Anterior cruciate ligament injuries of the knee: Patterns of association between the mechanism of injury and pathology visualised on magnetic resonance imaging

G L Strauss, MBChB,M.Sports.Med[1,2], **D C Janse van Rensburg,** MBChB, MSc, MMed, MD[2], **C C Grant,** PhD[2], **A Jansen van Rensburg,** MSc[2], **M D Velleman,** M.Med Rad D, FC Rad[1,3], **L Fletcher,** PhD[4]

[1] *Department of Diagnostic Radiology, University of Pretoria, Pretoria, South Africa.*
[2] *Section Sports Medicine, University of Pretoria, Pretoria, South Africa.*
[3] *Life Groenkloof hospital medical centre, Capital radiology and Pretoria MR trust, Pretoria, South Africa.*
[4] *Department of Statistics, Faculty of Natural and Agricultural sciences, University of Pretoria, Pretoria, South Africa.*

***Corresponding author:* G L Strauss** *(orgstrauss@yahoo.com)*

Background: Anterior cruciate ligament (ACL) injuries are common among athletes and the general public. These injuries may lead to significant absence from all activities with associated financial and social burdens for the patient. No definitive association has been described between the mechanism of injury and the pathology to enable the implementation of preventative measures to limit these injuries.

Aim: To determine whether there is an association between the mechanism of injury and the pathology seen on a magnetic resonance imaging (MRI) scan in ACL injuries.

Methods: This was a cross-sectional analytical study. Eighty-seven male patients with an ACL injury and who had an MRI scan of the knee within the last two years participated in this study. Participants were contacted to give their informed consent to participate in this study. The mechanism of injury and the pathology seen on the MRI scan was noted and categorised into different groups of injuries and associated pathologies. Statistical analyses included summaries of the data and a test for the association between the mechanism of injury and the pathology. Since there were multiple pathology responses to each mechanism, a modified version of the chi-square test for independence was used. A five percent level of significance was specified.

Results: MRI scans of ACL injuries indicated that the mechanism of a solid foot plant with rotation of the knee has a greater tendency to be associated with medial meniscal injuries (77%). There was also a 54% possibility for it to be associated with lateral meniscal injuries. A solid foot plant with a valgus stress on the knee showed a higher incidence of associated medial collateral ligament (MCL) injuries (41%) and femoral bone bruising (62%). These two mechanisms of injury are the most common in ACL injuries and contribute to the clinical significance found in this study. The p-value was, however, not statistically significant (p=0.44, chi-square value=20.27, df=45) for any association between the pathology and the mechanism of injury.

Conclusion: Some injury mechanisms causing an ACL injury were more common than others and had more associated pathologies. The most common mechanism of injury noted in this study was a solid foot plant with either rotation of the knee or valgus stress on the knee. Strengthening the tissue structures involved in those movement patterns causing these mechanisms can possibly limit future ACL injuries in athletes and the general public.

Keywords*:* knee injury, mechanism, association, pathology, MRI scan, prevention

S Afr J Sports Med 2018; 30:1-6. DOI: 10.17159/2078-516X/2018/v30i1a5265

The increase in ACL injuries in recent years in athletes as well as in the general population is concerning.[1] Although ACL injuries are common, the mechanism of injury is still not clearly defined. The ACL is one of the most frequently injured of the four knee ligaments. The function of the ACL is critical as a stabiliser of the knee joint during movement as well as preventing dislocation. The ACL also contributes to the stability of other movements of the knee joint, including angulation and rotation.[2] These functions are performed by the attachment of the ACL to the femur at the proximal end and to the tibia at the distal end. The other major ligaments of the knee contributing to movement and stability include the posterior cruciate ligament (PCL) and the medial and lateral collateral ligaments (MCL and LCL) respectively.[2]

Contact and non-contact sports as well as certain leisure activities, where the knee joint needs to move in different planes, such as with a change of direction, can put stress on the knee joint.

Holtzhausen et al. found that ligament sprains were the most common injuries during the 2005 Super 12 rugby competition with the knee as the second highest injury site.[3] Similarly, During the 2007 Rugby World Cup ligament injuries were one of the most common injuries with knee ligament injuries as the main type of injuries, while during the 2010 Women's Rugby World Cup, 15% of injuries were of the knee ligament.[4,5]

A review of studies investigating the biomechanics of ACL injuries revealed that the mechanism of injury is multi-factorial. [Numerous studies associated with ACL injuries and their mechanisms were identified. Evidence regarding plane of injury, supporting sagittal, frontal and/or transverse plane of mechanism was strong throughout. These studies indicated that it is highly probable that ACL injuries are more likely to occur during multi-planar rather than single-planar mechanism of injury.[6] This emphasises the need for grading of ACL injury.

According to published literature, it is clear that sports and activities requiring multi-plane movement of the knee have a higher risk of injury.[6] Variations in anatomy and gender may also contribute to a higher incidence for this type of injury. An understanding of the different factors contributing to these injuries is particularly important in preventing ACL injuries.[6]

In recent years the method of using magnetic resonance imaging (MRI) to grade an ACL injury has become popular.[7] This involves the use of a four point scoring system from the MRI scans, namely, intact, low-grade partial tear, high-grade partial tear and complete tear. This injury severity classification resulted from comparisons to arthroscopic findings.[7]

The aim of this study was to investigate the association between the pathology of ACL injuries and the mechanism of injury as seen on an MRI scan of the knee.

Methods

This was a cross-sectional analytical study. Eighty-seven male patients with an ACL injury and who had an MRI scan of the knee within a two-year period were voluntarily included in this study. Participants were contacted to give informed consent for their information be used in this study. Inclusion criteria specified that the patient should have a history of a complete ACL tear of the knee, have a clear history of the mechanism of the injury, and that knee surgery was not compulsory. Participants were not excluded based on age and fitness levels. Female patients and patients who could not recall the exact mechanism of their ACL injury were excluded from this study.

For this study, an ACL injury refers to a complete tear of the ACL. The mechanism of injury is the exact manner how the ACL was injured using six groups as listed in Table 1. Contact and non-contact injuries were included. An MRI of the knee refers to imaging done on a Magnetic Resonance Imaging scanner. These images were obtained with a 1.5 or 3 Tesla MRI scanner using a three mm slice thickness and a 0.3 mm gap. The sequences acquired were T2W fat saturated in the axial, coronal and sagittal planes, as well as Proton density, sagittal and coronal sequences. The pathology was defined as abnormal findings in and around the knee joint related to the ACL injury, using the ten most common groups as listed in Table 2.

MRI scan reports and contact numbers of male patients scanned during a two-year period were obtained. Permission to use this data was obtained from the radiology practise. The specific mechanism of injury and management plan of each patient was obtained telephonically. The exact questions asked telephonically were:

Question 1: How did you injure your knee?
Question 2: Please explain the exact mechanism.

The mechanism of injury was not further divided into more specific sub-categories due to the possible difficulty individuals may have in recalling this level of detail of their injury.

Patient names and data used in this study were anonymous. Each patient received an information letter explaining the study and written consent was obtained from each patient to use their injury and MRI scan findings. The information letter and informed consent form were emailed to the patient. The specific questions asked telephonically were stipulated in the informed consent form. After signing the information letter and informed consent form in the presence of a witness, the patient scanned the document and emailed it back to the principal investigator. The protocol was submitted to the Ethics Committee of the University of Pretoria and ethical approval was obtained (Ref. 375/2017).

Table 1. Mechanism of injury

Mechanism 1	Solid foot plant with rotation of the knee.
Mechanism 2	Solid foot plant with valgus stress on the knee.
Mechanism 3	Twist of the knee without foot plant.
Mechanism 4	Hyperextension injury of the knee.
Mechanism 5	Injury during changing of direction while running or walking
Mechanism 6	None of the above mentioned specific mechanisms of injury were present.

Table 2. Pathology on the MRI scan

Pathology 1	Other associated soft tissue injuries around the knee joint not mentioned below.
Pathology 2	Associated fractures of the bones around the knee joint.
Pathology 3	Complete anterior cruciate ligament tear.
Pathology 4	Medial meniscus injury (Including any pathology).
Pathology 5	Lateral meniscus injury (Including any pathology).
Pathology 6	Femoral bone bruise.
Pathology 7	Tibial bone bruise.
Pathology 8	Haemarthrosis or knee effusion present.
Pathology 9	Associated MCL injury (Including any pathology).
Pathology 10	Associated LCL injury (Including any pathology).

Statistical analysis

The data were analysed using the IBM SPSS Statistics program (Version 24). Results were entered into an Excel spread sheet (Microsoft 2010), summarised in tables, and graphically displayed with bar charts (i.e. to portray the profiles of the injuries per mechanism). Since the data can be regarded as multiple response sets (there are multiple pathology responses per mechanism) the standard chi-square test for independence was unsuitable. A modified version of the chi-square test, namely, a single-by-multiple marginal independence test, using the Rao-Scott corrected chi-square approximation to the sampling distribution, was used instead.[8,9] A five percent level of significance was specified to test the null hypothesis of independence.

Results

The age of the patients participating in this study ranged from 14 to 67 years, with 31 years being the average age (±13) years. The self-reported level of physical activity, fitness and general conditioning differed between individuals.

The mechanism of injury according to the broad groups listed and compared to the observed pathology on the MRI scan and patient experience is indicated in Table 3 and Figure 1 respectively.

Although the p-value was not statistically significant at 0.44 (chi-square value=20.27, df=45), the results show clinical importance in a number of ways.

Table 3. The observed counts of the mechanism of injury (M) versus the pathology (P) identified on the MRI scan

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	Total	No. of patients
Mechanism	*Other*	*Fracture*	*ACL*	*Medial meniscus*	*Lateral meniscus*	*Femoral bone bruise*	*Tibial bone bruise*	*Haemarthroses effusion*	*MCL*	*LCL*		
M1	21	2	35	27	19	14	20	13	9	4	164	35 (40%)
M2	17	2	34	18	17	21	20	11	14	1	155	34 (39%)
M4	6	2	14	9	6	9	10	6	8	0	70	14 (16%)
M5	1	0	2	2	1	1	0	0	1	0	8	2 (2%)
M6	2	0	2	2	1	0	0	0	0	0	7	2 (2%)
Total	47	6	87	58	44	45	50	30	32	5	404	87

Data presented as counts or percentage (%).
For each mechanism (M1 to M6), there are ten different possible pathology types (P1 to P10). There may be multiple pathology responses per mechanism. ACL, anterior cruciate ligament; LCL, lateral collateral ligament; MCL, medial collateral ligament.

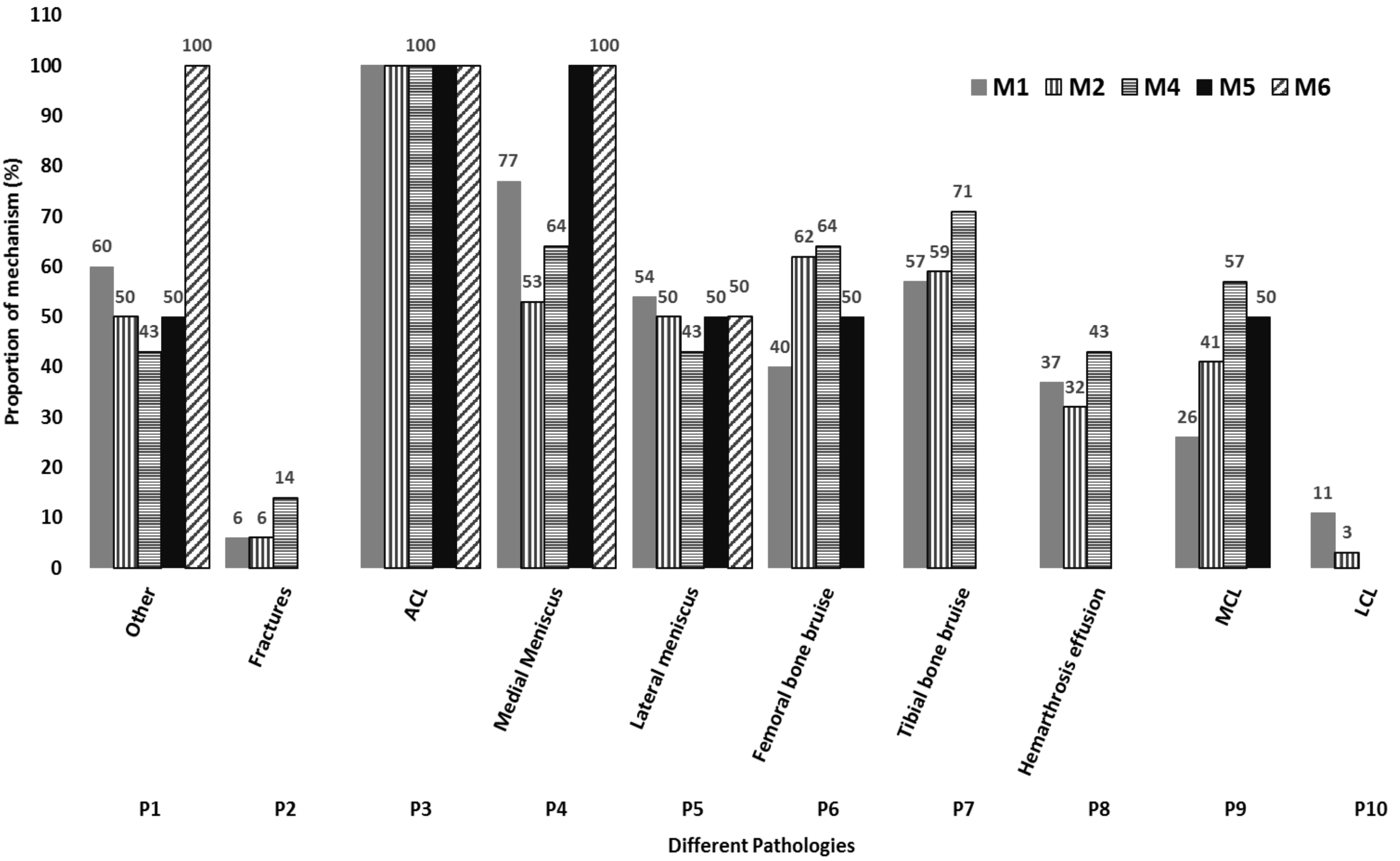

***Fig. 1**. Clustered bar chart of proportion (%) of each mechanism by pathology. There may be multiple pathology responses per mechanism. ACL, anterior cruciate ligament; LCL, lateral collateral ligament; MCL, medial collateral ligament.*

Mechanism 1 – a solid foot plant with rotation of the knee - had a high percentage of associated medial meniscal (77%) and lateral meniscal injuries (54%). Tibial bone bruises (57%) were more common than femoral bone bruises (40%). Only 26% had an associated MCL injury and 37% had a haemarthrosis. Few had an associated injury of the LCL (11%). Associated fractures accounted for a very small percentage of pathology found. The mechanism of solid foot plant (M1 and M2) accounted for 79% of ACL injuries.

Mechanism 2 – a solid foot plant with valgus stress on the knee - had the highest percentage of ACL injuries associated with bone bruising (femoral 62%, tibial 59%), followed by meniscal injuries (medial 53% and lateral 50%). Associated MCL injuries (41%) were more common compared to LCL injuries (3%), and 32% of ACL injuries had a haemarthrosis for this mechanism.

Mechanism 3 - no ACL injuries were observed where the mechanism of injury related to a twist of the knee without foot plant (M3).

Mechanism 4 - Hyperextension injury of the knee - indicated a high percentage of associated bone bruising (tibial 71%, femoral 64%) as an associated pathology. More associated medial meniscal injuries (64%) were seen and fewer lateral meniscal injuries (43%). MCL injuries (57%) were far more common than LCL injuries (0%). Haemarthrosis accounted for 43% of injuries.

Mechanisms 5 and 6 - The less common mechanisms (M5 and M6) of injury had a high percentage of medial meniscal injuries, less lateral meniscal injuries and almost no collateral ligament and bone bruising injuries. Related fractures were uncommon for all mechanisms.

Discussion

Mechanism 1, a solid foot plant with rotation of the knee, was the most frequent mechanism. This type of injury also has a greater tendency to be associated with medial meniscal injuries (77%) and a 54% possibility of being associated with lateral meniscal injuries. A solid foot plant with a valgus stress on the knee (Mechanism 2) was the second most common mechanism. When compared to Mechanism 1, a higher incidence of associated MCL injuries (41%) and femoral bone bruising (61%) were reported for Mechanism 2. These findings are in line with findings from previous studies.[10]

In this study the most common associated pathologies when the ACL was injured included medial meniscal, tibial bone bruise, femoral bone bruise and lateral meniscal injuries. Previous studies reported MCL injury and haemarthrosis as the most commonly associated pathology.[10] This is not replicated in the current study.

Mechanisms of ACL injury

The most common mechanism of injury reported in this study, namely Mechanism M1 and M2 (solid foot plant with rotation of the knee, and solid foot plant with valgus stress on the knee, respectively) corresponded well with the findings of Boden et al.[11] These researchers reported that significant advances have recently been made in understanding the mechanisms involved in non-contact ACL injuries. They found that most ACL injuries involve minimal to no contact.[11] Recent video analyses demonstrate significant differences in average leg and trunk position during injury compared to those in control subjects. Axial compressive forces are a critical component in non-contact ACL injuries. Above mentioned findings as well as those found in cadaveric and MRI studies found this statement to be true.[11]

A study by Sturnick et al. found that a decreased volume of the medial tibial spine is associated with an increased risk of ACL injuries in males only. A similar finding was not observed in females. Their analyses of males also revealed that an increased medial tibial spine volume was associated with a decreased risk of ACL injury. They found evidence to support the fact that smaller medial spines may provide less resistance to internal rotation and medial translation of the tibia relative to the femur. This could increase the chance of ACL sprains and the risk of ACL injury.[12] The most common mechanism of injury in this study did involve a solid foot plant with rotation of the knee and valgus stress on the knee, which corresponds well with the findings in the study by Sturnick et al., as a more prominent medial tibial spine could prevent the knee from a twist or valgus type injury mechanism.[12]

The mechanism of ACL injury identified in this study as occurring most frequently is also identified in another published review that found that most ACL injuries do not occur solely via sagittal, frontal or transverse plane mechanisms.[13] Collectively, the results showed that ACL injuries are more likely to occur during multi-planar rather than single-planar mechanisms of injury.[13]

A study by Yu and Garrett on ACL injuries in soccer players found that sagittal plane biomechanical factors such as small knee flexion angle, considerable posterior ground reaction force and quadriceps muscle force may be associated with significant quadriceps muscle force, in turn causing substantial anterior draw force at the knee.[14] The study further concluded that a small knee flexion angle is associated with a large patella tendon-tibia shaft angle and ACL elevation angle. This would result in excessive ACL loading. Knee valgus-varus moment and internal-external rotation moment alone are unlikely to result in isolated ACL injuries without injuring other knee structures. [14] These results confirmed that the mechanism of ACL injury occurs in many planes.

A study by Fuller et al. (2010) investigated the risk of injury associated with rugby union games played on artificial turf. The results showed that the incidence of ACL injuries were nearly four times higher when the game was played on artificial surfaces compared to grass surfaces. This could be due to the different mechanism of foot plant and knee rotation causing the injury.[15] These findings may also link the solid foot plant mechanism (M1 & M2) found in this present study as an important mechanism of injury; however, it needs to be further investigated and confirmed.

Associated pathology

Viskontas et al. investigated the correlation between bone bruise patterns and the mechanism of injury in ACL ruptures. Their results indicated that non-contact knee injury mechanisms appear to cause more severe bone bruising in both the medial and lateral compartments.[10] Although bone bruising was not the most common associated pathology found in this present study, it did account for more than 50% of associated injuries found in the most common mechanisms of injury, namely, M1, M2 and M4.

Prevention of ACL injuries

To understand the role and place of this present study and to interpret the results and make appropriate recommendations, the philosophy, theories and components of the prevention of ACL injuries and sport injuries in general must be considered.

A systematic approach to the prevention of sports injuries as shown in Figure 2 below has been described by van Mechelen et al..[16]

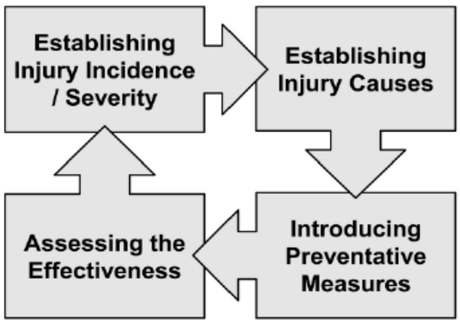

Fig. 2. Model of systematic approach to injury prevention

This present study could play an important role in establishing the causes of injury and the introduction of preventative measures. Research into the prevention of ACL injuries is very important and necessary. A study done in the United States found that paediatric patients who returned to sport too early after ACL reconstruction surgery had a higher risk for reinjuring the ligament. Proper rehabilitation protocols and return-to-sport recommendations should be in place and implemented to prevent this from happening.[17]

A study by Wellsandt et al. found that limb symmetry indexes can overestimate knee function after ACL injury and may be related to secondary ACL injury risk. These findings raise concerns as to whether the variety of criteria regarding return-to-sport utilised in current clinical practise is stringent enough to achieve a safe and successful return to sport.[18] This emphasises the need for standardised return-to-play protocols and that more than one factor should be considered when a return-to-play decision is made after ACL reconstructive surgery.

It is, however, important to understand that the values obtained from testing is not the only indicative factor to consider for functional knee movement, and that other biomechanical factors are also very important in preventing ACL injuries. Multifaceted programmes supported by videos and/or technical feedback, including eccentric hamstring exercises, would positively modify the biomechanical and/or neuromuscular anterior and/or hamstring injury risk factors.[19]

Strong evidence

The most common mechanisms of injury identified were a solid foot plant with rotation of the knee (M1) and valgus stress on the knee (M2), indicating a solid foot plant as the common denominator. These mechanisms led to more associated pathologies after injury in this study. It is clear from the findings in this study that movement patterns in athletes should change to prevent the foot from being planted flat and solidly during movement so that it prevents the foot from changing its position during the second movement, and knee joint stress with the second movement. This is a convincing reason to improve the strength of the lower leg muscles to help with flexion/extension of the ankle and inversion/eversion of the foot, as well as changing the biomechanics and movement patterns of the lower limbs, in order to assist the altered foot movements needed to prevent injury.

The mechanisms of injury where a solid foot plant was not present occurred far less commonly with less associated pathology. This supports the abovementioned recommendation of improving foot plant and position of the foot during activity to prevent ACL injury.

Weaker evidence

The fact that no statistically significant evidence of an association between the mechanism of injury and the pathology seen on the MRI scans could be found was most likely due to the small sample size and the commensurate lower power of the test in this study?. Using a larger sample size and dividing the pathology in even larger similar groups could be considered in future studies.

Trends

This study showed that ACL injuries are common in all ages of the population and can occur at different levels of activity. Some mechanisms are also indicated as more common than others. Attending to and correcting the movement patterns behind these injury mechanisms can assist in preventing ACL injuries in the future and limit the burden of these injuries on the professional sportsman and general public.

Limitations

Limitations of this study included: 1) recall bias, as some patients could not give an exact description of the mechanism of their injury, 2) the group of patients used was randomly selected and not a homogenous group, 3) there were fairly large age differences in the patients, 4) the level of physical activity and conditioning of patients differed significantly, with some being professional sports people.

Conclusion

Although no statistical significant association between the mechanism of injury and pathology as observed on a MRI scan could be proven in this study, some clinical relevant observations are reported. This research enables a better understanding of the specific mechanism of ACL injuries of the knee with the most common mechanisms of injury, a solid foot plant with either rotation of the knee or valgus stress on the knee. The findings also assist in improving the current knowledge of pathology patterns related to the mechanism of ACL injuries. These specific patterns of ACL injuries remain essential to the radiologists and sports physicians to document the multi plane movement of the knee which have a higher risk of injury. This awareness is furthermore crucial to the physiotherapist, biokineticist, personal trainer and coach improving movement patterns, implement preventative measures, and apply a pro-active programme specifically for athletes, in order to limit the number of ACL injuries.

References

1. Dodson CC, Secrist ES, Bhat SB, et al. Anterior cruciate ligament injuries in National Football League athletes from 2010 to 2013: A descriptive epidemiology study. Orthop J Sports Med 2016; 4(3): 2325967116631949. [doi:10.1177/2325967116631949]
2. Brukner P, Khan K. Clinical sports medicine. 3rd ed. McGraw-Hill, 2006:472-494.
3. Holtzhausen LJ, Schwellnus MP, Jakoet I, et al. The incidence and nature of injuries in South African rugby players in the rugby Super 12 competition. S Afr Med J 2006;96(12): 1260-1265.
4. Fuller CW, Laborde F, Leather RJ, et al. International Rugby Board Rugby World Cup 2007 Injury surveillance study. Br J Sports Med 2008;42(6): 452-459. [doi:10.1136/bjsm.2008.047035]
5. Taylor AE, Fuller CW, Molloy MG. Injury surveillance study during the 2010 IRB Women's Rugby World Cup. Br J Sports Med 2011;45(15):1243-1245. [doi: 10.1136/bjsports-2011-090024]
6. Quatman CE, Quatman-Yates CC, Hewett TE. A 'plane' explanation of anterior cruciate ligament injury mechanisms: a systemic review. Sports Med 2010;40(9):729-746. [doi:10.2165/11534950-000000000-00000]

7. Hong SH, Choi JY, Lee GK, et al. Grading of anterior cruciate ligament injury. Diagnostic efficacy of oblique coronal magnetic resonance imaging of the knee. J Comput Assist Tomogr 2003;27(5):814-819. [PMID: 14501376]
8. Thomas DR, Decady YJ. Testing for association using multiple response survey data: Approximate procedures based on the Rao-Scott approach. Int J Testing 2004; 4(1): 43-59. [doi: 10.1207/s15327574ijt0401_3]
9. Agresti A, Liu IM. Modelling a categorical variable allowing arbitrarily many category choices. Biometrics. 1999;55(3):936-943. [PMID: 11315032]
10. Viskontas DG, Giuffre BM, Duggal N, et al. Bone bruises associated with ACL rupture: correlation with injury mechanism. Am J Sports Med 2008;36(5):927-933. [doi: 10.1177/0363546508314791]
11. Boden BP, Sheehan FT, Torg JS, et al. Noncontact anterior cruciate ligament injuries: mechanisms and risk factors. J Am Acad Orthop Surg 2010; 18(9):520-527. [doi:10.5435/00124635-201009000-00003]
12. Sturnick DR, Argentieri EC, Vacek PM, et al. A decreased volume of the medial tibial spine is associated with an increased risk of suffering an anterior cruciate ligament injury for males but not females. J Orthop Res 2014;32(11):1451-1457. [doi: 10.1002/jor.22670]
13. Barraza LC, Krishna RG, Low JH, et al. The biomechanics of ACL injury: progresses toward prophylactic strategies. Crit Rev Biochem Eng 2013;41(4-5):309-321. [doi:10.1615/CritRevBiomedEng.2014010460]
14. Yu B, Garrett WE. Mechanism of non-contact ACL injuries. Br J Sports Med 2007;41 Suppl 1:i47-51. [doi: 10.1136/bjsm.2007.037192]
15. Fuller CW, Clarke L, Molloy MG. Risk of injury associated with rugby union played on artificial turf. J Sports Sci 2010;28(5):563-570. [doi: 10.1080/02640411003629681]
16. Verhagen EA, van Mechelen W, . Sport for all, injury prevention for all. Br J Sports Med 2010;44(3):158. [doi: 10.1136/bjsm.2009.066316]
17. Dekker TJ, Godin JA, Dale KM, et al. Return to sport after pediatric anterior cruciate ligament reconstruction and its effect on subsequent anterior cruciate ligament injury. J Bone Joint Surg Am 2017;99(11):897-904. [doi: 10.2106/JBJS.16.00758]
18. Wellsandt E, Failla MJ, Snyder-Mackler L. Limb symmetry indexes can overestimate knee function after anterior cruciate ligament injury. J Orthop Sports Phys Ther 2017;47(5):334-338. [doi: 10.2519/jospt.2017.7285]
19. Monajati A, Larumbe-Zabala E, Goss-Sampson M, et al. The effectiveness of injury prevention programs to modify risk factors for non-contact anterior cruciate ligament and hamstring injuries in uninjured team sports athletes: A systemic review. PloS ONE 2016;11(5):e0155272. [doi: 10.1371/journal.pone.0155272]