Introduction: The presence of cruciate ligaments are 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 narrowing in radiography and clinical and histopathologic integrity of anterior cruciate ligament (ACL) in patients undergoing knee replacement surgery.

Materials and methods: 102 candidates of knee replacement surgery were enrolled. In tunnel view radiography of the knees, femoral intercondylar notch (FIN) index was measured. During total knee arthroplasty (TKA), the anatomical status of ACL was examined. Then, ACL was removed and sent for histopathologic examination to assess ligament’s degeneration rate. The association between the femoral intercondylar notch index and the clinical and histopathological health of ACL was investigated.

Results: in 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. 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. There was no significant difference in mean total degeneration score (TDS) of ACL between the two groups with FIN more and less than 0.252.
Conclusion: There was a significant difference between the age and FIN narrowing (less than 0.252) and 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: prospective cohort, level II.

Keywords: knee arthroplasty, femoral intercondylar notch index, anterior cruciate ligament

Introduction

Total knee arthroplasty (TKA) is the most effective and commonly used procedure for treating advanced knee osteoarthritis (1). In the early 1970s, modern knee arthroplasty developed by development of condylar knee prosthesis. Bi-cruciate retaining prostheses were introduced in 1971 (2), designed with the aim of keeping 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). Therefore, the first thing to keep in mind is maintenance of normal knee structure as much as possible. In particular, the cruciate ligaments is an important criterion for obtaining the knee kinematics and may play an important role in unicompartiment arthroplasty and arthroplasty using cruciate and bicruciate-retaining prostheses (3, 8). In unicompartiment arthroplasty, keeping the cruciform ligaments improves joint stability and soft tissue balance and maintains normal kinematics of the knee. It has been suggested that, in laboratory studies, the absence of cruciate ligament, due to increased slip between the tibia and femur, causes polyethylene irritation and increase prosthesis failure (9, 10).

Keeping both cruciate ligaments during TKA provides a better joint kinematic, improves function, movement, stability, and proprioception (7, 11-16). However, there is much debate about the benefits of keeping 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 order of collagen fibers 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.

**Methods**

In this observational study, conducted as prospective analytic cohort, a total of 102 candidates of knee replacement were enrolled and examined for FIN. The 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 degrees of knee flexion so that the patella touches the radiation receptor, at a 10-inch distance from the knee and 10 degrees 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 with an index greater than zero point two five two and an index less than zero point two five two (29). (Figure 1)

In order to determine the clinical integrity of ACL during operation, the cruciate ligament was divided into completely healthy, attenuated, and torn using direct observation (22, 26).

To determine the histopathologic health of ACL during the operation, transverse and longitudinal specimens were taken, 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 criteria included advanced knee osteoarthritis and the exclusion criteria included 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. Data were analyzed using SPSS software version 20.

**Results**

In this observational prospective analytic cohort study, 102 patients (102 knees) with primary knee osteoarthritis, candidate of TKA, were enrolled. The mean age of patients was 69.33 ± 7.81 years (54 to 88 years); 77 (75.5%) were female and 25 (24.5%) were male.

There was no significant difference between the two groups with FIN more and less than zero point two five two 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 of greater than zero point two five two and 55 patients (53.92%) less than zero point two five two. In total, 41 patients (40.2%) had no or torn ACLs and 63 patients 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 zero point two five two 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, ¼ of ACLs were torn. In the group with high notch index, ACL was completely healthy in 40% of cases, but in the group with notch narrowing, ACL was completely healthy in 23% of cases (Table 1).

Comparison of mean TDS of ACL, defined as total histopathological changes resulting from ACL degeneration, between two groups 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 zero point two five two, that is, notch narrowing had no significant effect on ACL ligament degeneration severity (Table 1).

Comparison of histopathologic status of ACL between two groups showed no significant difference in histopathologic changes of ACL between the two groups with FIN index more and less than zero point two five two (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).

Investigating the association between ACL anatomic status during surgery and histopathologic changes in ACL: Based on this study, there was no significant difference 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).

Comparison of mean ± standard deviation of TDS of ACL in different life decades showed no association between the life decades and TDS changes in ACL (P = 0.583). There was no association between age and TDS of ACL (P = 0.839).
Comparison of mean and standard deviation of TDS of ACL and gender (Table 4) showed no association between gender and TDS of ACL (p = 0.196).

Comparison of mean and standard deviation of TDS of ACL between groups with knee coronal deformity of more than 15 and less than 15 degrees (Table 4) showed no significant difference between TDS ACL and deformity severity (P=0.07).

Comparison of histopathologic changes of ACL in patients with knee flexion contracture of less and more than 15 degrees (Table 4) showed that TDS of ACL were not significantly different in the groups with movement restriction (P = 0.878).

Discussion

In this observational prospective analytic cohort study, 102 patients (102 knees), candidates of TKA, were enrolled. The mean age of patients was 69.73 ± 7.81 years; 77 (77.5%) were female and 25 (24.5%) were male. 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 two groups with index of more and less than zero point two five two (p = 0.019), so that in more than 50% of patients who had 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).

The mean TDS of ACL was 3.30 ± 2.00 in all patients and there was no significant difference in the mean TDS of ACL between the two groups with FIN more or less than zero point two five two (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). Mean TDS 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).

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 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).

Geng et al. conducted a study, entitled “Intercondylar notch narrowing and ACL injury in non-athlete women with knee osteoarthritis” and compared 330 patients with ACL injury, 141 patients with knee osteoarthritis, and 89 healthy controls in the control group and showed that intercondylar notch narrowing was associated with ACL injury in knee osteoarthritis at the age of 41 to 65 years. In this study, the cut off for the intercondylar notch was less than zero point two six (32). The results of their study were consistent with our study. In our study, there was a significant difference between FIN with ACL status in the two groups with an index more and less than zero point two five two (p = 0.019) and ACL was not present or was torn during surgery in more than 50% of patients with narrowing.
In Chen’s study on 79 patients with moderate to severe knee osteoarthritis and 71 healthy patients, there were 38 patients with ACL injury and 41 patients with osteoarthritis without ACL tear. NWI was measured by MRI in three sequences: NWI-1 axial sequence, NWI-2 sagittal sequence, and NWI-A at ACL connection to femur. It was found that notch narrowing and Type “A” notch are a risk factor for moderate to severe osteoarthritis associated with ACL injury (33). These results are consistent with our study. In our study, there was a significant difference in FIN narrowing with ACL health status during surgery between two groups with an index of more and less than zero point two five two (p = 0.019), as more than 50% of patients with notch narrowing had no or torn ACL during surgery.

Monte et al. (2015) conducted a similar study to assess ACL histopathology on 174 patients undergoing knee replacement surgery. ACL was healthy in 43 cases, weak in 85, torn in 15 cases, and did not exist in 31 cases. In 85% of cases, ACL showed histopathologic changes of degeneration. The higher the osteoarthritis grade, the more the histopathological changes, especially regarding phosphate. In grade four, osteoarthritis changes were significantly associated with calcium pyrophosphate deposition, formation of microcysts, and a number of pathological changes. In general, high ages are associated with histopathological changes (34). Their study results differed from our study. In our study, there was no difference between the clinical and histopathological ACLs, but in the study of Monte et al. changes in grade four osteoarthritis significantly correlated with deposition of calcium pyrophosphate, formation of microcysts, and a number of pathological changes. In addition, in our study, age and histopathological changes were not associated, but there was a positive association between 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.

Another study by Chen et al. (2015), entitled “The association between radiographic
intercondylar notch narrowing and ACL injury”, showed that notch angle is a better parameter
than notch width. In patients with ACL injury, notch angle was significantly less than the control
group, but there was no significant association between the two groups in terms of notch width
(30). Their results are inconsistent with our study. In our study, there was a significant difference
in FIN narrowing between the two groups with index of more and less than zero point two five
two (p = 0.019), as more than 50% of patients with notch narrowing had no or torn ACL.

Gormeli (2015) measured FIN index on MRI of 18 patients with bilateral ACL injury, 38
patients with unilateral ACL injury, and 53 patients in the control group. NWI in bilateral ACL
injury was zero point two two seven, in the unilateral group was zero point two four five, and in
the control group was zero point two five one. The notch width index was significantly narrower
in patients with uni- or bi-lateral ACL tear, compared with that of the control group (35). Their
results were consistent with our study.

Stein et al. (2010) studied the histopathologic changes in macroscopically healthy ligaments and
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 (36). In our study, there was no statistically significant
difference in severity of degenerative histopathologic changes between completely healthy and weak ACLs (p> 0.05). The overall TDS in patients with normal ACL was 93.3 ± 1.94 and in the group with weak ACL was 3.04 ± 1.70 (P = 0.04).

In another study, Al-Saeed et al. studied the association between the intercondylar notch morphology, width index, and the risk of ACL injury and 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). These results are not consistent with our study. In our study, there was a significant difference between FIN narrowing and ACL health status of patients during surgery (p = 0.019), as ACL was not present or was torn during surgery in the more than 50% of patients with narrow notch.

In another study, Hernigo et al. (2002) published the results of the study, entitled “Intercondylar notch width and risk of ACL tear in osteoarthritis”, measured INW by radiography and CT scan on 30 knees with osteoarthritis, and showed that narrow notch less than twelve mm was associated with ACL tear (38). In our study, there was no association. The difference was due to the fact that in our study, FIN was used while Hernigo and his colleagues used the notch number.

Mullaji (2008) evaluated 45 ACLs in patients with knee replacement and found severe degenerative changes was more common in severe than low grade osteoarthritis (25). In our study, there was no significant difference between notch narrowing and histopathologic changes in ACL (p> 0.05). The mean TDS of ACL was 3.30 ± 2.00 in all patients. There was no significant difference in the mean TDS of ACL between the two groups with FIN less than zero point two five two (p = 0.816).
Levy et al. stated in a study, entitled “Histopathological changes in PCL by aging and osteoarthritis and its association with cartilage and ACL changes” on 120 samples 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.

**Conclusion:**

There was an association between age and clinical status of ACL (p = 0.017): as the age increases, the anatomical state of ACL gets worse. There was a significant difference between the two groups with index more and less than zero point two five two (p = 0.019); as ACL was not present or was torn during surgery in more than 50% of patients with narrow notch. However, there was no significant difference between notch narrowing and histopathological changes in ACL (p > 0.05). The mean TDS of ACL was 3.30 ± 2.00 in all patients. There was no significant difference in mean TDS of ACL between groups with FIN index of more or less than zero point two five two (p = 0.816). This means that notch narrowing had no significant effect on the severity of ACL ligament degeneration. There was no significant difference between healthy and weak ACL in terms of histopathological changes (p > 0.05). The TDS in patients with normal ACL was 3.96 ± 1.89 and in the attenuated ACL group was 3.16 ± 1.71 (P = 0.081). This indicates that if ACL exists, although apparently weak, it has the histologic characteristics of a healthy ligament and may have biomechanical and proprioceptive function.


Figure 1; measuring method of femoral intercondylar notch width index