

1 **Relationship between femoral intercondylar notch narrowing on radiography and**  
2 **anatomical and histopathologic integrity of anterior cruciate ligament in patients**  
3 **undergoing total knee replacement surgery**

4  
5 **Abstract**

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

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

17 **Results:** in 102 patients with mean age of  $69.73 \pm 7.81$  years , 39 patients (38.32%) had no or  
18 torn ACL, 31 patients (30.39%) had weak ACL, and 32 (31.37%) had normal ACL. There was a  
19 significant association between age and clinical status of ACL during surgery. There was a  
20 significant difference in FIN and ACL health status during surgery between the two groups with  
21 an index of more and less than 0.252. There was no significant difference in mean total  
22 degeneration score (TDS) of ACL between the two groups with FIN more and less than 0.252.

23       **Conclusion:** There was a significant difference between the age and FIN narrowing (less than  
24 0.252) and ACL clinical status during surgery. FIN narrowing had no significant effect on the  
25 severity of ACL degeneration and there was no significant difference in the severity of  
26 degenerative histopathologic changes between healthy and attenuated ACLs. This indicates that  
27 if ACL exists, although apparently attenuated, it has the histologic characteristic of a healthy  
28 ligament

29       **Level of evidence:** prospective cohort, level II.

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

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### 33 **Introduction**

34 Total knee arthroplasty (TKA) is the most effective and commonly used procedure for treating  
35 advanced knee osteoarthritis (1). In the early 1970s, modern knee arthroplasty developed by  
36 development of condylar knee prosthesis. Bi-cruciate retaining prostheses were introduced in  
37 1971 (2), designed with the aim of keeping ligaments, minimal bone resection, and close-to-  
38 normal knee movements, compared to other prostheses (3).

39 Maintaining ACL in TKA improves knee kinematics, proprioception, maximum flexion, and  
40 generally knee position (4).

41 Degenerative changes are observed in knee ligaments during TKA followed by osteoarthritis,  
42 especially in posterolateral bundle of ACL (5). It seems that achieving close-to-optimal knee  
43 function following TKA may be due to inability to place specific prostheses to replace the

44 normal complex knee kinematics (6,7). Therefore, the first thing to keep in mind is maintenance  
45 of normal knee structure as much as possible. In particular, the cruciate ligaments is an important  
46 criterion for obtaining the knee kinematics and may play an important role in unicompartement  
47 arthroplasty and arthroplasty using cruciate and bicruciate-retaining prostheses (3, 8). In  
48 unicompartement arthroplasty, keeping the cruciform ligaments improves joint stability and soft  
49 tissue balance and maintains normal kinematics of the knee. It has been suggested that, in  
50 laboratory studies, the absence of cruciate ligament, due to increased slip between the tibia and  
51 femur, causes polyethylene irritation and increase prosthesis failure (9, 10).

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

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

## 68 **Methods**

69 In this observational study, conducted as prospective analytic cohort, a total of 102 candidates of  
70 knee replacement were enrolled and examined for FIN.

71 The demographic data, including age, gender, and degree of flexion contracture and deformity in  
72 the preoperative coronal plane were evaluated.

73 FIN was examined in Tunnel view (postero-anterior knee radiography in 45 degrees of knee  
74 flexion so that the patella touches the radiation receptor, at a 10-inch distance from the knee and  
75 10 degrees caudal) (27) and obtained by dividing the notch width to the greatest distance  
76 between the two condyles in popliteal groove (28). Subsequently, the patients were divided into  
77 two groups with an index greater than zero point two five two and an index less than zero point  
78 two five two (29). (Figure 1)

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

81 To determine the histopathologic health of ACL during the operation, transverse and longitudinal  
82 specimens were taken, the proximal one third of ACL was removed and fixed in formalin. Then,  
83 four microscopic cuts were taken from specimens, stained with Hematoxylin & Eosin, and  
84 investigated in terms of myxoid changes, cystic myxoid or microcystic formation, chondroid  
85 metaplasia, acellular zone, vascular proliferation, fibroblast proliferation, calcium pyrophosphate  
86 deposits, and presence of gout. Pathologic changes were classified into four categories: absent  
87 (0), mild (1), moderate (2), and marked (3) based on each of the above items and classified

88 according to degenerative histologic changes and then total degenerative score (TDS) was given  
89 to each sample (24, 30, 31).

90 The inclusion criteria included advanced knee osteoarthritis and the exclusion criteria included  
91 underlying neuromuscular disease, knee joint degeneration due to underlying diseases such as  
92 rheumatologic diseases, previous infection or fracture at the knee joint surface, and damage to  
93 the knee ligament. Data were analyzed using SPSS software version 20.

## 94 **Results**

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

98 There was no significant difference between the two groups with FIN more and less than zero  
99 point two five two in terms of age ( $p = 0.318$ ) and gender ( $P=0.081$ ) (Table 1).

100 In general, 39 (38.32%) patients had no or torn ACL, 31 patients (30.39%) had weak, and 32  
101 (31.37%) had healthy ACLs. Of 102 patients, 47 cases (46.08%) had FIN score of greater than  
102 zero point two five two and 55 patients (53.92%) less than zero point two five two. In total, 41  
103 patients (40.2%) had no or torn ACLs and 63 patients had weak or healthy ACLs, sent for  
104 histopathologic examination. There was a significant association between age and anatomical  
105 status of ACL ( $p = 0.017$ ) and ACL health status worsened as age increased. There was no  
106 association between patients' gender and anatomical status of ACL ( $p = 0.17$ ).

107 Comparison of anatomical status of ACL between groups with FIN index more and less than  
108 zero point two five two showed statistical difference in clinical status of ACL between the  
109 groups ( $p = 0.019$ ). In the group with notch narrowing, more than 50% of ACL were torn, but in

110 the group with a high notch index, ¼ of ACLs were torn. In the group with high notch index,  
111 ACL was completely healthy in 40% of cases, but in the group with notch narrowing, ACL was  
112 completely healthy in 23% of cases (Table 1).

113 Comparison of mean TDS of ACL, defined as total histopathological changes resulting from  
114 ACL degeneration, between two groups showed that the mean TDS of ACL was  $3.30 \pm 2.00$  in  
115 all patients. There was no significant difference in the mean TDS of ACL ( $p = 0.816$ ) between  
116 the two groups with FIN index more and less than zero point two five two, that is, notch  
117 narrowing had no significant effect on ACL ligament degeneration severity (Table 1).

118 Comparison of histopathologic status of ACL between two groups showed no significant  
119 difference in histopathologic changes of ACL between the two groups with FIN index more and  
120 less than zero point two five two ( $p > 0.05$ ). With regard to the fact that no sample was taken from  
121 patients with torn ACLs, the results suggest that patients with a healthy or weak ACL, regardless  
122 of the severity of narrowing, show similar histopathological changes (Table 2).

123 Investigating the association between ACL anatomic status during surgery and histopathologic  
124 changes in ACL: Based on this study, there was no significant difference between healthy and  
125 weak ACLs in terms of intensity of degenerative changes in histopathology ( $p > 0.05$ ) (Table 3).

126 The total degenerative score in patients with normal ACL was  $3.96 \pm 1.89$  and in the attenuated  
127 ACL group was  $3.16 \pm 1.71$  ( $P = 0.081$ ) (Table 4).

128 Comparison of mean  $\pm$  standard deviation of TDS of ACL in different life decades showed no  
129 association between the life decades and TDS changes in ACL ( $P = 0.583$ ). There was no  
130 association between age and TDS of ACL ( $P = 0.839$ ).

131 Comparison of mean and standard deviation of TDS of ACL and gender (Table 4) showed no  
132 association between gender and TDS of ACL ( $p = 0.196$ ).

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

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

### 139 **Discussion**

140 In this observational prospective analytic cohort study, 102 patients (102 knees), candidates of  
141 TKA, were enrolled. The mean age of patients was  $69.73 \pm 7.81$  years; 77 (77.5%) were female  
142 and 25 (24.5%) were male. There was no statistically significant association between age and  
143 gender with FIN index ( $p > 0.05$ ).

144 There was a significant difference in FIN narrowing with ACL health status during surgery  
145 between two groups with index of more and less than zero point two five two ( $p = 0.019$ ), so that  
146 in more than 50% of patients who had notch narrowing, ACL was not present or was torn during  
147 surgery. However, there was no significant difference between notch narrowing and  
148 histopathological changes in ACL ( $p > 0.05$ ).

149 The mean TDS of ACL was  $3.30 \pm 2.00$  in all patients and there was no significant difference in  
150 the mean TDS of ACL between the two groups with FIN more or less than zero point two five  
151 two ( $p = 0.816$ ). This means that notch narrowing has no significant effect on the severity of  
152 ACL ligament degeneration. There was no statistically significant difference between healthy

153 and weak ACL in terms of intensity of degenerative histopathologic changes ( $p > 0.05$ ). Mean  
154 TDS score in patients with normal ACL was  $3.96 \pm 1.89$  and in the attenuated ACL group was  
155  $3.16 \pm 1.71$  ( $P = 0.081$ ).

156 . This indicates that if ACL exists, although apparently weak, it has histologic characteristics of a  
157 healthy ligament and may be functional in biomechanical and proprioceptive aspects. There was  
158 an association between age and anatomical status of ACL ( $p = 0.017$ ) and the anatomical status  
159 of the ACL worsened by increasing age, while there was no association between gender and  
160 ACL health status ( $p = 0.107$ ).

161 There was no significant difference between life decades and TDS of ACL ( $p > 0.05$ ) or between  
162 gender and TDS of ACL ( $p > 0.05$ ).

163 There was no significant difference between TDS of ACL and the degree of flexion contracture  
164 deformity ( $p > 0.05$ ) and TDS of ACL was not significantly different between the two groups  
165 with flexion contracture less or more than 15 degree ( $P > 0.05$ ).

166 Geng et al. conducted a study, entitled “Intercondylar notch narrowing and ACL injury in non-  
167 athlete women with knee osteoarthritis” and compared 330 patients with ACL injury, 141  
168 patients with knee osteoarthritis, and 89 healthy controls in the control group and showed that  
169 intercondylar notch narrowing was associated with ACL injury in knee osteoarthritis at the age  
170 of 41 to 65 years. In this study, the cut off for the intercondylar notch was less than zero point  
171 two six (32). The results of their study were consistent with our study. In our study, there was a  
172 significant difference between FIN with ACL status in the two groups with an index more and  
173 less than zero point two five two ( $p = 0.019$ ) and ACL was not present or was torn during  
174 surgery in more than 50% of patients with narrowing.



175 In Chen's study on 79 patients with moderate to severe knee osteoarthritis and 71 healthy  
176 patients, there were 38 patients with ACL injury and 41 patients with osteoarthritis without ACL  
177 tear. NWI was measured by MRI in three sequences: NWI-1 axial sequence, NWI-2 sagittal  
178 sequence, and NWI-A at ACL connection to femur. It was found that notch narrowing and Type  
179 "A" notch are a risk factor for moderate to severe osteoarthritis associated with ACL injury (33).  
180 These results are consistent with our study. In our study, there was a significant difference in FIN  
181 narrowing with ACL health status during surgery between two groups with an index of more and  
182 less than zero point two five two ( $p = 0.019$ ), as more than 50% of patients with notch narrowing  
183 had no or torn ACL during surgery.

184 Monte et al. (2015) conducted a similar study to assess ACL histopathology on 174 patients  
185 undergoing knee replacement surgery. ACL was healthy in 43 cases, weak in 85, torn in 15  
186 cases, and did not exist in 31 cases. In 85% of cases, ACL showed histopathologic changes of  
187 degeneration. The higher the osteoarthritis grade, the more the histopathological changes,  
188 especially regarding phosphate. In grade four, osteoarthritis changes were significantly  
189 associated with calcium pyrophosphate deposition, formation of microcysts, and a number of  
190 pathological changes. In general, high ages are associated with histopathological changes (34).  
191 Their study results differed from our study. In our study, there was no difference between the  
192 clinical and histopathological ACLs, but in the study of Monte et al. changes in grade four  
193 osteoarthritis significantly correlated with deposition of calcium pyrophosphate, formation of  
194 microcysts, and a number of pathological changes. In addition, in our study, age and  
195 histopathological changes were not associated, but there was a positive association between age  
196 and clinical status of ACL ( $p = 0.017$ ) and ACL status worsened as the age increased; the reason  
197 for this difference could be that in the study of Monte et al. ACL was clinically divided into four

198 groups of healthy, attenuated, torn, and no ACL and histopathological changes in ACL were  
199 categorized into three groups: healthy, attenuated, and torn ACL, whereas in our study, clinical  
200 ACL was divided into three groups: healthy, attenuated, and torn, and histopathologic changes  
201 into two groups of healthy and attenuated ACL and no sample was taken from torn ACLs for  
202 histopathological examination. Another difference between studies was the sample size that was  
203 174 in Monte's study and 102 in our study.

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

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

217 Stein et al. (2010) studied the histopathologic changes in macroscopically healthy ligaments and  
218 Trompetor et al. analyzed 55 ACLs during knee replacement surgery, 31 cases of which were  
219 macroscopically healthy cruciate ligament, and showed that in histological examination, 72%  
220 had moderate to severe histologic changes (36). In our study, there was no statistically significant

221 difference in severity of degenerative histopathologic changes between completely healthy and  
222 weak ACLs ( $p > 0.05$ ). The overall TDS in patients with normal ACL was  $93.3 \pm 1.94$  and in the  
223 group with weak ACL was  $3.04 \pm 1.70$  ( $P = 0.04$ ).

224 In another study, Al-Saeed et al. studied the association between the intercondylar notch  
225 morphology, width index, and the risk of ACL injury and showed that type “A” femoral notch  
226 was a risk factor for ACL tear, while reduced notch index had no significant association with  
227 ACL tear (37). These results are not consistent with our study. In our study, there was a  
228 significant difference between FIN narrowing and ACL health status of patients during surgery  
229 ( $p = 0.019$ ), as ACL was not present or was torn during surgery in the more than 50% of patients  
230 with narrow notch.

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

236 Mullaji (2008) evaluated 45 ACLs in patients with knee replacement and found severe  
237 degenerative changes was more common in severe than low grade osteoarthritis (25). In our  
238 study, there was no significant difference between notch narrowing and histopathologic changes  
239 in ACL ( $p > 0.05$ ). The mean TDS of ACL was  $3.30 \pm 2.00$  in all patients. There was no  
240 significant difference in the mean TDS of ACL between the two groups with FIN less than zero  
241 point two five two ( $p = 0.816$ ).

242 Levy et al. stated in a study, entitled “Histopathological changes in PCL by aging and  
243 osteoarthritis and its association with cartilage and ACL changes” on 120 samples that ligament  
244 degeneration was more in older people, but the association was weak and not significant (24). In  
245 our study, degenerative changes in ACL and PCL were not significantly different with age.

246 **Conclusion:**

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

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359 Figure 1; measuring method of femoral intercondylar notch width index

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