgeon with extensive clinical and research experience, and a former national women's handball team coach) analyzed the movies and the still images created in order to describe the loading mechanism on the elbow. After viewing the images, the analysts discussed among themselves and came to a common agreement. The information was recorded on a form which consisted of five questions; image quality, place of the ball impact, elbow flexion degree, cell of the impact and the direction of the elbow load (Table 3).

Fig. 1 Frontal view taken by the digital camera behind the striker

Analysts could choose between acceptable and non-acceptable recordings depending on the quality of the images to show the exact moment of impact. The location of the impact could be chosen among forearm, wrist-hand and fingers depending on where the ball hit the upper extremity. The elbow flexion degree could be chosen among full extension, 45° flexion and 90° flexion. The right side of the goalie was virtually divided into nine cells. The choices of the analysts ranged from 1 to 9 depending on where the ball went (Fig. 2).

Table 3 Form to be filled out by the three analysts

Image quality	Acceptable	Non-acceptable	
Place of the ball impact	Forearm	Wrist-hand	Fingers
Elbow flexion	Full extension	45° flexion	90° Flexion
Cell of impact	1	2	3
	4	5	6
	7	8	9
Elbow load	Pure valgus	Mostly valgus	
	Mostly hyperextension	Hyperextension	

Results

None of the players had a gross skeletal deformity. Mean results of range of motion of the joints are as follows; dominant elbow flexion: 142° (130°–150°), dominant elbow extension: 1.87° (–5° to 13°), non-dominant elbow flexion: 142° (130°–150°), non-dominant elbow extension: 2.33° (–5° to 10°), dominant forearm supination: 86.6° (80°–95°), dominant forearm pronation: 74.3° (70°–80°), non-dominant forearm supination: 85.6° (80°–90°), non-dominant forearm pronation: 75° (70°–80°), dominant shoulder internal rotation: 76.33° (50°–90°), dominant shoulder external rotation: 83° (40°–100°), non-dominant shoulder internal rotation: 90.67° (85°–100°), non-dominant shoulder external rotation: 77° (60°–95°) (Table 2).

After an appropriate warming up and stretching time, a total of 218 shots by the striker to the goalies were taken. The digital video camera that was placed above the goalkeeper which is referred as the superior view, taped all of the 218 shots to 15 different goalies on videotape. The digital video camera side view also captured all of the 218 shots to 15 different goalies. The digital camera that was used to capture the frontal view of the goalkeeper was able to capture 77 shots out of the 218 shots to 15 different goalies.

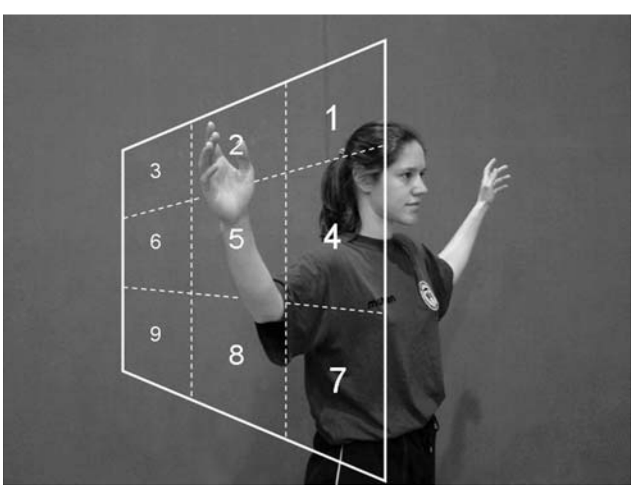

Fig. 2 The partition of the virtual ball impact cells

The analysts described that the best views of the elbow at the time of impact were shot by the video camera situated above the goalie. The recordings of the side view camera were mainly used for confirmation of information obtained from the superior view. Because it was not possible to frame all of the shots by the digital camera that was positioned behind the striker, the front views were also used for supplementation of the superior views.

Of the 218 balls shot, 67 did not strike on the hand of the goalie. When the remaining 151 shots were exported from the videotapes into still frames, 50 of them did not result in an acceptable quality of image. Consequently, this study is based on still captures of 101 shots taped by the video camera placed above the goalie and supplemented by the images obtained from the side view tape and the front view camera.

Eight balls hit the forearm, 85 balls hit the wrist or the hand and the remaining 8 balls hit the fingers. Eighty balls hit the target when the elbow was in almost full extension, 16 balls hit when the elbow was around 45° of flexion and 5 balls hit when the elbow was close to 90° of flexion. Nine balls were intercepted in cell no. 1, 36 balls were intercepted in cell no. 2, 1 ball was intercepted in cell no. 4, 44 balls were intercepted in cell no. 5, and 11 balls were intercepted in cell no. 8 (Table 4).

As described by the analysts, 78 out of 101 shots (77%) were valgus or mostly valgus load producing shots (Fig. 3). The remaining 23 (23%) were hyperextension or mostly hyperextension load producing shots (Table 5). Of the 91 balls were intercepted in the coronal plane (cells 2, 5, and 8) 74 were thought to produce a valgus or a mostly valgus load on the elbow (Fig. 4). Ten balls were intercepted in the forward area (cells 1, 4, and 7) and only four were thought to produce a valgus or mostly valgus load on the elbow, six produced hyperextension or mostly hyperextension load on the elbow (Fig. 5). This has shown us that when the ball is blocked in the coronal area, the elbow is more likely to be subjected to valgus loads than hyperextension load with a statistically significant difference (Pearson Chi-Square Test, $P < 0.01$) (Fig. 6).

Table 4 Documentation of the good-quality images

Place of the ball impact			Elbow flexion degree			Cell of impact									Elbow load			
Forearm	Wrist hand	Fingers	Full ext	45° Flexion	90° and beyond	1	2	3	4	5	6	7	8	9	Pure valgus	Mostly valgus	Mostly hyperext	Hyperext
8	85	8	80	16	5	9	36	0	1	44	0	0	11	0	56	22	19	4

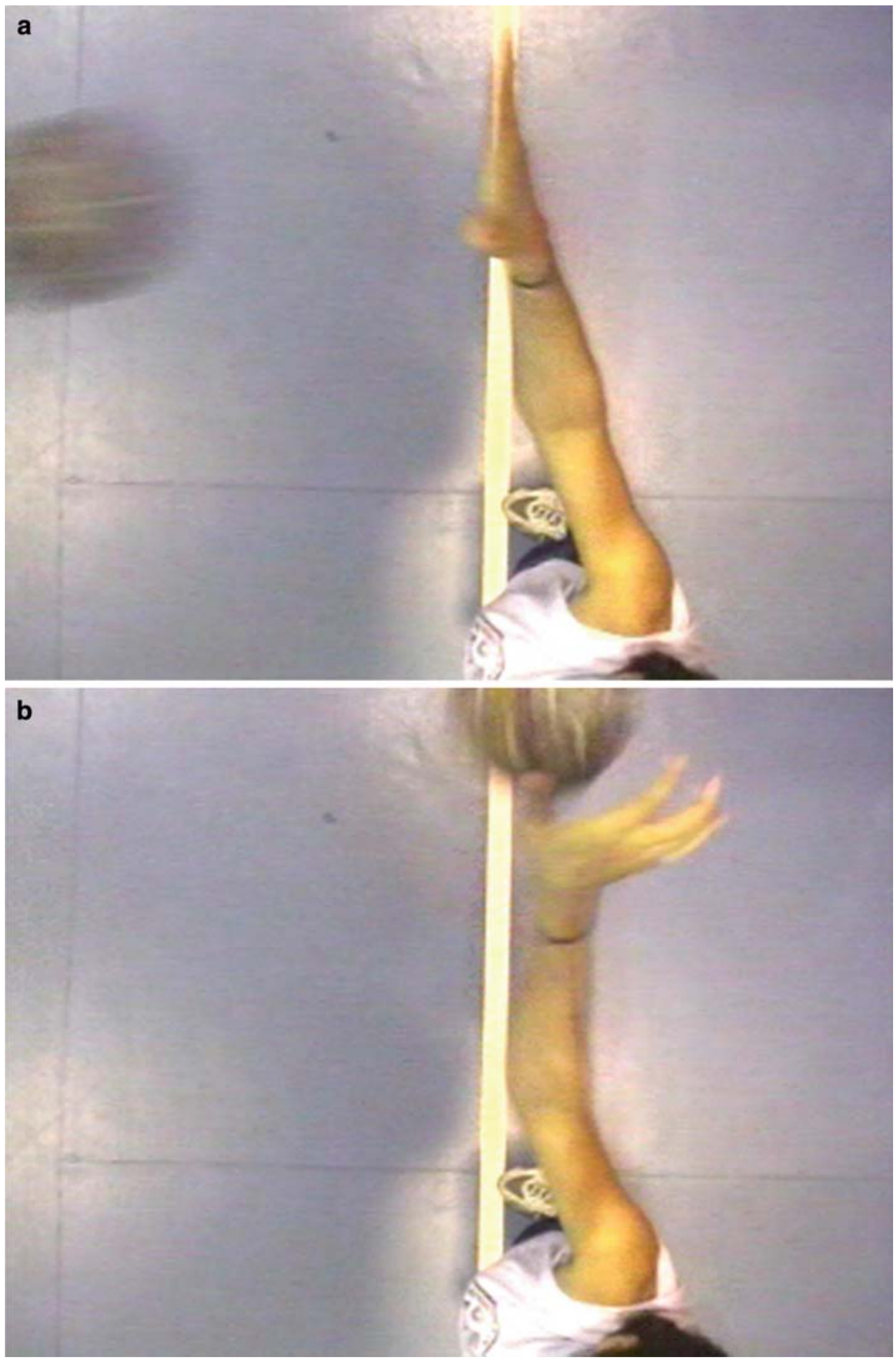

Fig. 3 **a** The superior view of the elbow position expecting the impact of the ball. **b** The valgus load on the elbow right after the impact

Table 5 Differentiation of the shots into respective loading mechanisms

Cell of impact	Pure valgus	Mostly valgus	Mostly hyperext	Hyperext
1	0	4	2	3
2	30	4	2	0
3	0	0	0	0
4	0	0	1	0
5	26	12	6	0
6	0	0	0	0
7	0	0	0	0
8	0	2	8	1
9	0	0	0	0
Total	56	22	19	4

Discussion

This study, to our knowledge, is the first video study to analyze the loads on the goalkeepers elbow. The main finding of this study is that the handball goalie's elbow experiences a valgus load most of the time while intercepting the ball in the coronal plane. We also observed that loads on the elbow while intercepting the ball forward to the coronal plane is predominantly hyperextension.

Video-analysis studies by nature are dependent on investigators' subjectivity. Therefore, our study has some limitations which need to be discussed. Unaccounted prejudice could exist during the shooting phase or in the evaluation process which were both carried out by independent investigators. In the shooting phase of the study, there were three cameras shooting separately that did not start simultaneously. The system we have used which requires synchronization to be performed later seems to place the recording phase as an inconsistent step. Secondly, superior views were the most referenced images as all three cameras failed to provide equally important information. In order to optimally use the cameras and increase their efficiencies, linear transformation method could be used. Linear transformation method requires placing 3-dimensional marker coordinates in the upper extremity followed by taping and digitizing the action. We believe we have overcome this by using independent analysts who did not attend the recording phase of the study but competent in processing images. Finally, we were unable to capture the exact moment of the impact of the ball in every shot which resulted in a lower number of accepted frames only. The quality of the accepted frames was not affected.

There were five men and ten women in the study group with ages ranging from 13 to 33 years. The game takes place at a higher speed in men's category than in women's and the mechanics of the upper limb especially the carrying angle differ between sexes and differ between the immature and the adult skeleton. In addition the tissues respond differently in different sexes at different ages. However, these factors (speed of the ball, carrying angle, different tissue response, and age) do not seem to bring a bias to the study. Speed of the ball is not a determinant of direction of load which we needed to create because our study is a qualitative study rather than a quantitative study. Our primary goal was to determine the direction of the load rather than the amount of load in the elbow. Changing with skeletal growth and maturity, carrying angle has been shown to be related to some morphometric measurements in the body [5]. However, Morrey has noted "this anatomic relationship (carrying angle) is more of academic and cosmetic interest than of clinical importance." in his textbook [3]. Carrying angle does not seem to be a factor in determining the direction of the load created, supported by absence of any data in the literature. In our search through the literature we have not come across a study comparing the adolescent and the adult kinematics. However, the only published study relating pediatric shoulder and elbow kinetics to elbow valgus loads conclude that their data closely approximate findings seen in adult population [8].

There are two determinants of the load type on the elbow; forearm rotation and the humeral rotation. Forearm rotation follows the palm of the hand which tries to face the ball at a right angle with fingers widely abducted. Handball goalkeepers have to stay close to the goal line because the goal is best covered if they keep their upper and lower extremity acting like a windshield wiper. The coronal plane (line between shoulders) is always perpendicular to the line of the coming ball as the palm of the hand is intended. The usual interception of the ball is through stopping the speed of the ball by blocking it with the hand which then requires a strong upper extremity chain. Upper extremity's function is to place the hand in space, based on the humeral rotation the forearm will find its rotation to optimally position the hand for final impact with the ball. We have been unable to find a study that analyzes the differences in loading of the elbow while the forearm is in maximal pronation, mid-pronation or maximal supination when the hand is struck. The closest study is by Chou et al. [1] in the study where they studied the elbow load with various forearm positions during one-handed pushup exercise. The study's main limitation is that the force on the hand and the forearm is an axial load where as the goalkeepers receive an angular impact on their hand. However, the study does give useful information that forces that are applied to the hand may produce differing loads on the elbow depending on the rotation of the elbow. The authors found that push-ups done in full supination of the forearm causes increasing loads on the elbow.

Humeral rotation is the second main variable in determining the type of the load on the elbow when the hand is subject to force. The upper extremity moves as if the shoulder is the pole of a hemisphere as shown by the Codman's paradox. The simplest explanation of the so called "paradox" is 90° of rotation about the z-axis and then the x-axis results in a different final position than rotation about the x-axis and then the z-axis. Serial angular rotations are not additive and are sequence dependent. Although the handball goalkeeper does cover an imaginary hemiglobe with his/her upper extremity, for the purpose of practicality we limited our study to coronal plane motion of the upper extremity. This motion is a basic anatomical element which is also well described in Leonardo Da Vinci's "*Study of proportions, from Vitruvius's De Architectura*" drawing. In the anatomical position, which is the starting position of motion, the humerus is in neutral rotation and the forearm is in supination. As the shoulder abducts in the coronal plane the humerus externally rotates to clear the tuberosity posteriorly for full arm elevation.

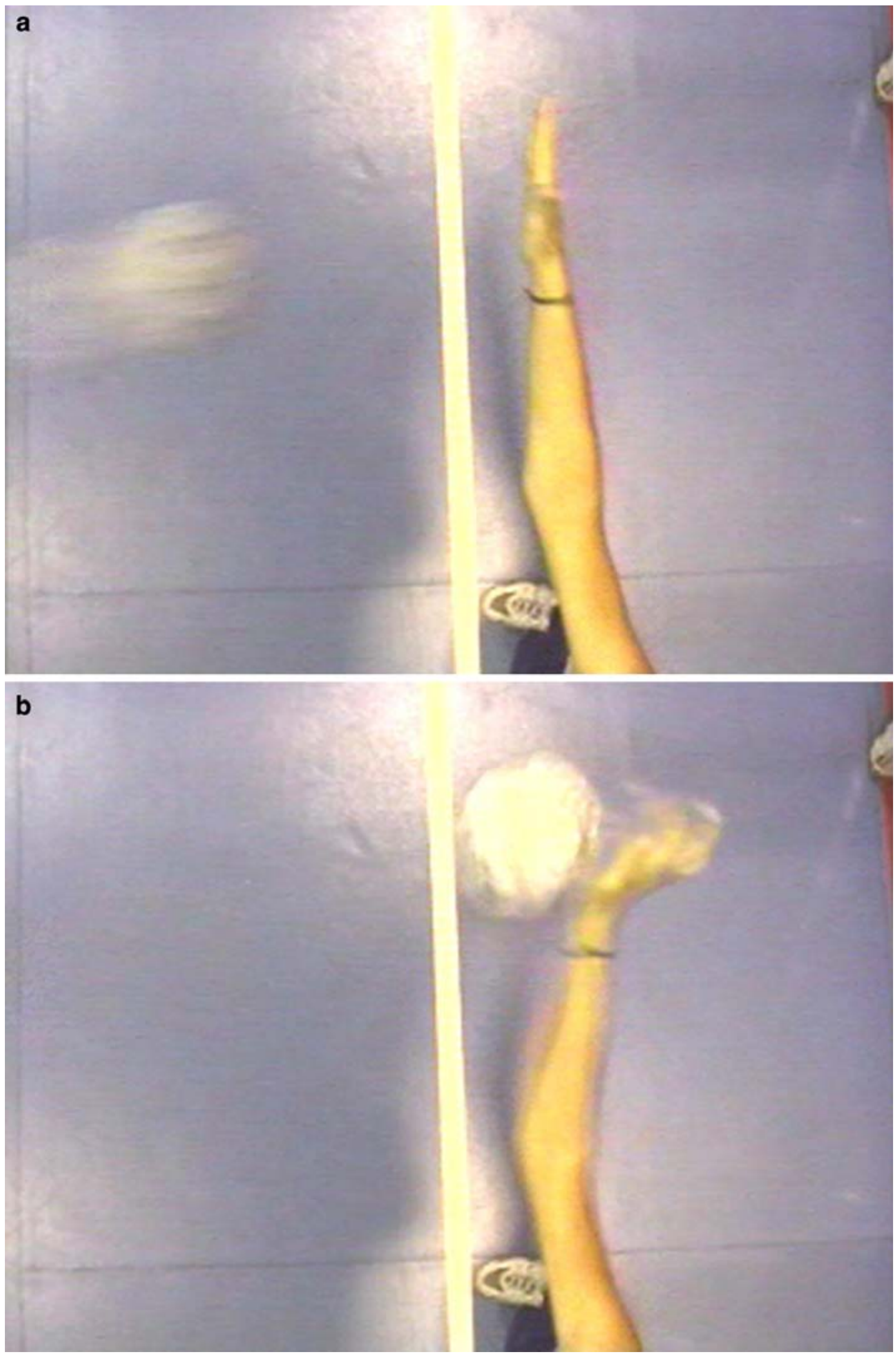

Fig. 4 **a** The superior view of the elbow position expecting the impact of the ball. **b** The valgus load on the elbow right after the impact

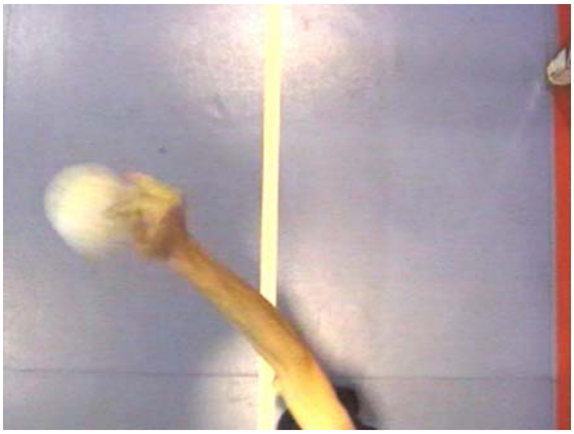

Fig. 5 The superior view of the elbow position about to experience a hyperextension load in cell no. 1, a forward area

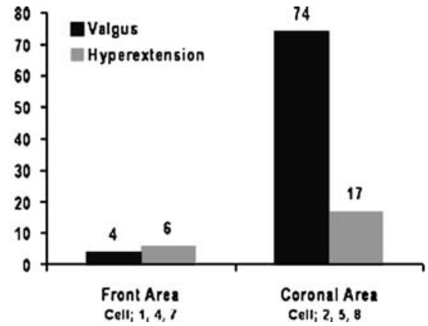

Fig. 6 Distribution of load directions among ball blocking cells

It is shown by laboratory studies that external rotation also loosens the inferior ligaments of the glenohumeral joint which also allows full elevation of the arm. At the time of a usual ball interception the shoulder is around 90° of elevation. At 90° of abduction the humerus will be in external rotation and forearm will be pronated so that the hand parallel to the coronal plane will block the ball at 90° to its motion direction. The ball's impact on the hand at this position will create a valgus load at the elbow.

This study has shown that the most frequent mechanism, the handball goalkeepers experience during ball blockade on their elbow' is a combination of valgus and hyperextension loads. "Valgus-extension overload syndrome" forms the basic pathophysiologic model behind the most common elbow injuries in the overhead athlete. The combination of large valgus loads and elbow extension produce tensile stress along the medial compartment restraints (ulnar collateral ligament, flexor-pronator mass, medial epicondyle apophysis, and ulnar nerve) and shear stress in the posterior compartment (posteromedial tip of the olecranon and trochlea/olecranon fossa), and compression stress is produced laterally (radial head and capitellum).

Reception of the ball at differing positions resulted in differing loads on the elbow. Interception of the ball in front of the coronal plane resulted more in hyperextension whereas interception of the ball to the side of the goalkeeper resulted in valgus load. A player who has symptoms of valgus overload syndrome could be trained with techniques that would able him/her to intercept the ball in front of the coronal plane. Thus allow damaged tissues to be protected while playing.

Current study is unable to disclose the underlying mechanism of the "handball goalie's elbow." Although seems likely, whether the combination of hyperextension-extension overload is the underlying mechanism is a matter of another study. Handball goalies' elbow is an important condition. In the most comprehensive study of handball goalkeepers' elbow symptoms, Tyrdal and Bahr [12] reported that pain (83%) is the leading complaint followed by weakness (22%), reduced range of motion (19%), apprehension (15%), numbness (13%), swelling (12%), clicking (12%), locking (11%) and instability (2.6%). In another study, Tyrdal and Finnanger [10] said that 82% of the pain complaints belonged to the medial side. In the same study they observed 21% radiological abnormalities were observed including medial instability, loose bodies, traction spur formation, and minor arthritic changes [10]. Numbness may be explained by Rise et al.'s [7] study where they acknowledged the possible relationship between handball goalkeepers' elbow problems and ulnar nerve pathology.

We believe that this video analysis forms the base of knowledge for further studies that will delineate the relationship between valgus-extension overload and handball goalie's elbow. Once the relationship is established a prevention program addressing the overload would be coined and a program consisting of strength and technique training should be implemented by cooperation between the athlete, coach, and medical partners.

Conclusion

In conclusion, we believe that handball goalkeepers are subject to valgus loads more than hyperextension loads on their elbows during the block of the shots. Our conclusion is based on the images captured from the video cameras which clearly show that at the time of impact between the ball and the hand there is a valgus load on the elbow most of the time. Similarities between symptoms of baseball pitchers' valgus extension overload syndrome and the handball goalkeepers' elbow complaints, also hint us to think that mechanism in these sports motion is the same [8].

In the future, studie(s) showing the relationship between valgus-hyperextension overload and handball goalies' elbow will aid in establishing a prevention program.

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