RESEARCH ARTICLE

Relationship between Femoral Intercondylar Notch Narrowing in Radiography and Anatomical and Histopathologic Integrity of Anterior Cruciate Ligament in Patients Undergoing Total Knee Replacement Surgery

Hosseinali Hadi, MD; Ali Rahbari, MD; Mahmood Jabalameli, MD; Abolfazl Bagherifard, MD; Ahmadreza Behrouzi, MD; Fatemeh Safi, MD; Zahra Rezaei, MD; Gholamreza Azarnia samarin, MD; Amir Azimi, MD

Research performed at Bone and Joint Reconstruction Center, Vali-Asr Hospital, Arak University of Medical Science, Arak, Iran

Received: 01 August 2018 *Accepted: 26 September 2018*

Abstract

Background: The presence of cruciate ligaments is very important for normal knee kinematics. Knee arthroplasty prostheses, in which these ligaments are maintained, have better kinematics. The aim of the present study was to investigate the association between femoral intercondylar notch (FIN) narrowing in radiography and clinical and histopathologic integrity of anterior cruciate ligament (ACL) in patients undergoing knee replacement surgery.

Methods: FIN index was measured in tunnel view radiography of the knees of 102 candidates of knee replacement surgery. The anatomical status of ACL was also examined during total knee arthroplasty (TKA). ACL was removed and sent for histopathologic examination to assess its degeneration rate. The association between the FIN index and the clinical and histopathological health of ACL was investigated.

Results: Among 102 patients with mean age of 69.73 ± 7.81 years , 39 patients (38.32%) had no or torn ACL, 31 patients (30.39%) had weak ACL, and 32 (31.37%) had normal ACL. There was a significant association between age and clinical status of ACL during surgery (*P=0.017*). There was a significant difference in FIN and ACL health status during surgery between the two groups with an index of more and less than 0.252 (*P=0.019* and *P=0.019*, respectively). There was no significant difference in the mean total degeneration score (TDS) of ACL between the two groups with FIN more and less than 0.252 (*P=0.816*).

Conclusion: There was a significant difference between the age and FIN narrowing (less than 0.252) as well as ACL clinical status during surgery. FIN narrowing had no significant effect on the severity of ACL degeneration and there was no significant difference in the severity of degenerative histopathologic changes between healthy and attenuated ACLs. This indicates that if ACL exists, although apparently attenuated, it has the histologic characteristic of a healthy ligament.

Level of evidence: II

Keywords: Anterior cruciate ligament, Femoral intercondylar notch, Knee arthroplasty

Introduction

Total knee arthroplasty (TKA) is the most effective and common procedure for treating advanced knee osteoarthritis (1). Modern knee arthroplasty was developed in the early 1970s by introduction of condylar knee prosthesis. Bi-cruciate retaining prostheses were introduced in 1971 (2), designed with the aim of keeping

Corresponding Author: Amir Azimi, Orthopedic Department, Vali-Asr Hospital, Arak University of Medical Science, Arak, Iran
Email: Dr.amir2011@yahoo.com

AB&JS THE ONLINE VERSION OF THIS ARTICLE ABJS.MUMS.AC.IR

ligaments, minimal bone resection, and close-to-normal knee movements, compared to other prostheses (3). Maintaining ACL in TKA improves knee kinematics, proprioception, maximum flexion, and generally knee position (4).

Degenerative changes are observed in knee ligaments during TKA followed by osteoarthritis, especially in posterolateral bundle of ACL (5). It seems that achieving close-to-optimal knee function following TKA may be due to inability to place specific prostheses to replace the normal complex knee kinematics (6,7). The first thing to keep in mind is the maintenance of normal knee structure as much as possible. In particular, the cruciate ligaments are an important criterion for obtaining the knee kinematics and may play an important role in unicompartment arthroplasty and arthroplasty using cruciate and bicruciate-retaining prostheses (3, 8). Preserving the cruciform ligaments in unicompartment arthroplasty improves joint stability and soft tissue balance and maintains normal knee kinematics. It has been suggested that, the absence of cruciate ligament in laboratory studies, causes polyethylene irritation and increases prosthesis failure due to increased slip between the tibia and femur (9, 10).

Keeping both cruciate ligaments during TKA provides a better joint kinematic and improves function, movement, stability, and proprioception (7, 11-16). However, there is much debate about the benefits of retaining ACL in knee arthroplasty. It is argued that these ligaments may have no function in knee osteoarthritis (13, 17). ACL is often removed in TKA, but some evidence has shown that keeping ACL improves knee kinematics (7, 18, 19). It seems that as long as the ligament is functional, the severity of degeneration does not hinder preservation of cruciate ligaments (8). ACL is more functional in more than 60% of patients undergoing arthroplasty (20, 21). In addition, although ACL may have a normal macroscopic appearance, it is not always associated with histological integrity (22, 23). There may be pathological changes in more than 97% (17, 24, 25). Histopathological changes in ACL have a high prevalence in knees with severe osteoarthritis (20). Histologically, degeneration of ligaments causes varying levels of cartilage metaplasia and myxoid degeneration, and changes in collagen fiber allignment and cystic changes (20, 24, 26). These changes are related to demographic factors and knee degeneration (24).

The purpose of this study was to estimate the functional status of ACL before knee arthroplasty on radiographs using femoral intercondylar notch (FIN) index.

Materials and Methods

A total of 102 patient candidates for knee replacement were enrolled in this prospective analytic cohort study and examined for FIN.

Demographic data, including age, gender, and degree of flexion contracture and deformity in the preoperative coronal plane were evaluated. FIN was examined in tunnel view (postero-anterior knee radiography in 45° knee flexion so that the patella touches the radiation receptor, at a 10" distance from the knee and 10° caudal) (27) and obtained by dividing the notch width to the greatest distance between the two condyles in popliteal groove (28). Subsequently, the patients were divided into two groups: index>0.252 and index<0.252 (29) [Figure 1].

In order to determine the clinical integrity of ACL

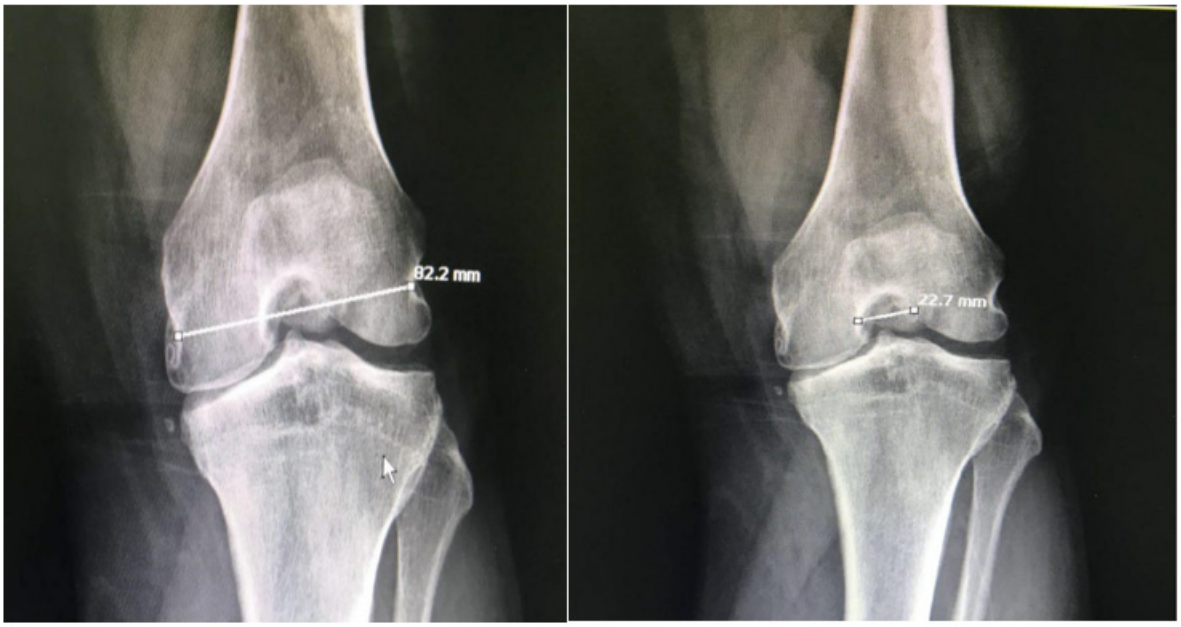

Figure 1. Measuring method of femoral intercondylar notch width index.

during operation, the cruciate ligament was divided into completely healthy, attenuated, and torn through direct observation (22, 26).

To determine the histopathologic health of ACL during the operation, the transverse and longitudinal specimens were excised and the proximal one third of ACL was removed and fixed in formalin. Then, four microscopic cuts were taken from specimens, stained with Hematoxylin & Eosin, and investigated in terms of myxoid changes, cystic myxoid or microcystic formation, chondroid metaplasia, acellular zone, vascular proliferation, fibroblast proliferation, calcium pyrophosphate deposits, and presence of gout. Pathologic changes were classified into four categories: absent (0), mild (1), moderate (2), and marked (3) based on each of the above items and classified according to degenerative histologic changes and then total degenerative score (TDS) was given to each sample (24, 30, 31).

The inclusion criterion was advanced knee osteoarthritis while underlying neuromuscular disease; knee joint degeneration due to underlying diseases such as rheumatologic diseases; previous infection or fracture at the knee joint surface; and damage to the knee ligament were defined as the exclusion criteria. Data were analyzed using SPSS software version 20.

Results

The mean age of patients was 69.33 ± 7.81 years (range: 54-88 years); 77 (75.5%) were female and 25 (24.5%) were male. The two groups were homogeneous in terms of age (*P=0.318*) and gender (*P=0.081*) [Table 1]. In general, 39 (38.32%) patients had no or torn ACL, 31 patients (30.39%) had weak, and 32 (31.37%) had healthy ACLs. Of 102 patients, 47 cases (46.08%) had FIN score >0.252 and 55 patients (53.92%) <0.252. In total, 39 patients (38.23%) had no or torn ACLs and 63 patients (61.77%) had weak or healthy ACLs, sent for histopathologic examination. There was a significant association between age and anatomical status of ACL (*P=0.017*) and ACL health status worsened as age increased. There was no association between patients' gender and anatomical status of ACL (*P=0.17*).

Comparison of anatomical status of ACL between groups with FIN index more and less than 0.252 showed statistical difference in clinical status of ACL between the groups (*P=0.019*). In the group with notch narrowing, more than 50% of ACL were torn, but in the group with a high notch index, one fourth of ACLs were torn. ACL was completely healthy in 40% of cases in the group with high notch index, but, only 23% of cases in the group with notch narrowing had completely healthy ACLs [Table 1].

Comparison of mean TDS of ACL between two groups, defined as total histopathological changes resulting from ACL degeneration, showed that the mean TDS of ACL was 3.30 ± 2.00 in all patients. There was no significant difference in the mean TDS of ACL (*P=0.816*) between the two groups with FIN index more and less than 0.252, that is, notch narrowing had no significant effect on ACL ligament degeneration severity [Table 1].

Comparison of histopathologic status of ACL showed no significant difference in histopathologic changes of ACL between the two groups with FIN index more and less than 0.252 (*P>0.05*). With regard to the fact that no sample was taken from patients with torn ACLs, the results suggest that patients with a healthy or weak ACL, regardless of the severity of narrowing, show similar histopathological changes [Table 2].

No significant difference was found between healthy and weak ACLs in terms of intensity of degenerative changes in histopathology (*P>0.05*) [Table 3].

The total degenerative score in patients with normal ACL was 3.96 ± 1.89 and in the attenuated ACL group was 3.16 ± 1.71 (P=0.081) [Table 4].

No association was found between TDS of ACL and age (*P=0.839*) and gender (*P=0.196*), severity of deformity (<15° and >15°) (*P=0.07*), and movement restriction (*P=0.878*).

Table 1. Comparing two groups with femoral intercondylar notch (FIN) index ≥ or < 0.252

		FIN index more or equal 0.252	FIN index less than 0.252	*P value*
Age	Age	69.98±8.26	69.44±7.34	0.318
gender	Female	39(82.97)	38(69.09)	0.081
	Male	8(17.02)	17(30.9)	0.081
	Total	47(100)	55(100)	0.081
clinical status of ACL	Healthy Acl	19(40.42)	13(23.63)	0.019
	Attenuated Ac	17(36.17)	14(25.45)	0.019
	Torn Acl	11(23.4)	28(50.9)	0.019
	Total	47(100)	55(100)	0.019
Total degenerative score		3.2±51.04	3.1±62.64	0.816

Table 2. Histopathologic status of ACL between two groups with and without notch stenosis

Histopathologic situation		FIN index more or equal 0.252 (number/percent)	FIN index less than 0.252 (number/percent)	*P value*
Myxoid change	Absence(0)	1(3.22)	4(12.5)	0.4
	Mild(1)	22(70.96)	20(62.5)	
	Moderate(2)	7(22.58)	8(25)	
	Marked(3)	1(3.22)	0(0)	
Cystic myxoid or microcycystic formation	Absence(0)	8(25.80)	5(15.62)	0.317
	Mild(1)	12(38.70)	11(34.37)	
	Moderate(2)	8(25.80)	14(43.75)	
	Marked(3)	3(9.67)	2(6.25)	
Chondroid metaplasia	Absence(0)	26(83.87)	28(87.05)	0.459
	Mild(1)	5(16.12)	3(9037)	
	Moderate(2)	0(0)	1(3.12)	
	Marked(3)	0(0)	0(0)	
acellular zone	Absence(0)	28(90.32)	28(87.5)	0.5
	Mild(1)	3(9.67)	4(12.5)	
	Moderate(2)	0(0)	0(0)	
	Marked(3)	0(0)	0(0)	
Vascular proliferation	Absence(0)	14(45.16)	17(53.12)	0.644
	Mild(1)	12(38.70)	9(28.12)	
	Moderate(2)	5(16.12)	7(21.87)	
	Marked(3)	0(0)	0(0)	
Fibroblast proliferation	Absence(0)	24(77.41)	29(90.62)	0.293
	Mild(1)	6(19.35)	3(9.37)	
	Moderate(2)	1(3.22)	0(0)	
	Marked(3)	0(0)	0(0)	
Calcium pyrophosphate deposits	Absence(0)	31(100)	31(96.87)	0.5
	Mild(1)	0(0)	1(3.12)	
	Moderate(2)	0(0)	0(0)	
	Marked(3)	0(0)	0(0)	
Presence of gout	Absence(0)	31(100)	32(100)	0.05>
	Mild(1)	0(0)	0(0)	
	Moderate(2)	0(0)	0(0)	
	Marked(3)	0(0)	0(0)	

Table 3. Association between clinical status of ACL during surgery with histopathological changes of ACL

Histopathologic situation		Normal ACL Number/percent	Attenuated ACL Number/percent	*P value*
Myxoid change	Absence(0)	1(3.12)	4(12.90)	0.357
	Mild(1)	23(71.87)	19(61.29)	
	Moderate(2)	7(21.87)	8(25.80)	
	Marked(3)	1(3.12)	0(0)	

Table 3 Continued.				
Cystic myxoid or microcycystic formation	Absence(0)	7(21.87)	6(19.35)	0.372
	Mild(1)	9(28.12)	14(45.16)	
	Moderate(2)	12(37.5)	10(32.25)	
	Marked(3)	4(12.5)	1(3.22)	
Chondroid metaplasia	Absence(0)	26(81.25)	28(90.32)	0.217
	Mild(1)	6(18.75)	2(6.45)	
	Moderate(2)	0(0)	1(3.22)	
	Marked(3)	0(0)	0(0)	
acellular zone	Absence(0)	28(87.5)	28(90.32)	0.5
	Mild(1)	4(12.5)	3(9.67)	
	Moderate(2)	0(0)	0(0)	
	Marked(3)	0(0)	0(0)	
Vascular proliferation	Absence(0)	15(46.87)	15(48.38)	0.420 0.42
	Mild(1)	10(31.25)	11(35.48)	
	Moderate(2)	7(21.87)	2(6.45)	
	Marked(3)	0(0)	0(0)	
Fibroblast proliferation	Absence(0)	25(87.12)	28(90.32)	0.341
	Mild(1)	6(18.75)	3(9.67)	
	Moderate(2)	1(3.12)	0(0)	
	Marked(3)	0(0)	0(0)	
Calcium pyrophosphate deposits	Absence(0)	31(96.87)	31(100)	0.5
	Mild(1)	1(3.12)	0(0)	
	Moderate(2)	0(0)	0(0)	
	Marked(3)	0(0)	0(0)	
Presence of gout	Absence(0)	32(100)	31(100)	>0.05
	Mild(1)	0(0)	0(0)	
	Moderate(2)	0(0)	0(0)	
	Marked(3)	0(0)	0(0)	

Table 4. Relationship of gender, coronal deformity and flexion contracture with total degenerative score of ACL and Comparison of mean ± standard deviation of total degenerative score of ACL among the two groups with different clinical status of ACL			
		TDS	***P Value***
Gender	Male	3.1±20.33	0.196
	female	3.1±33.92	0.196
Coronal deformity	More than 15 degree	3.1±14.82	0.07
	Less than 15 degree	3.2±52.33	0.07
Flexion contracture	More than 15 degree	3.0±00.00	0.878
	More than 15 degree	3.2±31.01	0.878
clinical status of ACL	Healthy acl	3.1±96.89	0.081
	Attenuated acl	3.1±16.71	0.081

Discussion

Considering the need for normal cruciate ligament function in order to use bi cruciate retaining prosthesis, our goal was to evaluate the performance of the cruciate ligaments before surgery using radiographic evaluation. There was no statistically significant association between age and gender with FIN index (*P>0.05*). There was a significant difference in FIN narrowing with ACL health status during surgery between the two groups with index of more and less than 0.252 (*P=0.019*), so that in more than 50% of patients with notch narrowing, ACL was not present or was torn during surgery. However, there was no significant difference between notch narrowing and histopathological changes in ACL (*P>0.05*). There was no significant difference in the mean TDS of ACL between the two groups with FIN more or less than 0.252 (*P=0.816*). This means that notch narrowing has no significant effect on the severity of ACL ligament degeneration. There was no statistically significant difference between healthy and weak ACL in terms of intensity of degenerative histopathologic changes (*P>0.05*). There was no statistically significant difference between the mean TDS score in patients with normal ACL and in the attenuated ACL group (*P=0.081*). This indicates that if ACL exists, although apparently weak, it has histologic characteristics of a healthy ligament and may be functional in biomechanical and proprioceptive aspects. There was an association between the age and anatomical status of ACL (*P=0.017*) and the anatomical status of the ACL worsened by increasing age, while there was no association between gender and ACL health status (*P=0.107*). There was no significant difference between life decades and TDS of ACL (*P>0.05*) or between gender and TDS of ACL (*P>0.05*). There was no significant difference between TDS of ACL and the degree of flexion contracture deformity (*P>0.05*) and TDS of ACL was not significantly different between the two groups with flexion contracture less or more than 15 degree (*P>0.05*).

As the first limitation in our study, we could have used more accurate imaging methods such as CT scan or MRI in order to examine the FIN index, which would increase the accuracy of the FIN index, but tunnel view radiography was used considering the imposition of radiation on patients as well as the ethical issues. Secondly, ACL clinical health was divided into three groups in our study: completely healthy, attenuated, and torn, but, it could have been better to add one group to absent ACL. And Finlly, lack of BMI recording in patients with BMI flactuations could change the histopathological changes of ACL

Geng et al. showed that intercondylar notch narrowing was associated with ACL injury in knee osteoarthritis at the age of 41 to 65 years (32). Chen found that notch narrowing and Type "A" notch are risk factors for moderate to severe osteoarthritis associated with ACL injury (33). The notch width index in Gormeli (2015) was significantly narrower in patients with uni- or bi-lateral ACL tear, compared with that of the control group (34). Stein et al. showed a lower notch width index in people with osteoarthritis and torn ACL (35). These results are consistent with our study in which, a significant difference was seen in FIN narrowing with ACL health status during surgery between the two groups with an index of more and less than 0.252, as, more than 50% of patients with notch narrowing had no or torn ACL during surgery.

In a different study by Monte et al. (2015) 85% of cases had histopathologic changes of ACL degeneration. The higher the osteoarthritis grade, the more the histopathological changes. In general, they deduced that high ages are associated with histopathological changes (36). However, while there was no difference between the clinical and histopathological ACLs in our study, changes in grade four osteoarthritis significantly correlated with histopathological changes in the study of Monte et al. In addition, age and histopathological changes in our study were not associated, but there was a positive association between the age and clinical status of ACL (*P=0.017*) and ACL status worsened as the age increased. The reason for this difference could be that in the study of Monte et al. ACL was clinically divided into four groups of healthy, attenuated, torn, and no ACL and histopathological changes in ACL were categorized into three groups: healthy, attenuated, and torn ACL; whereas, in our study, clinical ACL was divided into three groups: healthy, attenuated, and torn, and histopathologic changes into two groups of healthy and attenuated ACL and no sample was taken from torn ACLs for histopathological examination. Another difference between studies was the sample size that was 174 in Monte's study and 102 in our study.

Al-Saeed et al. studied the association between the intercondylar notch morphology, width index, and the risk of ACL injury. Inconsistent with our study, their findings showed that type "A" femoral notch was a risk factor for ACL tear, while reduced notch index had no significant association with ACL tear (37). In our study, there was a significant difference in FIN narrowing between the two groups with index of more and less than 0.252 (P=0.019), as more than 50% of patients with notch narrowing had no or torn ACL.

Trompetor et al. analyzed 55 ACLs during knee replacement surgery, 31 cases of which were macroscopically healthy cruciate ligament, and showed that in histological examination, 72% had moderate to severe histologic changes (17). Mullaji (2008) evaluated 45 ACLs in patients with knee replacement and found that severe degenerative changes were more common in severe than low grade osteoarthritis (25). In our study, there was no statistically significant difference in severity of degenerative histopathologic changes between completely healthy and weak ACLs (*P>0.05*) and was no significant difference between notch narrowing and histopathologic changes in ACL (*P>0.05*)

Levy et al. showed that ligament degeneration was more in older people, but the association was weak and not significant (24). In our study, degenerative changes in ACL and PCL were not significantly different with age. Considering the aforementioned limitations in our study, further studies with proprioceptive receptor

examinations are suggested.

According to our findings, the clinical status of ACL had a relationship with age. As the age increases, the anatomical state of ACL gets worse. Also, notch narrowing had no significant effect on the severity of ACL ligament degeneration. Moreover, there was no significant difference between healthy and weak ACL in terms of histopathological changes. Finally, in the presence of ACL, no matter how weak, the histologic characteristics of a healthy ligament as well as biomechanical and proprioceptive function can be present.

Hosseinali Hadi MD
Gholamreza Azarnia Samarin MD
Amir Azimi MD
Orthopedic Department, Arak University of Medical Sciences, Arak, Iran

Ali Rahbari MD
Pathology Department, Arak University of Medical Sciences, Arak, iran

Mahmood Jabalameli MD
Abolfazl Bagherifard MD
Bone and Joint Reconstruction Research Center, Shafa Yahyaian Hospital, Iran university of Medical Science, Tehran, Iran

Ahmadreza Behrouzi MD
Valiasr Hospital, Arak University of Medical Sciences, Arak, Iran

Fatemeh Safi MD
Zahra Rezaei MD
Radiology Department, Faculty of Medicine, Arak University of Medical Sciences, Arak, Iran

References

1. NiemeläInen MJ, MäKelä KT, Robertsson O, W-Dahl A, Furnes O, Fenstad AM, et al. Different incidences of knee arthroplasty in the Nordic countries: a population-based study from the Nordic Arthroplasty Register Association. Acta Orthop. 2017; 88(2):173-8.
2. Townley CO. Total knee arthroplasty. A personal retrospective and prospective review. Clin Orthop Relat Res. 1988; 236(1):8-22.
3. Pritchett JW. Bicruciate-retaining total knee replacement provides satisfactory function and implant survivorship at 23 years. Clin Orthop Relat Res. 2015; 473(7):2327-33.
4. Abdelbadie A, Toreih AA, Radwan MA. ACL status in arthroplasty patients, why not to preserve? SICOT J. 2018; 4(1):1.
5. Watanabe A, Kanamori A, Ikeda K, Ochiai N. Histological evaluation and comparison of the anteromedial and posterolateral bundle of the human anterior cruciate ligament of the osteoarthritic knee joint. Knee. 2011; 18(1):47-50.
6. Nowakowski AM, Stangel M, Grupp TM, Valderrabano V. Investigating the primary stability of the transversal support tibial plateau concept to retain both cruciate ligaments during total knee arthroplasty. J Appl Biomater Funct Mater. 2012; 10(2):127-35.
7. Stiehl JB, Komistek RD, Cloutier JM, Dennis DA. The cruciate ligaments in total knee arthroplasty: a kinematic analysis of 2 total knee arthroplasties. J Arthroplasty. 2000; 15(5):545-50.
8. Sabouret P, Lavoie F, Cloutier JM. Total knee replacement with retenti on of both cruciate ligaments: a 22-year follow-up study. Bone Joint J. 2013; 95(7):917-22.
9. Engh GA, Ammeen D. Is an intact anterior cr uciate ligament needed in order to have a well-functioning unicondylar knee replacement? Clin Orthop Relat Res. 2000; 428(1):170-3.
10. Suggs JF, Li G, Park SE, Steffensmeier S, Rubash HE, Freiberg AA. Function of the anterior cruciate ligament after unicompartmental knee arthroplasty: an in vitro robotic study. J Arthroplasty. 2004; 19(2):224-9.
11. Nakamae A, Ochi M, Deie M, Adachi N, Kanaya A, Nishimori M, et al. Biomechanical function of anterior cruciate ligament remnants: how long do they contribute to knee stability after injury in patients with complete tears? Arthroscopy. 2010; 26(12):1577-85.
12. Bach Jr BR, Warren RF, Wickiewicz TL. The pivot shift phenomenon: results and description of a modified clinical test for anterior cruciate ligament insufficiency. Am J Sports Med. 1988; 16(6):571-6.
13. Butler DL, Noyes FR, Grood ES. Ligamentous restraints to anterior–posterior drawer in the human knee. A biomechanical study. J Bone Joint Surg Am. 1980; 62(2):259-70.
14. Hughston JC, Andrews JR, Cross MJ, Moschi A. Classification of knee ligament instabilities. Part I. The medial compartment and cruciate ligaments. J Bone Joint Surg Am. 1976; 58(2):159-72.
15. Andriacchi TP, Galante JO, Fermier RW. The influence of total knee-replacement design on walking and stair-climbing. J Bone Joint Surg Am. 1982; 64(9):1328.
16. Kuroyanagi Y, Mu S, Hamai S, Robb WJ, Banks SA. In vivo knee kinematics during stair and deep flexion activities in patients with bicruciate substituting total knee arthroplasty. J Arthroplasty. 2012; 27(1):122-8.

17. Trompeter AJ, Gill K, Appleton MA, Palmer SH. Predicting anterior cruciate ligament integrity in patients with osteoarthritis. Knee Surg Sports Traumatol Arthrosc. 2009; 17(6):595-9.
18. Komistek RD, Allain J, Anderson DT, Dennis DA, Goutallier D. In vivo kinematics for subjects with and without an anterior cruciate ligament. Clin Orthop Relat Res. 2002; 404(1):315-25.
19. Schmidt R, Komistek RD, Blaha JD, Penenberg BL, Maloney WJ. Fluoroscopic analyses of cruciate-retaining and medial pivot knee implants. Clin Orthop Relat Res. 2003; 410(1):139-47.
20. Cushner FD, La Rosa DF, Vigorita VJ, Scuderi GR, Scott WN, Insall JN. A quantitative histologic comparison: ACL degeneration in the osteoarthritic knee. J Arthroplasty. 2003; 18(6):687-92.
21. Douglas MJ, Hutchison JD, Sutherland AG. Anterior cruciate ligament integrity in osteoarthritis of the knee in patients undergoing total knee replacement. J Orthop Traumatol. 2010; 11(3):149-54.
22. Allain J, Goutallier D, Voisin MC. Macroscopic and histological assessments of the cruciate ligaments in arthrosis of the knee. Acta Orthop Scand. 2001; 72(3):266-9.
23. Noyes FR, DeLucas JL, Torvik PJ. Biomechanics of anterior cruciate ligament failure: an analysis of strain-rate sensitivity and mechanisms of failure in primates. J Bone Joint Surg Am. 1974; 56(2):236-53.
24. Levy YD, Hasegawa A, Patil S, Koziol JA, Lotz MK, D'Lima DD. Histopathological changes in the human posterior cruciate ligament during aging and osteoarthritis: correlations with anterior cruciate ligament and cartilage changes. Ann Rheum Dis. 2013; 72(2):271-7.
25. Mullaji AB, Marawar SV, Simha M, Jindal G. Cruciate ligaments in arthritic knees: a histologic study with radiologic correlation. J Arthroplasty. 2008; 23(4):567-72.
26. Hasegawa A, Otsuki S, Pauli C, Miyaki S, Patil S, Steklov N, et al. Anterior cruciate ligament changes in the human knee joint in aging and osteoarthritis. Arthritis Rheum. 2012; 64(3):696-704.
27. Babatunde OM, Danoff JR, Patrick DA, Lee JH, Kazam JK, Macaulay W. The Combination of the tunnel view and weight-bearing anteroposterior radiographs improves the detection of knee arthritis. Arthritis. 2016; 2016(1):9786924.
28. Souryal TO, Moore HA, Evans JP. Bilaterality in anterior cruciate ligament injuries: associated intercondylar notch stenosis. Am J Sports Med. 1988; 16(5):449-54.
29. Chen C, Ma YH, Tan XY, Zhang B, Geng B, Jiang J, et al. Relationship between coronal intercondylar notch width index and osteoarthritis. Nan Fang Yi Ke Da Xue Xue Bao. 2015; 35(10):1384-9.
30. Hasegawa A, Nakahara H, Kinoshita M, Asahara H, Koziol J, Lotz MK. Cellular and extracellular matrix changes in anterior cruciate ligaments during human knee aging and osteoarthritis. Arthritis Res Ther. 2013; 15(1):R29.
31. Stubbs G, Dahlstrom J, Papantoniou P, Cherian M. Correlation between macroscopic changes of arthrosis and the posterior cruciate ligament histology in the osteoarthritic knee. ANZ J Surg. 2005; 75(12):1036-40.
32. Geng B, Wang J, Ma JL, Zhang B, Jiang J, Tan XY, et al. Narrow intercondylar notch and anterior cruciate ligament injury in female nonathletes with knee osteoarthritis aged 41-65 years in plateau region. Chin Med J. 2016; 129(21):2540-5.
33. Chen C, Ma Y, Geng B, Tan X, Zhang B, Jayswal CK, et al. Intercondylar notch stenosis of knee osteoarthritis and relationship between stenosis and osteoarthritis complicated with anterior cruciate ligament injury: a study in MRI. Medicine. 2016; 95(17):e3439.
34. Görmeli CA, Görmeli G, Öztürk BY, Özdemir Z, Kahraman AS, Yıldırım O, et al. The effect of the intercondylar notch width index on anterior cruciate ligament injuries. Acta Orthop Belg. 2015; 81(2):240-4.
35. Stein V, Li L, Guermazi A, Zhang Y, Kent Kwoh C, Eaton CB, et al. The relation of femoral notch stenosis to ACL tears in persons with knee osteoarthritis. Osteoarthritis Cartilage. 2010; 18(2):192-9.
36. Mont MA, Elmallah RK, Cherian JJ, Banerjee S, Kapadia BH. Histopathological evaluation of the anterior cruciate ligament in patients undergoing primary total knee arthroplasty. J Arthroplasty. 2015; 31(1):284-9.
37. Al-Saeed O, Brown M, Athyal R, Sheikh M. Association of femoral intercondylar notch morphology, width index and the risk of anterior cruciate ligament injury. Knee Surg Sports Traumatol Arthrosc. 2013; 21(3):678-82.