CASE STUDY

Uncovering the Biomechanical Role of Hip Flexion in Non-Contact ACL Injuries during Athletic Maneuvers: A Case-Control Study Using YouTube Video Analysis

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Abstract

Introduction: The anterior cruciate ligament (ACL) is crucial in preventing anterior tibial translation, and a complete rupture is a severe sports injury. This study aimed to test if hip joint angle contributes to non-contact ACL injuries in male professional athletes during three maneuvers: changing direction, landing from a jump, and deceleration.

Methods and Materials: From October to December 2020, an online case-control study was conducted involving 37 male professional athletes. Out of 37 videos, 19 showed athletes who had suffered an ACL injury during one of three maneuvers, while the remaining 18 videos depicted athletes performing similar maneuvers without prior ACL injury. Hip joint angle was analyzed in each video using Kinovea software.

Results: Injured group had a greater hip flexion angle during the change of direction maneuver compared to the control group, and less ROM. No significant differences in hip angle during jump-landing, but injured individuals had less ROM. No significant difference in hip flexion angle and ROM was found between the groups during deceleration maneuvers.

Conclusion: An increased hip flexion angle during change of direction may heighten the risk of non-contact ACL injury in male professional athletes.

Keywords

Anterior cruciate ligament; Hip joint; Sport injury, Athletes; Biomechanics

Introduction

The anterior cruciate ligament (ACL) is a crucial knee ligament that attaches to the front of the tibia and runs upward, laterally, and posteriorly to connect to the back of the medial surface of the lateral femoral condyle. Its main role is to restrict forward movement of the tibia, offering 86% passive resistance and limiting rotation[1].

ACL injury is a common sports injury worldwide, with complete rupture potentially leading to lifelong pathological conditions such as osteoarthritis, joint effusion, and knee instability[2]. ACL injuries are prevalent in Saudi Arabia and can impact athletes across various sports and skill levels[3-5]. Understanding the mechanism and causes of ACL injuries is crucial in reducing their incidence, given their increasing prevalence worldwide[6,7].

Most ACL injuries occur non-contact, meaning there is no physical contact between athletes at the time of injury. ACL injuries have been extensively studied in the past few decades and are mostly attributed to intrinsic variables in female athletes[8]. However, less attention has been given to studying male athletes, who are exempt from some of these variables. This shifts the focus to the biomechanical factors of their injuries. Most researchers agree that excessive anterior shear force at the knee during athletic manoeuvres is the primary cause of non-contact ACL injuries[9-12]. However, few researchers have examined the role of the hip joint in causing the injury.

Understanding the primary cause of non-contact ACL injury is crucial. Despite numerous studies on non-contact ACL injuries, researchers consistently identify anterior shear force as the primary cause, including:

1. Berns et al. measured anterior shear force on cadaver knees. This group found that pure anterior shear force between 0° and 30° of knee flexion, without any accompanying internal or external tibial rotation or knee varus and valgus moment, had a significant impact[10].

2. Markolf et al. found that anterior shear force, knee valgus and varus moment, and internal rotation of the tibia all generated significant loading on the ACL[12].

3. Arms et al. and Draganich et al. found that the quadriceps muscles generated a significant tibial anterior shear force through the patellar tendon at knee flexion angles between 0° and 45°[9,11].

Various researchers have investigated the biomechanical factors associated with ACL injury, based on the analysis of video footage of common manoeuvres. In one such study, Villa et al. focused on soccer players and found that those who exhibited an upright trunk posture, early hip flexion, and low knee flexion during initial contact were at a higher risk of ACL injury[13]. Moreover, other researchers have also reported similar findings regarding the importance of hip flexion during initial landing contact. Specifically, high hip flexion during landing has been associated with an increased risk of non-contact ACL injuries[14,15]. However, it is important to note that there are contrasting findings in the literature as well. Some researchers have reported that reduced hip flexion during landing can increase stiffness and the risk of ACL injury[16,17].

Therefore, in this study we investigate the role of hip joint angle in ACL injuries among male athletes during manoeuvres involving changes in direction, jump-landing, and speed. Due to conflicting reports on its involvement, we will compare athletes with and without ACL injury who perform similar manoeuvres in basketball, football, and soccer to explore the hip joint's role in ACL injuries among athletes.

Materials and Methods

This is an observational case-control study and was conducted at King Abdulaziz University Hospital from October to December 2020. We gathered 50 injury cases from YouTube. Only 37 cases, including both injured and control groups, met the inclusion criteria: 19 cases of athletes with ACL injury (injured group), and 18 non-injured athletes (control group) that had similar manoeuvre cases. Ethical approval was obtained from KAU's Research Ethics Committee for the study.

Analyzed sports were basketball, American football, and soccer. Basketball cases were from the National Basketball Association, football cases from the National Football League, and soccer cases from various leagues such as the Italian League, La Liga, Premier League, and Spanish League. Seven injuries (n = 7) occurred during change of direction: two in basketball (cases 1 and 2), four in American football (cases 10, 11, 13, and 14), and one in soccer (case 18). Five injuries (n = 5) occurred during jump-landing: two in basketball (cases 7 and 8) and three in soccer (cases 15, 16, and 17). Seven injuries (n = 7) occurred during deceleration: five in basketball (cases 3, 4, 5, 6, and 19) and two in American football (cases 9 and 12) (see Table 1).

Among the control group, seven cases (n = 7) were collected during change of direction, five (n = 5) during jump-landing, and six (n = 6) during deceleration. The cases were from basketball, American football, and soccer. Only case 12 lacked a comparable movement by a control group during deceleration (see Table 1). All videos had to be sagittal view across all three

Table 1. **Raw Data**

Case No.	Sport	Maneuvers	Initial-Contact	Mid-Contact	End-Contact	Displacement	Group
1	Basketball	Change of direction	50	44	37	Valgus	Injured
2	Basketball	Change of direction	48	50	36	Valgus	Injured
3	Basketball	Deceleration	40	45	40	Valgus	Injured
4	Basketball	Deceleration	55	53	59	Anterior	Injured
5	Basketball	Deceleration	49	41	36	Valgus	Injured
6	Basketball	Deceleration	51	52	58	Valgus	Injured
7	Basketball	Jump-landing	5	8	17	Valgus	Injured
8	Basketball	Jump-landing	24	28	31	Valgus	Injured
9	NFL	Deceleration	51	41	37	Valgus	Injured
10	NFL	Change of direction	34	37	39	Valgus	Injured
11	NFL	Change of direction	51	53	51	Valgus	Injured
12	NFL	Deceleration	33	30	49	Valgus	Injured
13	NFL	Change of direction	57	55	48	Valgus	Injured
14	NFL	Change of direction	45	42	48	Valgus	Injured
15	Soccer	Jump-landing	0	0	0	Hyperextension	Injured
16	Soccer	Jump-landing	29	27	25	Hyperextension	Injured
17	Soccer	Jump-landing	-11	-2	0	Valgus	Injured
18	Soccer	Change of direction	50	38	34	Valgus	Injured
19	Basketball	Deceleration	52	48	46	Valgus	Injured
20	Basketball	Change of direction	50	49	35	N/A	Control
21	Basketball	Change of direction	49	48	48	N/A	Control
22	Basketball	Deceleration	42	49	32	N/A	Control
23	Basketball	Deceleration	45	43	54	N/A	Control
24	Basketball	Deceleration	34	40	33	N/A	Control
25	Basketball	Deceleration	54	46	43	N/A	Control
26	Basketball	Jump-landing	2	17	27	N/A	Control
27	Basketball	Jump-landing	13	20	29	N/A	Control
28	NFL†	Deceleration	54	53	53	N/A	Control
29	NFL†	Change of direction	35	34	27	N/A	Control
30	NFL†	Change of direction	39	33	28	N/A	Control
31	NFL†	Change of direction	24	11	0	N/A	Control
32	NFL†	Change of direction	23	18	1	N/A	Control
33	Soccer	Jump-landing	28	41	37	N/A	Control
34	Soccer	Jump-landing	25	23	18	N/A	Control
35	Soccer	Jump-landing	22	21	34	N/A	Control
36	Basketball	Deceleration	53	67	65	N/A	Control
37	Soccer	Change of direction	37	33	27	N/A	Control

Table 1 present the raw data of sports-related injuries, which includes information such as case number, sport, type of maneuvers, initial contact, mid-contact, end-contact, displacement, and injury group. The dataset comprises of injuries sustained during basketball, NFL, and soccer, encompassing a range of maneuvers and injury categories. The dataset incorporates injuries sustained by the control group.
†NFL: National Football League (USA)

sequences and sourced from YouTube to be included. Inclusion criteria for the injured group required that the knee injury could not be caused by direct or indirect contact. The control group had to be similar to the injured group and have no prior ACL injury for analysis. Athletes' medical reports were not obtained; only media reports were available. Excluded from the study were videos with obstructed views of the legs or lacking a sagittal view.

The study was conducted online. Data were collected from October to December 2020. The analysts categorized movements into three categories: change of direction, landing, and deceleration. To ensure consistency, one researcher analyzed hip flexion in all videos. Kinovea software was used to segment videos into three sequences and measure hip joint angles[18]. Videos were downloaded in mp4 format from www.youtube.com using www.y2mate.com. Videos were analyzed with Kinovea after upload.

Analysis of movements for both groups began at initial contact (IC) of the foot with the ground, measuring the hip angle. The end contact (EC) was assessed differently in the experimental and control groups. EC for the injured group was determined by the moment of injury. The control group's endpoint was reaching maximum knee flexion, lifting the foot,

Figure 1. **Hip joint measurement method for case 9. a) IC, b) MC, and c) EC.**

or supporting the analyzed leg with the other leg. The mid-contact (MC) sequence was determined by analyzing the frame closest to the halfway point between IC and EC times. Hip flexion was measured by drawing a line downward from the posterior inferior iliac spine (Figure 1). Visual cues estimated hip flexion angles when leg view was blocked or from the opposite direction. Range of motion (ROM) was calculated and compared between groups.

Data were saved and graphs were created using Microsoft Excel 2016. Hip flexion is positive, while hip hyperextension is negative. For statistical analysis we used Megastat software. Mean, standard deviation, and standard error were calculated for statistical analysis. Means and standard errors were used in the graphs. Descriptive statistics were obtained for each sequence in every manoeuvre. Simple T test was used to compare sequences between injured and control groups during the same manoeuvres. Statistical significance was set at 0.05.

Results

Change of Direction

Change of direction manoeuvres were shown in 14 out of 37 cases, with seven in each group. During IC, the injured group had a mean hip flexion angle of 47.86° compared to 36.71° for the control group, with standard deviations of 7.10° and 10.69°, respectively. During MC, the injured group had a mean hip flexion angle of 45.57° compared to the control group's 32.29°. Standard deviations were 7.18° and 14.07° for the injured and control groups, respectively. During EC, the injured group had a mean hip flexion angle of 41.86° compared to the control group's 23.71°, with standard deviations of 6.91° and 17.49°, respectively. Statistically significant differences in hip flexion were found in all sequences ($p < 0.05$, $p < 0.05$, and $p < 0.05$, respectively); see Figure 2 and Table 2 for more information. Furthermore, hip ROM in the injured group had significantly lower average ROM of 6° (SD = 0.19°) compared to the control group's average ROM of 13° (SD = 6.8°) ($p < 0.05$).

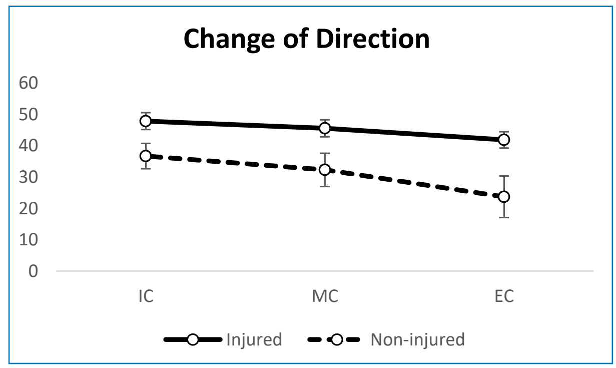

Figure 2. **Mean hip flexion and change of direction error were measured for both groups. The three sequences are labeled IC (initial contact), MC (mid contact), and EC (end contact) contact.**

Jump-landing

Ten out of 37 cases were jump-landings. Both the injured and control groups had five cases. Injured group: mean hip flexion of 9.4° (SD = 16.7°) during IC; control group: mean of 18° (SD = 10.5°). Injured group: mean hip flexion of 12.2° (SD = 14.4°) during MC. Control group: mean of 24.4° (SD = 9.5°). Injured group: mean hip flexion of 14.6° (SD = 14.2°) during EC. Control group: mean of 29° (SD = 7.3°). No significant difference was found between IC and MC during hip flexion ($p > 0.05$ and $p > 0.05$, respectively). EC was insignificant ($p > 0.05$) (Figure 3). The hip ROM injured group had significantly lower mean ROM (5.2°, SD = 2.5°) compared to the control group (11°, SD = 3.2°) with a p value of < 0.05.

Deceleration

Out of 37 cases, 13 were deceleration cases, with seven injuries and six controls. During IC, the injured group had a mean hip flexion angle of 46.2° (SD=7.7°) compared to the control group's mean of 47° (SD =

Table 2. Results of Sequences in Injured and control Groups, Presented as Mean and Standard Deviation (SD). Group Comparison Shown as p-values. Statistical test used: Simple T test

		Injured		Control		*P*-value
Maneuver	Sequence	Mean	SD†	Mean	SD†	
Change of direction	IC†	47.8	7.1	36.7	10.6	* P < 0·05
	MD†	45.5	7.1	32.2	14.0	* P < 0·05
	EC†	41.8	6.9	23.7	17.4	* P < 0·05
Landing	IC†	9.4	16.7	18.0	10.5	** P > 0·05
	MD†	12.2	14.4	24.4	9.5	** P > 0·05
	EC†	14.6	14.2	29.0	7.3	** P > 0·05
Change of speed	IC†	46.2	7.7	47.0	8.1	** P > 0·05
	MD†	43.2	8.7	49.6	9.6	** P > 0·05
	EC†	46.0	10.0	46.6	13.0	** P > 0·05

** Indicating significance (P < 0·05)*
*** Indicating insignificance (P > 0·05)*
†SD: Standard deviation, IC: Initial-contact Maneuver; MC: Mid-contact Maneuver; EC: End-contact Maneuver.

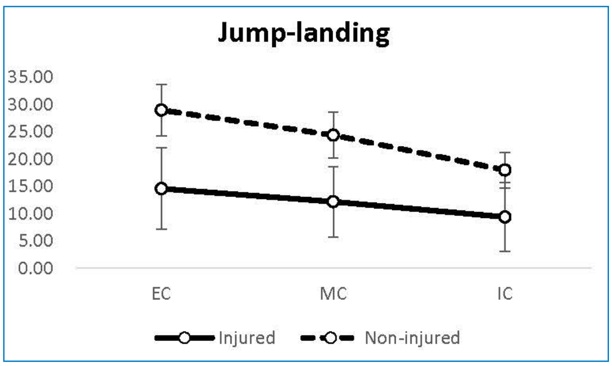

Figure 3. Mean hip flexion and Jump-landing error were measured for both groups. The three sequences are labeled IC (initial contact), MC (mid contact), and EC (end contact) contact.

8.1°). During MC analysis, the injured group had a mean hip flexion angle of 44.2° (SD = 7.9°) compared to the control group's mean of 49.6° (SD = 9.6°). In the EC, the injured group had a mean hip flexion angle of 46.4° (SD = 9.4°) compared to the control group's mean of 46.6° (SD = 13°). No statistical significance was found in any of the sequences (p > 0.05, p > 0.05, and p > 0.05). The injured group had an average hip flexion ROM of 0.14° (SD = 1.7°), while the control group had an average of 0.3° (SD = 4.8°), but the difference was not significant (p > 0.05).

Discussion

Change of Direction

We collected 14 cases with the change of direction manoeuvre: seven injured and seven control cases. The injured group had a higher mean degree of hip flexion (IC: 47.8°, MC: 45.5°, and EC: 41.8°) compared to the control group (IC: 36.7°, MC: 32.2°, and EC: 23.7°) in all three sequences (Table 2). In addition, the difference between the two groups was statistically significant in all sequences (p < 0.05, p < 0.05, and p < 0.05, respectively). These results suggest that performing a manoeuvre with higher hip flexion coupled with low knee flexion is a factor in causing ACL injury. In contrast to Walden et al.'s results, wherein they conducted a video analysis study on 36 rugby players, it was found that athletes with non-contact ACL injury had less than 40° of hip flexion during the IC, which led to valgus displacement of the knee[19]. However, Montgomery et al., in a similar study to analyze videos of rugby athletes, did not find any significant difference between the injured and control groups, with a median of 30° for the injured group compared to 30° for the control group during change of direction[20]. The injured group exhibited a statistically significant reduction in hip ROM, with an average decrease of 6° (SD = 0.19°), in comparison to the control group's ROM of 13° (SD = .8°) (p < 0.05). Similar findings were described by Koga et al., who found that the injured group had stiffer hip joint ROM than the control group; however, they described no statistical difference between the injured and control groups that had an average hip flexion of degrees throughout the manoeuvre[15].

The proposed non-contact mechanism of ACL injury is that, during the change of direction, there is a penultimate phase (deceleration), full foot contact phase (plant step to change direction), and reacceleration phase (acceleration in the new direction)[21]. The focus was on the full foot contact phase because most injuries in our data occurred during this phase. Let us assume that a player is attempting to perform a change of direction. The player is at the full foot contact phase, and the knee joint is at full or near full extension. According to our data, the injured

Figure 4. **Valgus displacement of two cases in change of direction. a) case 11 b) case 1.**

group had an IC of 47.8° of hip flexion, while the control group had 36.7°. When IC occurs in the aforementioned position, the lower extremity is positioned away from the body due to high hip flexion, making the lower extremity unstable. Combined with the full placement of the foot and the attempt to change direction, valgus displacement occurs (Figure 4). Low knee flexion causes an anterior shear force, which by itself causes a significant strain to the ACL; combined with valgus displacement, greater strain is applied to the ACL[10]. In addition, as has been suggested by Hashemi al.[22], "harmonious co-flexion" of the hip and knee joints results in less loading on the ACL. However, high hip flexion may disturb the "harmonious co-flexion" of both joints, leading to stiffer landings, as has been shown by our results in which the injured group had significantly stiffer ROM than the control group ($p < 0.05$). Because the hip is relatively flexed in IC, its capacity to act as a part of the protective mechanism with the knee to lower the load applied to the ACL is prevented. This makes the lower extremity muscles less able to absorb ground reaction force in the injured group than in the control group.

Jump-landing

Ten cases were jump-landings, with five cases each in both the injured and control groups. The injured group had a mean hip flexion of 9.4° (SD = 16.7°) during IC, compared to the control group's mean of 18° (SD = 10.5°). During MC, the injured group had a mean hip flexion of 12.2° (SD = 14.4°) compared to the control group's mean of 24.4° (SD = 9.5°). During end-stance (EC), the injured group had less hip flexion (mean = 14.6°, SD = 14.2°) than the control group (mean = 29°, SD = 7.3°). No significant difference was found among IC, MC, and EC during hip flexion ($p > 0.05$ for all) (Figure 3). The injured group had significantly lower hip ROM (mean = 5.2°, SD = 2.5°) compared to the control group (mean = 11°, SD = 3.2°) ($p < 0.05$). Our data suggest that hip flexion degree and position during jump-landing are not significant risk factors for ACL injury. This is consistent with Leppanen et al.'s study, in which they found no significant difference in hip flexion between injured and control groups during jump-landing; however, they did find that a stiffer landing was a significant difference between the two groups[16]. Boden et al. found that the injured group had significantly higher hip flexion (52.4°) than the control group (33.4°), contradicting our findings[14]. Also, Walden et al. found that ACL injuries in soccer athletes were associated with low hip flexion, with a median hip flexion of 10° or less in IC; however, Walden et al. did not have a control group to compare with[19]. Both groups started the landing with almost fully extended hips, but the control group showed greater ROM than the injured group by the end of the landing. Our data showed no significant difference in hip flexion, but a significant difference in ROM ($p < 0.05$) was observed. Therefore, the degree of hip flexion may not be a risk factor for ACL injury. Instead, the rate of hip flexion increases the risk of ACL injury. Faster hip flexion during landing reduces ACL load in athletes.

Change of Speed

We identified 13 cases as deceleration cases, consisting of seven injuries and six controls. The injured group exhibited a mean hip flexion angle of 46.2° (SD = 7.7°) during IC, whereas the control group had a mean of 47° (SD = 8.1°). During MC analysis, the injured group had a mean hip flexion angle of 44.2° (SD = 7.9°), whereas the control group had a mean of 49.6° (SD = 9.6°). In the EC, the injured group had a mean hip flexion angle of 46.4° (SD = 9.4°), whereas the control group had a mean of 46.6° (SD = 13°). However, no statistical significance was observed in any of the sequences ($p > 0.05$, $p > 0.05$, and $p > 0.05$). The injured group had an average hip flexion ROM of 0.14° (SD = 1.7°), whereas the control group had an average of 0.3° (SD = 4.8°), but the difference was, also, not statistically significant ($p > 0.05$). Further research on this matter is recommended.

Limitation

Our data are limited by the fact that the videos of ACL injuries were obtained from YouTube, which did not include any follow-up or treatment information for the players. Low-quality YouTube videos limited video clarity or reference points to determine extremity position.

Conclusion

The injured group exhibited a higher degree of hip flexion angle during the change of direction manoeuvre in comparison to the control group, along with a reduced ROM. Although no significant differences were observed in hip angle during jump-landing, the injured individuals displayed a decreased ROM. No significant differences were noted in hip flexion angle and ROM between the groups during deceleration maneuvers. Further studies to be conducted in a prospective manner with close follow-ups are recommended.

Conflict of Interest

The authors declared that there is no conflict of interest that is related to this study and this article.

Disclosure

The authors did not receive any form of commercial support, including compensation or financial assistance, for this case report. Additionally, the authors have no financial interest in any of the products, devices, or drugs mentioned in this article.

References

[1] Loch DA, Luo ZP, Lewis JL, Stewart NJ. A theoretical model of the knee and ACL: theory and experimental verification. J Biomech 1992; 25(1): 81-90.

[2] Yu B, Garrett WE. Mechanisms of non-contact ACL injuries. Br J Sports Med. 2007; 41 Suppl 1(Suppl 1): i47-i51.

[3] Almaawi A, Awwad W, Bamugaddam A, Alasheikh M, Muaddi M, Almutair O, Alomar AZ. Prevalence of knee injuries among male college students in Riyadh, Kingdom of Saudi Arabia. J Orthop Surg Res 2020; 15(1): 126.

[4] Alrubayyi M, Alzahrani S, Alotaibi A, Albalawi A, Asiri M, Alzahrani S, Alotaibi A, Alenezi S. A survey of injuries to the anterior cruciate ligament among Makkah population, Saudi Arabia: prevalence and observations on injury mechanism. Int J Adv Res 2018; 6(5): 814–819.

[5] Dafalla SE, Bokhari YA, Yazbik RS, Ali AS, Sheikh KH, Alnaggar RA. Prevalence of anterior cruciate ligament injury and other ligament injuries among the Saudi community in Jeddah City, Saudi Arabia. Int J Radiol Imaging Technol 2020; 6(1): 062.

[6] Mall NA, Chalmers PN, Moric M, Tanaka MJ, Cole BJ, Bach BR Jr, Paletta GA Jr. Incidence and trends of anterior cruciate ligament reconstruction in the United States. Am J Sports Med 2014; 42(10): 2363-2370.

[7] Zbrojkiewicz D, Vertullo C, Grayson JE. Increasing rates of anterior cruciate ligament reconstruction in young Australians, 2000-2015. Med J Aust 2018; 208(8): 354-358.

[8] Aurich M, Bedi HS, Smith PJ, Rolauffs B, Mückley T, Clayton J, Blackney M. Arthroscopic treatment of osteochondral lesions of the ankle with matrix-associated chondrocyte implantation: early clinical and magnetic resonance imaging results. Am J Sports Med 2011; 39(2): 311-319.

[9] Arms SW, Pope MH, Johnson RJ, Fischer RA, Arvidsson I, Eriksson E. The biomechanics of anterior cruciate ligament rehabilitation and reconstruction. Am J Sports Med 1984; 12(1): 8-18.

[10] Berns GS, Hull ML, Patterson HA. Strain in the anteromedial bundle of the anterior cruciate ligament under combination loading. J Orthop Res 1992; 10(2): 167-176.

[11] Draganich LF, and Vahey JW. An in vitro study of anterior cruciate ligament strain induced by quadriceps and hamstrings forces. J Orthop Res 1990; 8(1): 57-63.

[12] Markolf KL, Burchfield DM, Shapiro MM, Shepard MF, Finerman GA, Slauterbeck JL. Combined knee loading states that generate high anterior cruciate ligament forces. J Orthop Res 1995; 13(6): 930-935.

[13] Della Villa F, Buckthorpe M, Grassi A, Nabiuzzi A, Tosarelli F, Zaffagnini S, et al. Systematic video analysis of ACL injuries in professional male football (soccer): injury mechanisms, situational patterns and biomechanics study on 134 consecutive cases. Br J Sports Med [Internet]. 2020; 54(23): 1423–32. Available from: http://dx.doi.org/10.1136/bjsports-2019-101247

[14] Boden BP, Torg JS, Knowles SB, Hewett TE. Video analysis of anterior cruciate ligament injury: Abnormalities in hip and ankle kinematics. Am J Sports Med. 2009;37:252–9.

[15] Koga H, Nakamae A, Shima Y, Bahr R, Krosshaug T. Hip and Ankle Kinematics in Noncontact Anterior Cruciate Ligament Injury Situations: Video Analysis Using Model-Based Image Matching. Am J Sports Med. 2018; 46: 333–40.

[16] Leppänen M, Pasanen K, Krosshaug T, Kannus P, Vasankari T, Kujala UM, et al. Sagittal Plane Hip, Knee, and Ankle

Biomechanics and the Risk of Anterior Cruciate Ligament Injury: A Prospective Study. Orthop J Sports Med. 2017;

[17] Hewett TE, Myer GD, Ford KR, Heidt RS, Colosimo AJ, Mclean SG, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: A prospective study. Am J Sports Med. 2005; 33: 492–501.

[18] Charmant J. [Internet]. Kinovea. [cited 2021 Jul 12]. Available from: https://www.kinovea.org/

[19] Waldén M, Krosshaug T, Bjørneboe J, Andersen TE, Faul O, Hägglund M. Three distinct mechanisms predominate in non-contact anterior cruciate ligament injuries in male professional football players: a systematic video analysis of 39 cases. Br J Sports Med [Internet]. 2015; 49(22): 1452–60. Available from: http://dx.doi.org/10.1136/bjsports-2014-094573

[20] Montgomery C, Blackburn J, Withers D, Tierney G, Moran C, Simms C. Mechanisms of ACL injury in professional rugby union: a systematic video analysis of 36 cases. Br J Sports Med [Internet]. 2018; 52(15): 994–1001. Available from: http://dx.doi.org/10.1136/bjsports-2016-096425

[21] Clarke R, Mundy P, Aspe RR, Sargent D, Hughes J, Mundy P. Technical models for change of direction: biomechanical principles. Change of Direction Technical Models. Professional Strengths and Conditioning. www.ukcsa.org.uk. 2018: 17-13 [cited 2021 Feb 18]. Available from: https://www.researchgate.net/publication/328561167_Change_of_Direction_Technical_Models_Biomechanical_Principles

[22] Hashemi J, Breighner R, Chandrashekar N, Hardy DM, Chaudhari AM, Shultz SJ, Slauterbeck JR, Beynnon BD. Hip extension, knee flexion paradox: a new mechanism for non-contact ACL injury. J Biomech 2011; 44(4): 577-585.