Introduction: The anterior cruciate ligament (ACL) plays an important role in restraining anterior tibial translation (ATT) and tibial rotation. In ACL injured patients, thick ACL remnants were frequently observed and bridged between the tibia and either femur or posterior cruciate ligament (PCL) during the arthroscopic inspection. Recently, some studies reported that human ACL remnants contain several types of mechanoreceptors which may contribute to proprioceptive functioning of knee. On the other hand, there were several reports regarding the biomechanical function of ACL remnants by the KT or navigation measurements[1-3], however, its biomechanical function has not been fully examined. Therefore, the purpose of the present study is to quantitatively evaluate the biomechanical function of ACL remnants in antero-posterior (A-P) and dynamic knee stability in ACL injured patients. It is hypothesized that the ACL remnants, which are attached to the non-anatomical ACL insertion sites, did not contribute to the knee stability.

Methods: One hundred and twenty one unilateral ACL injury patients (59 male/ 62 female, 25±10 y.o.) who underwent primary ACL reconstruction between December 2008 and December 2012 were included in this study. The patients diagnosed as partial ACL tear were excluded. In addition, the patients who had severe collateral ligament injury, PCL injury or contralateral knee injury were also excluded.

All patients were evaluated under general anesthesia before ACL reconstruction. ATT was measured using the KT-1000 Knee Ligament Arthrometer (Medmetric Corp., San Diego, CA) with the knee at 30 degrees of flexion in both injured and contralateral knee, and the mean side to side difference in ATT was calculated. ATT during the Lachman test, and tibial acceleration during the pivot shift test were also measured using an electromagnetic device (Liberty, Polhemus, Colchester, VT, USA)[4 5]. This electromagnetic measurement system (EMS) consists of a transmitter that produces an electromagnetic field and three electromagnetic receivers. Two of the receivers were firmly attached on the thigh and the calf with a plastic brace and were used to track the femoral and tibial motion respectively. Each femoral and tibial coordinate system proposed by Grood was configured from the three dimensional position data of anatomical landmarks which were digitized by the third receiver and provided six degree-of-freedom knee kinematics. The mean side-to-side difference in ATT during the Lachman test was calculated.

Subsequently, arthroscopic evaluation was performed, and the configuration of the ACL remnants and their attachments to the femur or PCL were characterized. The attachments of the ACL remnants were classified into 4 morphologic patterns as follows, group 1: bridging between PCL and tibia, group 2: bridging between the roof of intercondylar notch and tibia, group 3: bridging between the lateral wall of the intercondylar notch and tibia, group 4: no substantial ACL remnants, as Crain EH, et al. previously reported[1].

All values were showed as mean ± standard deviation. One way Analysis of variance (ANOVA) was used to compare each value between 4 groups, and post hoc analysis was performed using Fisher’s protected least significance difference test. A P-value <0.05 was considered statistically significant.

Results: The morphologic patterns of the ACL remnants were as follows: group 1, 27 knees (22.3%); group 2, 34 knees (28.1%); group 3, 27 knees (22.3%); group 4, 33 knees (27.3%). There were no statistically significant differences between 4 groups with age, sex, period from injury to surgery, or meniscal injury (Table 1).

The mean side to side difference of ATT using KT-1000 arthrometer was 5.2±3.4, 5.7±3.1, 3.4±2.0, 5.9±3.0 (mm) in group 1, 2, 3, and 4 respectively. In group 3, the mean side to side difference of ATT using KT-1000 arthrometer was significantly small than those in group 2, 4 (p<0.05). That in group 1 was larger than that in group 3, but there was not statistically significant difference (Figure 1). The mean side to side difference of ATT during the Lachman test was 8.6±3.8, 8.5±3.5, 5.3±3.1, 7.6±2.9 (mm) in group 1, 2, 3, and 4 respectively. The mean side to side difference of ATT during the Lachman test in group 3 was significantly small compared with those in group 1, 2 and 4 (p<0.05) (Figure 2). On the other hand, tibial acceleration was 2.0±1.1, 1.7±0.6, 1.9±0.6, 1.8±1.0 (m/sec²) in group 1, 2, 3, and 4 respectively. There was no statistically significant difference in tibial acceleration between each group (Figure 3).
Discussion: The main finding of the present study was that ACL remnants of group 3 partially contributed A-P stability, but did not contribute dynamic knee stability evaluated with tibial acceleration during the pivot shift test. Crain EH, et al.[1] firstly reported about ACL remnants, and showed that the resection of ACL remnants attached with the femur increased anterior knee laxity. Nakamae A, et al.[2] demonstrated that ACL remnants which attached with PCL or femur contributed to A-P knee stability for up to 1 year after injury using a navigation system, but this contribution to A-P stability was less than ACL partial tears. Maeda S, et al.[3] also reported that ACL remnants bridged with lateral wall of intercondylar notch significantly decreased anterior knee laxity, but the knee stability provided by ACL remnants was not adequate. In the present study, group 3 ACL remnants significantly decreased ATT not only with KT-1000 arthrometer but also with EMS during Lachman test, which was similar with previous reports[1-3]. However, ACL remnants did not decrease the tibial acceleration during the pivot shift test which is correlated with knee function and patient satisfaction.

In conclusion, the present study suggests that ACL remnants did not have enough contribution to the stabilization of the knee joint. Therefore, in patients with non-anatomic ACL remnants, augmentation procedure is not appropriate in the biomechanical point of view although ACL remnants preservation may be important for biological healing.

Significance: The antero-posterior and dynamic knee stability provided by ACL remnants was quantitatively evaluated using the electromagnetic measurement system. It was suggested that non-anatomical ACL remnants attached to PCL or intercondylar notch had insufficient contribution to the stabilization of the knee joint.

Acknowledgments:

Table 1. Patient profile

<table>
<thead>
<tr>
<th>Group 1 (attached to PCL)</th>
<th>Number</th>
<th>Age at surgery (y.o.)</th>
<th>Sex (male/female)</th>
<th>Injury-surgery period (days)</th>
<th>Meniscal tear (number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 2 (attached to the roof of intercondylar notch)</td>
<td>34</td>
<td>25.7±9.0</td>
<td>17/17</td>
<td>179.0±189.1</td>
<td>12</td>
</tr>
<tr>
<td>Group 3 (attached to the lateral wall of intercondylar notch)</td>
<td>27</td>
<td>23.5±9.7</td>
<td>16/11</td>
<td>131.0±93.1</td>
<td>8</td>
</tr>
<tr>
<td>Group 4 (no attachment)</td>
<td>33</td>
<td>24.0±9.2</td>
<td>15/18</td>
<td>173.0±226.7</td>
<td>14</td>
</tr>
</tbody>
</table>

There was no statistically significant difference between each group.
Figure 1. The mean side-to-side difference of ATT using KT-1000 arthrometer.
The mean side-to-side difference of ATT in group 3 was significantly small compared with group 2 and 4 (*p<0.05).
Figure 2. The mean side-to-side difference of ATT during the Lachman test.
The mean side-to-side difference of ATT in group 3 was significantly small compared
with group 1, 2 and 4 (*p<0.05).
Figure 3. Tibial acceleration during the pivot shift test. There was no significant difference between each group (n.s.: not significant).