CLINICAL ARTICLE

Risk factors of young males with physically demanding occupations having accumulated damage of anterior cruciate ligament

Wang Yu, PhD[1], Liu Xianmin, MD[1], Xiang Liangbi, MD[1], Li Chunbao, MD[2]

[1]Department of Orthopaedics, General Hospital of Shengyang Military Area Command of Chinese PLA, Shenyang and [2]Department of Orthopaedics, the Fourth medical center of Chinese PLA General Hospital, Beijing, China

Objective: To present the clinical characteristics of accumulated anterior cruciate ligament (ACL) damage among young male patients undergoing routine exercise, and to evaluate the related risk factors.

Methods: A retrospective study involving ACL-accumulated damage from June 2015 to December 2019 was conducted. Baseline characteristics, such as age, body mass index (BMI), training parameters, and clinical signs, were recorded. The results of the radiologic examinations and related standardized tests were obtained to evaluate the research outcomes. These results were compared using Student's *t*-test or Chi-square test, and the impact of risk factors on the patient's injury were analyzed.

Results: A total of 86 men with accumulated ACL damage were included in this study. Exercise pain (86 [100%]), synovitis (80 [93.0%]), and intra-articular effusion (79 [91.9%]) were the most common clinical symptoms. Loosening of ligaments, decreased tension, mild hyperplasia, and intercondylar fossa effusion were observed using radiography, magnetic resonance imaging, and arthroscopy. Age, BMI, training intensity, length of training, and knee hyperextension were identified as risk factors for accumulated ACL damage.

Conclusion: This study suggests that accumulated ACL damage has differentiated clinical symptoms, imaging features, and risk factors compared to common ACL injuries.

Key words: Anterior cruciate ligament; Clinical manifestations; Damage accumulation; risk factors

Introduction

The anterior cruciate ligament (ACL) injury is a typical intra-knee lesion, particularly in military personnel and athletes.[1] ACL lesions are non-contact injuries that are closely related to the deformation of the knee joint during exercise. More than 70% of ACL lesions are caused by the participants' physical actions, such as rapidly changing directions or twisting the knee joint when jumping to the ground. The annual incidence of ACL lesions among the athlete population is 0.06–3.70 cases per 1000 h of competition with acute ACL lesions being the most common type of ACL injury.[2] According to data from the US Centers for Disease Control and Prevention, approximately 100,000 ACL reconstruction operations are performed each year, ranking sixth among the most common types of surgeries in the United States.

Most chronic ACL lesions develop from the acute form caused by undiagnosed or untreated trauma and then turn into long-term meniscal and cartilage injuries.[3,4] The common non-contact ACL injury is due to accidental or traumatic ACL rupture caused by fatigue training. The present study found not ACL rupture but degenerative changes such as chronic laxity and creep of the ACL induced by intense and long-term trainingin physical training populations, such as military and police officers. Primarily, we assume this is a chronic, insidious

Address for correspondence Chunbao Li, MD, Department of Orthopaedics, PLA General Hospital, 28 Fuxing Road, Haidian District, Beijing, China. Email: lichunbao301@163.com
All authors have submitted disclosure forms.
Funding information This work was supported by the Natural Science Foundation of Liaoning Province under Grant 2020-MS-037.
Received 10 November 2020; accepted 21 March 2022

ACL accumulated damage, which is another type of ACL lesion classified by time rather than acute or chronic. There are 6810 active athletes in China, including 3983 males and 2827 female athletes. Among various types of sports injuries, the incidence of ACL lesions is as high as 0.47. The sport that caused the most ACL damage was basketball, followed by football, and young people accounted for 75.5% of the injured.[5]

Staging for cruciate ligament lesions can be divided into contact and non-contact lesions, according to the cause.[6] In addition, the lesions can be classified as tendon-bone interface lesions at ligament insertion, avulsion fractures, and ligament body fractures.[7] These patients manifested with symptoms of knee pain, mild instability, and abnormal magnetic resonance imaging (MRI) during exercise. Furthermore, existing evidence shows that neuromuscular fatigue can compromise athletes' performance and increase the anterior tibial translation, leading to diminished exercise endurance and escalating the risk of ACL lesion.[8] Although fatigue classifications upon population undergoing routine exercise were reported in previous studies,[9–11] related evidence with regard to clinical characteristics is lacking.

Therefore, this study aimed to present the clinical characteristics of accumulated ACL damage among young male patients that have a history of routine exercise, and to evaluate its related risk factors.

Materials and Methods

Inclusion and exclusion criteria

The inclusion criteria were as follows: (i) demonstrated history of routine exercise (more than 5 years); (ii) no history of severe knee trauma and swelling; (iii) primary symptom of knee pain or buckling when standing or exercising; (iv) history of intense training experiences, such as long-distance running, high jump, obstacle training, and competitive sports; and (v) aberrant ACL signal confirmed by MRI.

Patient data and ethics statement

This study was approved by the Ethics Review Board of our institution. Data of patients between June 2015 and December 2019 from the authors' hospital orthopedic clinic database were retrospectively reviewed, and 86 patients were selected who had undergone treatment for knee pain or knee instability during training.

Definition of ACL accumulated damage

While common ACL injury occurs when an excessive tension force is applied on the ACL immediately, accumulated ACL damage occurs when a person generates extreme pressures at the knee during routine exercise, spreading long-term loading and triggering chronic injury of the ACL.

Patients with accumulated ACL damage without external trauma were admitted, and shared typical symptoms, such as knee pain, knee instability, and abnormal ACL signals on MRI (Fig. 1).

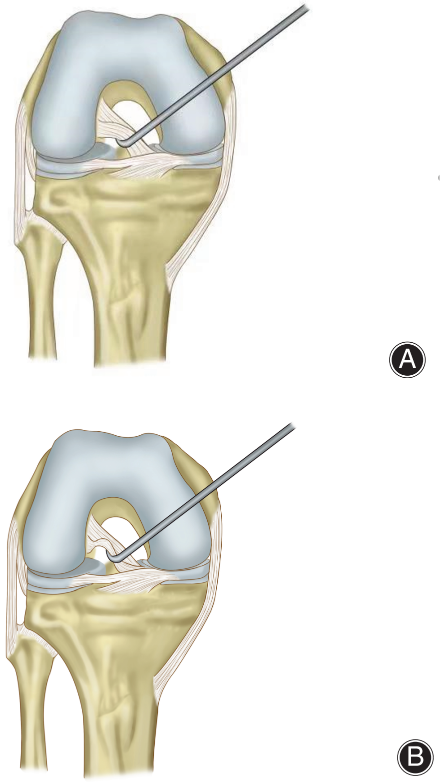

Fig. 1 (A) The normal ligaments have glossy surface, full of vascular descent, uniform thickness of AM and PL beams, no yellow synovial membrane at the femoral stopping point, good tension observed by the probe, and unable to be lifted; (B) ACL accumulated damage presented dark and thinning of the ligament, mild atrophy, as well as compensatory synovial hyperplasia at the femoral insertion point. Since the tension is significantly reduced, the ligament can be easily lifted by the probe

Clinical assessment and outcome measures

The study consent form collected baseline characteristics, including age, body mass index (BMI), training exercise, and training intensity. Clinical symptoms were defined based on the type of knee pain, anterior drawer test (ADT), and Lachman test.[12] Imaging features presented by plain radiography, MRI, and arthroscopy were also included for assessment. All participants were evaluated using the Lysholm questionnaire, which is the gold standard for clinical follow-up.[13]

Statistical analysis

First, a descriptive analysis of the data was carried out. Continuous variables of normal distribution were expressed as mean ± standard deviation, and Student's *t*-test or Chi-square test was used to compare each group. The impact of risk factors on the patients' injury was analyzed using a

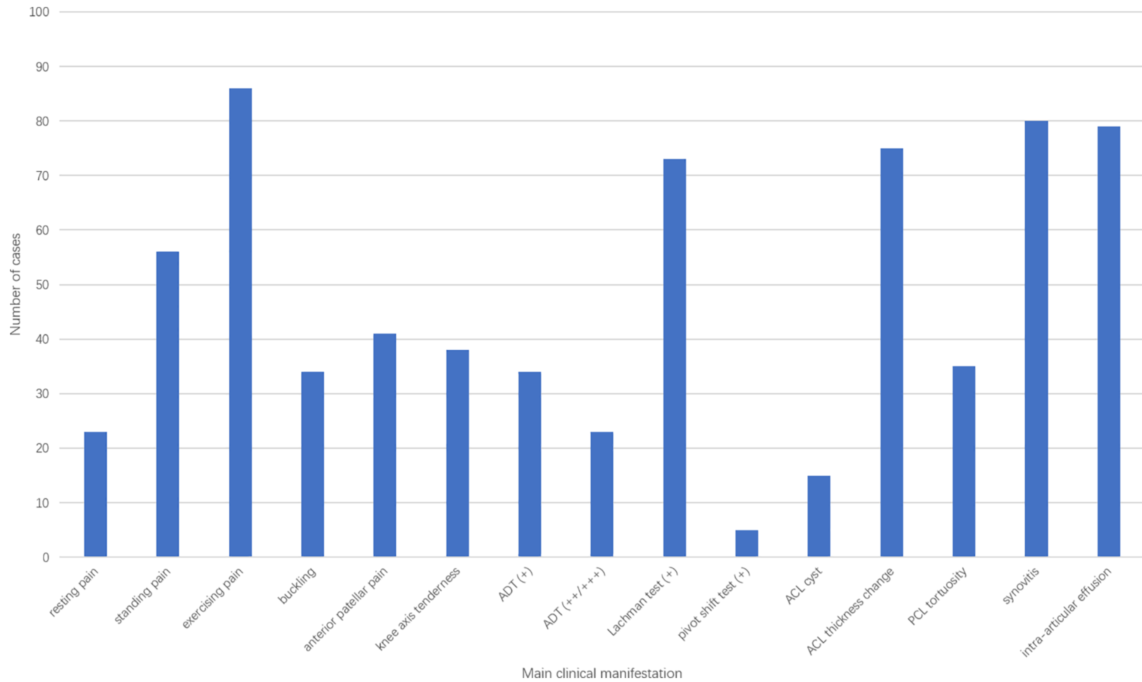

Fig. 2 Clinical symptoms

Fig. 3 Effusion shadow was observed in intercondylar fossa of knee joint; we observed decreased tension, increased diameter (yellow arrow), tortuous posterior cruciate ligament, and intercondylar fossa effusion (red arrow)

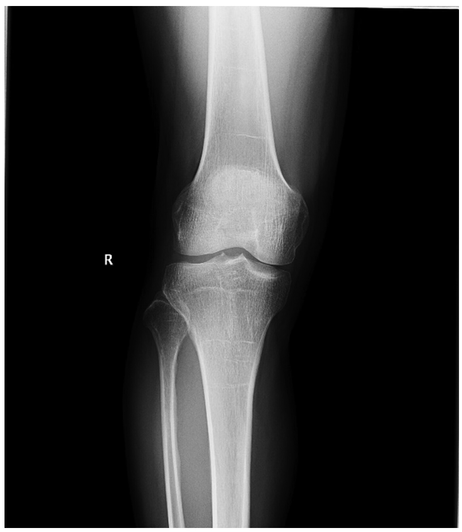

Fig. 4 The X-ray showed mild hyperplasia of intercondylar spine

logistic regression model. Statistical significance was set at $P < 0.05$. All statistical analyses were conducted using the SPSS software (version 18.0, IBM, Armonk, NY, USA).

Results

General results and clinical symptoms

A total of 86 male patients were involved in this study, with an average age of 28 ± 2.32 years and an average BMI index of 25.43 ± 2.93 kg/m^2. There were 59 patients with left knee lesions and 27 patients with right knee lesions. Exercising pain (86 [100%]), synovitis (80 [93.0%]), and intra-articular effusion (79 [91.9%]) were the most commonly observed clinical symptoms (Fig. 2).

Imaging features

While MRI showed weakened tension and uniform thickening of the ACL in the adjacent layers of the intercondylar fossa (Fig. 3), plain radiography revealed mild proliferation of the tibial intercondylar spine (Fig. 4). Arthroscopic

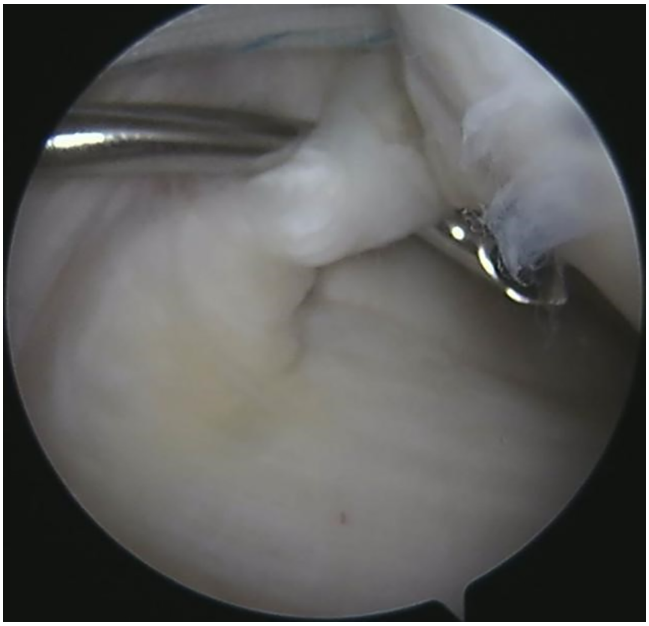

Fig. 5 The shrinking and loosening ligament from arthroscopic view

TABLE 1 Comparisons of functional results

Variables	n	Lysholm score	t or χ^2 value	p value
Age			23.134	<0.001
Under 30	41	58.2 ± 9.5		
Over 30	45	47.3 ± 6.8		
Training intensity (per week)			45.341	<0.001
≤15 h	20	60.3 ± 8.4		
15–25 h	32	52.3 ± 7.5		
≥25 h	34	45.6 ± 9.2		
BMI (kg/m^2)			54.234	<0.001
<25	42	63.3 ± 5.7		
≧25	44	47.1 ± 8.9		
Training experience			28.134	<0.001
<3 years	50	56.1 ± 7.6		
≥3 years	36	49.3 ± 8.5		
Knee hyperextension (≥5°)			32.144	<0.001
Yes	45	46.8 ± 5.6		
No	41	53.1 ± 7.7		

examination revealed injury to the insertion site of the posterolateral bundle and relaxation of the ligament (Fig. 5).

Risk factors

There were 41 cases of patients younger than 30 years that scored 58.2 ± 9.5 which is significantly higher than the other 45 patients that were older than 30 years that scored 47.3 ± 6.8. There were 20 cases with a training intensity of less than 15 h/week that scored significantly higher (60.3 ± 8.4) than the other 32 cases (15–25 h/week) (52.3 ± 7.5) and 34 cases (25+ h/week) with greater training intensity. The comparisons of BMI, training experience, and knee hyperextension are shown in Table 1.

Discussion

Clinical manifestation of ACL accumulated damage

The etiological features included long-term routine exercise or a history of no serious trauma. The histogram display mainly shows pain during exercise, a positive Lachman test, and MRI changes in the clinical manifestation. Accumulated ACL damage presents as a small amount of effusion in the joints combined with synovitis on MRI. The ACL signal primarily manifests as thinning, thickening, tension change, etc., and can also incorporate the adaptive change of the PCL. We believe that thinner ACLs tend to be injured at the same training intensity, which leads to blurred ACL edges and changes in tension. In addition, partial ACL damage leads to changes in the biomechanical structure of the joint, which causes synovitis and joint effusion. Further research on changes in images of accumulated ACL damage will be conducted by our team in the near future.

Some research has pointed out that fatigue could cause acute ACL lesion,[14–22] but the definition of ACL accumulated damage has not been revealed entirely from the academic field. Not until 2013 did Ashton-Miller's biomechanical study based on a knee model demonstrate through human cadavers that repetitive pressure jumping could lead to cruciate ligament non-contact injury. Still, Miller's research is limited to the biomechanical field, not involving clinical research.[23,24] For two cases, arthroscopy surgery was performed, and it was concluded that ACL accumulated damage without trauma history manifested as ligament relaxation and partial femoral end damage.

Risk factors of ACL accumulated damage

The causes of accumulated ACL damage are still under investigation. However, there are many factors that can explain the development of ACL lesions. For example, Dhillon *et al.*'s analysis of cross-ligament injuries at risk for mechanoreceptor changes suggests that the number of mechanoreceptors is related to the duration of the ligament lesion and that the longer the damage, the fewer the mechanoreceptors. Thus, the signal receptors on the ligament surface suggest the existence of an abundance of mechanical receptors on the ACL surface, especially at the ligament endpoints and synovial folds.[25,26] Reviewing the literature and clinical observations, we argue that fatigue can weaken muscle strength around the knee joint and diminish the dynamic stability of the knee. The static stability of the knee is subject to ligament stands outranged by tension, deforming ligaments, and decreasing mechanical receptors. Eventually, a chronic ACL lesion develops.

Swanik *et al.* also reported that athletes maintained a slow response and a slower processing speed in the non-contact ACL lesion group than in the control group.[19] From the cases we encountered in the clinic, including an individual patient with accumulated ACL damage, all of them had experienced long-term, high-intensity training. In addition, warm-up preparation before training, fatigue recovery status between training intervals and after training, and stretching movements lack scientific guidance. More reports have confirmed that in a fatigued state, neuromuscular control is diminished, and ligament tension and joint pressure are altered, which increases the risk of cruciate ligament rupture.[27,28]

Furthermore, another theory states the cruciate ligament will gradually degenerate with knee osteoarthritis development as age grows, accompanied by decreasing ACL function and knee proprioception.[29] The cruciate ligament degeneration is mainly associated with inflammation, an active, cell-mediated extracellular matrix reduction, and remodeling.[30] Therefore, the deterioration of ligaments and the weakening of proprioception of knee joints will promote the further development of osteoarthritis, which complement each other.[31] This theory could also explain our finding that ACL accumulated damage is more common in sporty people over 30 while rare in patients under 25.

Our findings are consistent with those of previous studies in which defective ACL development, intercondylar fossa abnormalities, BMI, sex, and polyarticular laxity were risk factors for ACL injuries.[32–37]

Limitations

This report has several limitations. First, the evaluation of degree of fatigue may not be completely accurate because of the complexity of qualifying fatigue. Second, the content and intensity of the training varied according to the patients' occupation. Finally, the sample size was small as this study was a preliminary clinical observation. A controlled study with a sizable population is needed to confirm this conclusion.

Conclusions

In this study, accumulated ACL damage presented differentiated clinical symptoms, imaging features, and risk factors compared to common ACL injuries.

Acknowledgments

This work was supported by the Natural Science Foundation of Liaoning Province under Grant 2020-MS-037. We thank all the authors and staff who related to this work.

References

1. Tennent DJ, Posner MA. The military ACL. J Knee Surg. 2019; 32: 118–22.
2. Herrington L, Cooke R. Retrospective analysis of non-contact ACL injury risk: a case series review of elite female athletes. J Sports Med Ther. 2017; 2: 1–8.
3. Relph N, Herrington L, Tyson S. The effects of ACL injury on knee proprioception: a meta-analysis. Physiotherapy. 2014; 100: 187–95.
4. Stone KR, Adelson WS, Pelsis JR, Walgenbach AW, Turek TJ. Long-term survival of concurrent meniscus allograft transplantation and repair of the articular cartilage: a prospective two- to 12-year follow-up report. J Bone Joint Surg Br. 2010; 92: 941–8.
5. Salem HS, Shi WJ, Tucker BS, Dodson CC *et al*. Contact versus noncontact anterior cruciate ligament injuries: is mechanism of injury predictive of concomitant knee pathology. Art Ther, 2018; 34: 200–204.
6. Trivedi V, Mishra P, Verma D. Pediatric ACL injuries: a review of current concepts. Open Orthop J. 2017; 11: 378–88.
7. Temponi EF, de Carvalho Júnior LH, Sonnery-Cottet B, Chambat P. Partial tearing of the anterior cruciate ligament: diagnosis and treatment. Rev Bras Ortop. 2015; 50: 9–15.
8. Barber-Westin SD, Noyes FR. Effect of fatigue protocols on lower limb neuromuscular function and implications for anterior cruciate ligament injury prevention training: a systematic review. Am J Sports Med. 2017; 45: 3388–96.
9. Borotikar BS, Newcomer R, Koppes R, McLean SG. Combined effects of fatigue and decision making on female lower limb landing postures: central and peripheral contributions to ACL injury risk. Clin Biomech (Bristol, Avon). 2008; 23: 81–92.
10. Tsai LC, Sigward SM, Pollard CD, Fletcher MJ, Powers CM. Effects of fatigue and recovery on knee mechanics during side-step cutting. Med Sci Sports Exerc. 2009; 41: 1952–7.
11. Bourne MN, Webster KE, Hewett TE. Is fatigue a risk factor for anterior cruciate ligament rupture. Sports Med. 2019; 49: 1629–35.
12. Yaver J. The Users' guide to the musculoskeletal examination: fundamentals for the evidence-based clinician. Phys Ther. 2008; 88: 1605–6.
13. Johnson DS, Smith RB. Outcome measurement in the ACL deficient knee—what's the score? Knee. 2001; 8: 51–7.
14. Coventry E, O'Connor KM, Hart BA, Earl JE, Ebersole KT. The effect of lower extremity fatigue on shock attenuation during single-leg landing. Clin Biomech (Bristol, Avon). 2006; 21: 1090–7.
15. Orishimo KF, Kremenic IJ. Effect of fatigue on single-leg hop landing biomechanics. J Appl Biomech. 2006; 22: 245–54.
16. Chappell JD, Herman DC, Knight BS, Kirkendall DT, Garrett WE, Yu B. Effect of fatigue on knee kinetics and kinematics in stop-jump tasks. Am J Sports Med. 2005; 33: 1022–9.
17. Webster KE, Santamaria LJ, McClelland JA, Feller JA. Effect of fatigue on landing biomechanics after anterior cruciate ligament reconstruction surgery. Med Sci Sports Exerc. 2012; 44: 910–6.
18. Noyes FR, Barber-Westin SD. Neuromuscular retraining intervention programs: do they reduce non-contact anterior cruciate ligament injury rates in adolescent female athletes? Art Ther. 2014; 30: 245–55.
19. Swanik CB, Covassin T, Stearne DJ, Schatz P. The relationship between neurocognitive function and non-contact anterior cruciate ligament injuries. Am J Sports Med. 2007; 35: 943–8.
20. Behrens M, Mau-Moeller A, Wassermann F, Bruhn S. Effect of fatigue on hamstring reflex responses and posterior-anterior tibial translation in men and women. PLoS One. 2013; 8:e56988.
21. Gillot T, L'Hermette M, Garnier T, Tourny-Chollet C. Effect of fatigue on functional stability of the knee: particularities of female handball players. Int J Sports Med. 2019; 40: 468–76.
22. Lipps DB, Wojtys EM, Ashton-Miller JA. Anterior cruciate ligament fatigue failures in knees subjected to repeated simulated pivot landings. Am J Sports Med. 2013; 41: 1058–66.
23. Chen J, Kim J, Shao W, et al. An anterior cruciate ligament failure mechanism. Am J Sports Med. 2019; 47: 2067–76.
24. Katonis PG, Assimakopoulos AP, Agapitos MV, Exarchou EI. Mechanoreceptors in the posterior cruciate ligament. Histologic study on cadaver knees. Acta Orthop Scand. 1991; 62: 276–8.
25. Toda H, Nagano A, Luo Z. Age and gender differences in the control of vertical ground reaction force by the hip, knee and ankle joints. J Phys Ther Sci. 2015; 27: 1833–8.
26. Dhillon MS, Bali K, Vasistha RK. Immunohistological evaluation of proprioceptive potential of the residual stump of injured anterior cruciate ligaments (ACL). Int Orthop. 2010; 34: 737–41.
27. DeAngelis AI, Needle AR, Kaminski TW, Royer TR, Knight CA, Swanik CB. An acoustic startle alters knee joint stiffness and neuromuscular control. Scand J Med Sci Sports. 2015; 25: 509–16.
28. Roberts D, Andersson G, Fridén T. Knee joint proprioception in ACL-deficient knees is related to cartilage injury, laxity and age: a retrospective study of 54 patients. Acta Orthop Scand. 2004; 75: 78–83.
29. Sled EA, Khoja L, Deluzio KJ, Olney SJ, Culham EG. Effect of a home program of hip abductor exercises on knee joint loading, strength, function, and pain in people with knee osteoarthritis: a clinical trial. Phys Ther. 2010; 90: 895–904.
30. Tsauo JY, Cheng PF, Yang RS. The effects of sensorimotor training on knee proprioception and function for patients with knee osteoarthritis: a preliminary report. Clin Rehabil. 2008; 22: 448–57.

31. Hernigou P, Garabedian JM. Intercondylar notch width and the risk for anterior cruciate ligament rupture in the osteoarthritic knee: evaluation by plain radiography and CT scan. Knee. 2002; 9: 313–6.
32. Alentorn-Geli E, Pelfort X, Mingo F *et al*. An evaluation of the association between radiographic intercondylar notch narrowing and anterior cruciate ligament injury in men: the notch angle is a better parameter than notch width. Art Ther, 2015, 31: 2004–2013.
33. Stein V, Li L, Guermazi A, Zhang Y, et al. The relation of femoral notch stenosis to ACL tears in persons with knee osteoarthritis. Osteoarthr Cartil. 2010; 18: 192–9.
34. Chaudhari AM, Zelman EA, Flanigan DC, Kaeding CC, Nagaraja HN. Anterior cruciate ligament-injured subjects have smaller anterior cruciate ligaments than matched controls: a magnetic resonance imaging study. Am J Sports Med. 2009; 37: 1282–7.
35. Sonnery-Cottet B, Archbold P, Cucurulo T, et al. The influence of the tibial slope and the size of the intercondylar notch on rupture of the anterior cruciate ligament. J Bone Joint Surg Br. 2011; 93: 1475–8.
36. Uhorchak JM, Scoville CR, Williams GN, Arciero RA, St Pierre P, Taylor DC. Risk factors associated with noncontact injury of the anterior cruciate ligament: a prospective four-year evaluation of 859 west point cadets. Am J Sports Med. 2003; 31: 831–42.
37. Myer GD, Ford KR, Paterno MV, Nick TG, Hewett TE. The effects of generalized joint laxity on risk of anterior cruciate ligament injury in young female athletes. Am J Sports Med. 2008; 36: 1073–80.