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MECHANISMS OF ANTERIOR CRUCIATE LIGAMENT INJURY

MEHANIZAM POVREDE PREDNJEG UKRŠTENOG LIGAMENTA

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Summary

Introduction. The goal of this study is to analyze the mechanisms of injury of patients diagnosed with anterior cruciate ligament injury and their correlation with risk factors in our clinical material. **Material and Methods.** The study included 1,471 patients, 1192 male and 279 female, with a diagnosed anterior cruciate ligament injury, that were surgically treated in the period between the end of January 2012 and the middle of June 2018. **Results.** Of the total number of women, around 51% sustained the injury when changing direction, 35% during landing, and 12% during a collision. Among men, 46% sustained injuries during a change of direction, 30% during landing, while the percentage of injuries sustained during a collision was higher than among women, amounting to 23%. The impact of gender on the type of injury mechanism and on the injury mechanism is statistically significant. The incidence of left knee injuries is higher in non-contact injuries, while right knee injuries are more common in contact injuries. The level of sports activity showed no statistically significant impact on the type of the mechanism of injury, but its impact on the category of mechanism of injury proved to be statistically significant. The impact of sport on the type of the mechanism of injury, as well as on the mechanism of injury categories was statistically significant. Non-contact injuries commonly occurred during the warm-up, beginning and end of a training session, while collisions mostly occurred halfway through the activity. Contact injuries were most often sustained on grass and training mats, while non-contact injuries occurred more often on other surfaces. **Conclusion.** Most participants sustained injury through non-contact mechanisms and the most frequent non-contact mechanism is change of direction.

Key words: anterior cruciate ligament, injury mechanism of anterior cruciate ligament, sex characteristics, sport

Sažetak

Uvod. Cilj istraživanja je analiza mehanizma povrede pacijenta sa dijagnostikovanom povredom prednjeg ukrštenog ligamenta kolena i njihova povezanost sa faktorima rizika na našem kliničkom materijalu. **Materijal i metode.** Ispitivanje je obuhvatilo 1.471 pacijenta, 1.192 muškarada i 279 žena sa dijagnostikovanom povredom prednjeg ukrštenog ligamenta kolena, koji su operativno lečeni u periodu od kraja januara 2012. godine do sredine juna 2018. godine. **Rezultati.** Od ukupnog broja žena, oko 51% povredilo se prilikom izmene pravca, 35% prilikom doskoka, a 12% prilikom sudara. Kod muškaraca povrede su nastale prilikom izmene pravca (46%) i doskoka (30%), dok je udeo povreda nastalih prilikom sudara veći nego kod žena i iznosi 23%. Uticaj pola na vrstu mehanizma povrede i na mehanizam povrede je statistički značajan. Udeo povreda levog kolena veći je kod nekontaktnih, dok su povrede desnog kolena češće kod kontaktnih povreda. Uticaj nivoa sportske aktivnosti na vrstu mehanizma povrede nije se pokazao statistički značajnim, dok se njegov uticaj na kategorije mehanizma povrede pokazao kao statistički značajan. Uticaj sporta na vrstu mehanizma povrede, kao i na pojedinačne kategorije mehanizma povrede, pokazao se statistički značajnim. Do nekontaktnih povreda je dolazilo na zagrevanju, početku i kraju treninga, dok je do sudara najčešće dolazilo sredinom treninga. Do kontaktnih povreda najčešće je dolazilo na travi i strunjači, dok su nekontaktne češće nastajale na ostalim podlogama. **Zaključak.** Najveći broj ispitanika povredio se nekontaktnim mehanizmom, a najučestaliji nekontaktni mehanizam je izmena pravca.

Ključne reči: prednji ukršteni ligament, mehanizam povrede prednjeg ukrštenog ligament, polne karakteristike, sport.

Introduction

Anterior cruciate ligament (ACL) is the central stabilizing ligament of the knee that has a key role in physical activity [1, 2]. It prevents anterior tibial translation relative to the femur, thus facilitating normal function of the knee, and it also contributes to transverse and rotational stability of the joint [3, 4]. Damage to the ACL is the most common injury of the knee joint sustained as a result of sports activities [5, 6]. It represents a complex trauma resulting in mechanical and functional instability, usually combined with limited range of motion, muscular weakness and irregular movement patterns, all of which resulting in rare return to pre-injury levels of activity [7].

The ACL injuries are sustained as a result of contact or non-contact mechanisms. About 70% of ACL injuries are sustained through non-contact and 30% via a contact mechanism [8]. Olsen et al. defined non-contact ACL injuries as injuries which occurred without a contact with other players, and divided contact injuries into direct and indirect. Direct injuries are

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Abbreviations
ACL – anterior cruciate ligament
BMI – body mass index

caused by an impact on a lower extremity (thigh, knee or shin), while indirect injury is caused through contact on another body part that indirectly causes damage to ACL (for example posture, players pushing, and so on) [9]. In indirect injuries, damage to ACL happens when internal loads exceed the elastic properties of the ligament, while in contact injuries the knee is subjected to external loads applied by another person or object [10]. The causes of non-contact ACL injuries include rapid change of direction combined with deceleration, landing with the knee in or near the state of full extension, and turning with the knee in extension and the foot firmly planted [11]. Usually, ACL injury is the consequence of increased valgus load on the knee combined with outward rotation of the tibia, or hyperextension combined with inward rotation of the tibia [12, 13].

While the problem of ACL injury itself is well documented, mechanisms and risk factors causing it are still not fully understood, and their identification will play a key role in developing effective means of prevention [14, 15]. The goal of this study is to analyze the mechanisms of injury in patients diagnosed with ACL injury of the knee and their correlation with risk factors in our clinical material.

Material and Methods

A retrospective study was carried out at the Clinic of Orthopedic Surgery and Traumatology in Novi Sad, with the approval of the Ethics Committee of the Clinical Center of Vojvodina. It included 1,471 patients diagnosed with ACL injury who underwent surgical treatment between the end of January of 2012 and the middle of June 2018. Data were collected from patients' medical records and the following parameters were included in the analysis: age and sex distribution, body weight, body height, body side of the injury, activity during which the injury was sustained, level of sports activity, type of sport, location of injury, mechanism of injury, time of injury, and type of surface **(Table 1)**.

The collected data were statistically processed using the Microsoft Office 2016 (Word, Access and Excel) and IBM SPSS v. 23. The measure of central tendency of numerical indicators is shown as arithmetic mean, dispersion is shown as standard deviation, minimum and maximum. Attributive indicators are shown in absolute and relative frequency. Proportional differences were examined using the Fisher's exact and χ^2 tests, significance level set at 5%. Results are shown in tables and graphs.

Results

Of the total number of women, around 51% sustained the injury when changing direction, 35% during landing, and 12% during collision. In men, there were somewhat fewer injuries sustained when changing direction (46%) and landing (30%), while the percentage of injuries sustained during collision exceeds that found in women, amounting to 23% **(Table 2)**.

Based on the Fisher's test ($p = 0.000 < 0.05$) it can be concluded that gender has a statistically significant impact on the type of injury mechanism. The proportion of non-contact injuries is much higher in women, while the proportion of contact injuries is much higher in men.

According to age, the participants were divided into three groups of approximately similar size **(Table 2)**. The impact of age on injury mechanisms was examined using the χ^2 test and showed no statistical significance.

With regards to body mass index (BMI), since there was a total of 25 malnourished, obese or grossly obese patients across all three groups, these three weight groups were excluded from analysis. The BMI showed no impact on the type of injury mechanism.

Table 1. Demographic data
Tabela 1. *Demografski podaci*

Gender/*Pol*	Age (years)/*Uzrast (godine)*	Weight/*Težina*	Height/*Visina*	BMI/*BMI*
Male/*Muški* 1192 (81%)	13 - 21 (39.20%)	Min. 47 kg	Min. 147	Min. 17.31
Female/*Ženski* 279 (19%)	22 - 27 (27.80%)	Max. 190 kg	Max. 212	Max. 68.03
∑ 1471	Over 27/*Stariji od 27* (33%)	80.96 ± 14.61	180.75 ± 8.54	24.68 ± 3.75

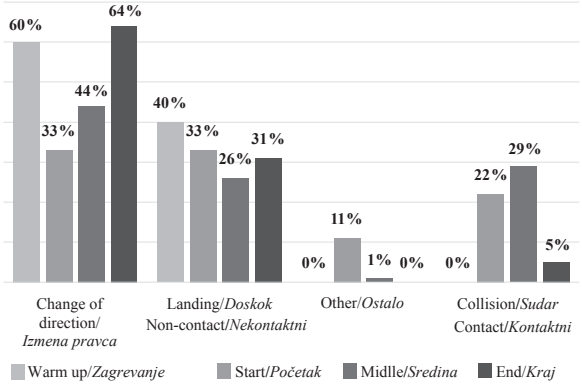
Legend: BMI - body mass index
Legenda: BMI - indeks telesne mase

Table 2. The impact of gender and age on injury mechanisms
Tabela 2. *Uticaj pola i starosti na mehanizam povrede*

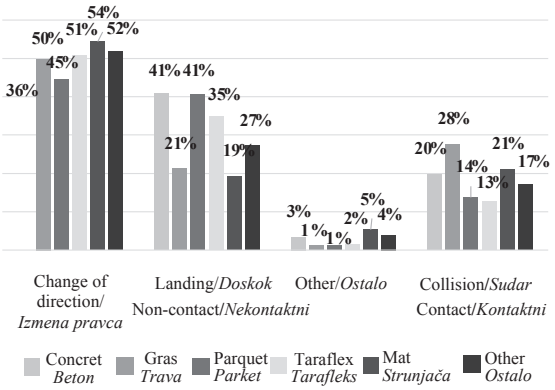
Injury mechanism *Mehanizam povrede*	Male *Muškarci*	Female *Žene*	Age/*Uzrast* < 21	Age/*Uzrast* 21 - 27	Age/*Uzrast* > 27
Change of direction/*Izmena pravca*	46.2%	50.7%	43.5%	49.4%	49.3%
Landing/*Doskok*	29.2%	34.8%	33.5%	28.5%	28.5%
Other/*Ostalo*	1.7%	3%	2.7%	0.5%	2.8%
Collision/*Sudar*	22.6%	11.5%	20.4%	21.6%	19.5%

Table 3. The impact of side and level of sports activity on the injury mechanisms
Tabela 3. *Uticaj strane i nivoa sportske aktivnosti na mehanizam povrede*

Injury mechanism *Mehanizam povrede*	Left knee *Levo koleno*	Right knee *Desno koleno*	Non-athlete *Nesportista*	Recreationalist *Rekreativac*	Professional athlete *Profesionalni sportista*
Change of direction/*Izmena pravca*	48.5%	45.1%	33%	51%	43%
Landing/*Doskok*	33.1%	28.7%	42%	29%	32%
Other/*Ostalo*	1.8%	2.4%	6%	2%	2%
Collision/*Sudar*	16.6%	23.8%	19%	19%	22%



Graph 1. The impact of the stage of a training session on the injury mechanisms
Grafikon 1. *Uticaj dela treninga na mehanizam povrede*



Graph 2. The impact of surface on the injury mechanisms
Grafikon 2. *Uticaj vrste podloge na mehanizam povrede*

The analysis of the body side of the injury showed higher incidence of injury in the right knee during collision (Fisher's test p = 0.000.). The impact of the body side of the injury was examined using the χ^2 test and showed a statistically significant difference χ^2 **(Table 3)**.

Change of direction is the most common injury mechanism in skiers (65%), hokey players (55%), football players (51%), martial artists (48%), basketball players (45%), and handball players (43%). Landing is the most common mechanism of injury in volleyball players (72%), but also among handball players (43%), basketball players (38%) and football players (22%). Collision is the most frequent mechanism of injury in rugby players (46%).

Injuries during warm-up were caused by a change of direction in 60% of cases, and in 40% during landing **(Graph 1)**. At the beginning of a training session, 33% of injuries were sustained during a change of direction, 33% during landing, and 22% during a collision. Halfway through a training session, 44% of injuries were sustained during a change of direction, 26% during landing, and 29% during a collision. Towards the end of a training session, 64% of injuries happened during a change of direction, 31% during landing, and only 5% during a collision. The impact of the stage of a training session on the type of injury mechanism was shown to be statistically significant.

During warm-up, 58% of injuries were sustained during landing and 42% during a change of direction. At the beginning of the game, change of direction was the cause of injury in 42% of cases, landing in 32%, and a collision in 24%. Halfway through the game, change of direction was the cause of injury in 43% of cases, landing in 29%, and a collision in 27%. At the end of the game, change of direction was the cause of injury in 46% of cases, landing in 30%, and a collision in 21%. The impact of the stage of the game was not shown to be statistically significant.

Contact injuries were more frequently sustained on grass and training mats, while non-contact injuries were more frequent on other surfaces. The impact of surface on the category of injury mechanism was also shown to be statistically significant **(Graph 2)**.

Discussion

Potential risk factors leading to ACL injury are divided into intrinsic and extrinsic. Extrinsic factors include level of competition, level of personal skills, type of footwear, friction coefficient of the floor, and preventative use of orthoses, while intrinsic factors include sex, age, BMI, previous injuries, muscle strength, balance issues, and postural stability [13].

Almost 70% of ACL injuries occur during sports activities; the highest injury rates in Serbia are in football, basketball and handball [13]. Of the 1,471 patients included in our study, most sustained injury playing football (48.2%), basketball (15.4%) and handball (10%). The fact that a large number of injuries happened while participating in these sports indicates their popularity in our country. This is further confirmed by the fact that in Vojvodina, 37 - 50% of patients sustained injuries playing football [16]. In Scandinavian countries the most popular and the most risky sports are handball and skiing, and in the United States of America these are rugby and basketball [14]. Authors from Japan consider basketball and gymnastics the highest risk sports with regards to sustaining ACL injuries [16].

The ACL injuries happen as a result of contact or non-contact mechanisms. The percentage of left knee injuries is higher in non-contact, while right knee injuries are more common in contact sports. Non-contact injury is mostly the result of abrupt deceleration and change of direction, while the foot is firmly planted. Torsion in the knee joint resulting from sudden change of direction is considered to be the cause of ACL tearing [17]. Within the frame of our study, the injury mechanisms include change of direction, landing and collision, and by type (for the purpose of easier comparison) non-contact (change of direction, landing) and contact (collision). In our clinical material, 80% of patients suffered non-contact and 20% contact injuries.

The same or similar results were found in two other studies, one including 120 patients [18], and in the other non-contact injuries accounted for 78% and contact injuries for 22% [13]. In a study conducted by Krosshaug et al., 72% of injuries were non-contact injuries and similar results were obtained by Hurd et al. In their study, non-contact injuries were sustained in 71.3% of cases, and contact in 26.4% [10, 19]. In a study by Salem et al., 518 injuries were sustained through non-contact and 169 through contact injury mechanisms [20]. This is in agreement with the results of our study. Of the injuries sustained through non-contact mechanisms, the most common were during a sudden change of direction (47%) and landing (30.5%), while other non-contact mechanisms accounted only for 2.1% of cases. Đuričin also reported the change of direction as the most frequent mechanism of injury in 43.3%, while the results obtained by Ristić et al. showed that the greatest number of injuries occurred during landing [13, 18]. This may be caused by presenting more handball (22%) and volleyball players (7%) compared to our sample (10%:3.7%) since volleyball and handball have a high frequency of injury during landing after a jump.

The kind of sport was proven to have a statistically significant impact on ACL injuries. Change of direction is the most frequent injury mechanism in skiers (65%), hokey players (55%) and football players (51%), landing in volleyball players (72%), handball players (43%) and basketball players (38%), and collision in rugby players (46%). Professional athletes more frequently sustained injuries during collision.

In a study performed by Ristić et al., non-contact mechanisms were the leading cause of injury in volleyball, basketball and handball players, gymnasts and skiers, while contact mechanisms were more prevalent in football players and martial artists [13]. As far as non-contact injuries are concerned our results match, but in our sample rugby players had the highest incidence of contact injuries followed by football players (25%). This is in accordance with the study of Montgomery et al., describing injury mechanisms in professional rugby players, who found that contact injuries accounted for 57% of cases and non-contact for 43%. Rugby is a contact sport, which explains higher incidence of these injuries compared to basketball or football [21].

Devetag et al. reported that the greatest number of injuries in female volleyball players were sustained through non-contact mechanisms, and that the leading injury mechanism was landing, which is a part of blocking and smashing in volleyball [22]. Landing was also the most frequent mechanism of injury in basketball players reported by Krosshaug et al., and two most frequent situations in volleyball during which ACL injuries occur are the cut shot maneuver and landing on one foot after a stroke [19]. The difference in rates of non-contact and contact injuries comes from the fairly limited number of patients playing contact sports in our sample.

Increased popularity of sports and elevated risk of knee injuries, particularly in women, has lead to a remarkable increase in ACL injuries in sports [11]. This is further corroborated by the fact that, in Novi Sad, ACL reconstructions accounted for 19% of surgeries in 2005 And for 29% in 2008. Due to the prevalence of men in sports activities, ACL injuries are more frequent in men, but female athletes are between two to ten times more likely to sustain ACL injury, depending on the sport [16, 23]. In their study, Arendt and Dick found that the rate of ACL injury in football is 2.4 times higher in women, and 4.1 times higher in basketball [24]. The causes of ACL epidemic in women are due to anatomical differences between the sexes, such as the size of the Q angle, higher valgus of the knee, narrow intercondylar notch of the femur, wider pelvis, the influence of estrogen on ligaments during the menstrual cycle, ligament laxity and different timings between contractions of the quadriceps and hamstring muscles [16]. Out of 1,471 patients in our sample, 81% (1.192) were male, and 19% (279) female. Our study showed that sex has a significant impact on the injury mechanism. The percentage of injuries sustained during a change of direction (50.7%) and landing (34.8%) is higher in women, while collision injuries are more common in men (22.6%). In our study, the percentage of non-contact injuries is significantly higher in women, while contact injuries are more frequent in men.

In order to compare our results with literature data, we calculated that the total percentage of non-contact injuries in women in our sample was 85.5%, and 75.7% in men. Kobayashi et al. reported similar results, showing that the percentage of non-contact injuries in women was 70%, which is significantly higher than the percentage of non-contact injuries in men (52%) [6]. Mountcastle et al. found that the percentage of non-contact injuries in men is 67.2% and in women 89.4% [25]. In a study by Takahashi et al., 279 women and 261 men sustained non-contact ACL injuries, while 239 men and 221 women sustained contact injuries; this matches our findings that women more frequently suffer injuries through non-contact and men through contact mechanisms [26]. Since the percentage of women who suffered a contact injury in our sample is small (11.5%), this indicates their lower participation in contact sports.

In 90% of cases, ACL injuries occur between the second and the fourth decade of life, and the younger demographic is at the highest risk of sustaining this injury [13]. The average age of patients in our study was 25.33 ± 7.79 years, ranging from 13 to 57 years. Most patients were 21 years old or less (39.2%), and

67% of them were less than 27 years old, which supports the findings that the younger population which is actively training is at highest risk [26]. Our results confirm the results of Renstrom et al., that the incidence of ACL injury is still high, especially among young athletes between the age of 14 and 19 years [27]. Devetag et al. divided the participants into five age groups, and the most injuries were sustained between the age of 21 and 25 (44%) [22]. In a study by Majewski et al., 43.1% of participants were between the age of 20 and 29 years, 20.9% were between 30 and 39, and 16.9% were between the age of 10 and 19 years [28]. In their study, Walden et al. found that at the time of injury the average age of women (20.6 ± 2.2) was lower than the average age of men (25.2 ± 4.5), and similar results were obtained by Roos et al. who found that the injured women were also younger than men and were at a higher risk of sustaining an injury before the age of 20 [29, 30]. The reason for high percentage of participants older than 27 (33%) in our study is due to the sample itself, since there were 62% recreational and non-athletes, while the remaining 38% were professional athletes. In our study, age did not show a significant impact on the mechanism of injury, but the level of sports activity was proven to be statistically significant. The most frequent case of injury in non-athletes was landing (42%), recreational participants most frequently sustained injuries during change of direction (51%), while the professionals most frequently sustained injuries during collision (22%).

Anthropometric parameters, such as body height, body weight and BMI are considered to be potential risk factors for sustaining non-contact ACL injuries [28, 29, 31]. Elevated BMI can result in higher intensity of forces transferred onto the ligamentous and muscular structures of the knee. A high BMI also implies greater expansion in the knee joint during landing, which increases the risk of ACL tearing [31]. Our results showed that the vast majority of patients (59.9%) had normal BMI, followed by overweight patients (32.9%), while there were only 0.7% of malnourished patients. The average BMI in our pool of participants was 24.68 ± 3.75 kg/m². Faude et al. reported an average BMI of 21.5 kg/m² in injured participants and players who were injured through non-contact mechanisms had significantly higher body weight [32]. Al-Jassir et al. compared contact and non-contact ACL injuries in participants with BMI > 30, who were considered overweight, and participants with BMI < 30. Their results showed that the percentage of both contact and non-contact injuries in overweight patients was 27%, and in patients with normal weight it was 73%; thus, the BMI has no impact on the mechanism of injury [33]. In our study, the BMI showed no statistically significant effect on injury mechanisms either.

In our sample, 47% of patients sustained a left knee and 53% a right knee injury. The impact of the side of the body on injury mechanisms was shown to be statistically significant. Left knee injuries happened most frequently through non-contact and right knee injuries through contact mechanisms. Walden et al. believe that the ACL injury affects both knees to the same degree, as was shown in our results, and that injury of the dominant leg is less frequent [29]. In a study by Devetag et al., 64.7% of participants sustained a left knee and 35.3% a right knee injury. In their opinion, the side of the injury represents useful information for professional trainers, who can use it as basis for improving the skill and strength of their players [22].

Out of 559 professional athletes, 17% sustained injury during training and 47% during a game or a competition. Similar results were obtained by Kobayashi et al., who found that the percentage of injuries sustained during a competition was 49.2%, and the percentage sustained during training was 34.8% [6]. Myklebust et al. reported that 75% of all injuries happened during a game and 25% during training [34]. Although athletes spend far more time training than in a game or a competition, where they practice new techniques and formations and are therefore subjected to elevated risk of injury, the stress an athlete experiences during a game, both physical and mental, results in greater risk of injury than during training [6]. When it comes to the time when the injury was sustained, athletes most often sustained injuries halfway through (45.3%) and at the start of a game (35.6%), while more than half of those injured during training sustained their injury halfway through the activity (55.7%). In their study, Ristić et al. reached the opposite conclusion, claiming that injuries sustained at competitions most frequently happen towards the end due to landing or sudden change of direction with no contact with other participants, on a dry surface, in insufficiently prepared athletes [35]. Apart from the stages of training, games or competitions, we also examined the stage of the season when the ACL injury occurred. In athletes injured during training, the injury was most frequently sustained during the preparation phase (38.3%), with the instance of injuries decreasing as the season continued. Injuries sustained during a game happened throughout the season, with fewest occurring during preparations (17.4%), and most of them at the start of a season (29.9%). Studying the injury mechanisms in football players, Agel et al. found a significantly higher frequency of contact injury during games (61%) compared to contact injuries sustained during training (26%), while the percentage of non-contact injuries sustained during training (47%) greatly exceeded the percentage of non-contact injuries sustained during games (19.9%) [36]. In our case, the stage of games showed no effects on injury mechanisms, but the stage of training sessions was proven to be statistically significant. Non-contact injuries were sustained during the warm-up, beginning and end of training, while collision injuries happened most frequently halfway through the activity. This may be the case because halfway through a training session athletes often split into teams for technical and tactical preparations, which can result in duels or collisions and therefore ACL injuries.

The ACL injuries most often occurred on the following surfaces: grass – 39% of cases, parquet 28%, concrete 12%, and training mats and taraflex in 4% of cases. In our sample, grass was proven to be the most dangerous surface for contact injuries (28%), while injuries due to landing mostly happened on parquet and

concrete (41%). Our results showed that the surface has a significant impact on injury mechanisms, and that contact injuries happened most often on grass and training mats, while non-contact injuries were predominant on other surfaces. Alentorn-Geli et al. confirmed that the properties of the surface, regardless of whether they are subjected to weather conditions or not, affect the rates of ACL injuries [11]. In a study conducted by Hagel et al., rates of injury of the lower extremities on synthetic grass were higher than those on natural grass in both dry and wet conditions [37]. Footwear traction is higher on hard and dry surfaces, or dense grass coverage. Games played on hard surfaces, where footwear traction is high, are probably more dynamic, which can increase the risk of injury [38]. High level of friction between floors and footwear is identified as the main risk factor for non-contact ACL injuries [23]. Myklebust et al. reported that activities where there was a high level of friction between the footwear and the floor caused 55% of ACL injuries [34]. Higher frequency of contact injuries on grass and training mats is the result of contact sports played on such surfaces. Taraflex, parquet and concrete lead to increased friction coefficient when the foot is firmly planted, which makes it easier for non-contact ACL injury to occur.

To reach a complete insight, it is necessary to perform an analysis of combined injuries, and compare their incidence in contact and non-contact mechanisms of ACL injuries. Different sports vary in popularity in different countries, which makes international comparison of study results difficult. There is also the difference in frequency between contact and non-contact injuries due to the limited number of patients who play contact sports in our sample. The results collected and processed in our sample are geographically and ethnically representative; it would therefore be interesting to compare them to data gathered from different ethnic groups. Further work should be done to investigate how much neuromuscular training improves active stabilization of ACL and reduces the incidence of injury. Investigation into risk factors leading to ACL injury and their identification through screening could provide the foundation for an effective strategy for reducing the incidence of ACL injury.

Conclusion

Most of the study participants (80%) sustained injury through non-contact mechanisms, and the most frequent non-contact mechanism is change of direction (47%). Change of direction is the most frequent mechanism of injury in both men and women, while collision injuries are more frequent in men (22.6%). Age and body mass index did not show statistically significant impact on injury mechanisms. The percentage of left knee injuries is higher in non-contact, and right knee injuries are more frequent in contact injuries. Non-athletes most frequently sustained injury during landing (42%), and recreational (51%) and professional athletes (43%) during change of direction. Contact injuries were most frequent in professional athletes (22%). The highest frequency of injury due to change of direction was found in skiers, hokey players, football players, martial artists, basketball and handball players. Landing was the most common cause of injury in volleyball and handball players, and collision in rugby players. During training, injuries were most frequently caused by change of direction, while collision injuries most often happened halfway through the training session (29%). Injuries sustained during warm-ups and at the beginning of the game were most often caused by landing (58%), and during the rest of the game the most frequent injury mechanism was change of direction. In regard to surface, most injuries were caused by change of direction on grass, parquet, taraflex and training mats, while landing injuries happened most frequently on concrete (41%). The percentage of contact injuries was highest on grass (28%) and training mats (21%).

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