A Radiological Study after Anterior Cruciate Ligament Reconstruction

Background. Disruption of the anterior cruciate ligament is a common injury, often resulting in functional instability. Currently, arthroscopic anterior cruciate ligament (ACL) reconstruction using the central third bone-patellar tendon-bone graft is a common surgical procedure. The purpose of this study was to evaluate the postoperative structural remodeling in the ligament following ACL reconstruction over time by X-ray and magnetic resonance imaging (MRI).

Methods. We performed arthroscopic ACL reconstruction with central third bone-patellar tendon-bone autograft for 27 patients (14 males, 13 females, mean 27.2 years old) between October 1995 and January 1999. All patients were examined postoperatively at 3, 6, 12, and 18 months by X-ray to evaluate the sequential change of the tibia bone tunnel and by MRI to monitor the sequential signal changes in the recipient and donor sites.

Results. The MRI showed an increased signal at the patellar tendon (donor site) at 3 and 6 months and decreased signal after 1 year. The signal of ACL graft from MRI remained in increased after operation. On AP, lateral view of X-ray, the diameter at the joint site of the tunnel was larger than at the bone plug site. Pearson correlation analysis revealed that the diameter of the bone tunnel expanding at the joint site was statistically greater than that at the bone plug site (p < 0.05). The difference between the bone tunnel diameter at the bone plug site and the joint site was not statistically correlated with the distance between them (by linear regression method, p = 0.77).

Conclusions. We concluded that the windshield wiper effect could not be the only factor in the large extent of the bone tunnel, based on our results. The signal change of patellar tendon was more obvious than that of the bone-patellar tendon-bone graft.

Key Words
anteri or cruciate ligament; magnetic resonance imaging; patellar tendon

Original Article


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METHODS

Twenty-seven patients (14 males, 13 females; 18-45 years old, mean age, 27.2 years) underwent arthroscopic ACL reconstruction with central one-third bone-patellar tendon-bone autograft by the same surgeon between October 1995 and January 1999. All patients were evaluated for more than 18 months, postoperatively.

Surgical procedure

Each patient was instructed to lie in supine position and prepared for the knee operation in an aseptic manner. The arthroscopic ACL reconstruction was performed under pneumatic tourniquet inflation. A longitudinal skin incision was made from middle pole of the patella to the tibial tuberosity. The autogenous central third bone-patellar tendon-bone graft was obtained (10 mm width of the patellar tendon autograft). Anterolateral, anteromedial and central transpatellar tendon portal were used. Then removal of ACL stump and notchplasty were performed. With the aid of a targeting device, a tibial guide pin was inserted from the medial aspect of the proximal tibia to the posterior area of the footprint of the ACL. Along the tibial guide pin, a 10 mm width of tibial tunnel was created by using a hollow reamer. A femoral guide pin was inserted through the tibial bone tunnel into origin area of anterior cruciate ligament. Then a 10 mm wide, 30 mm depth of femoral tunnel was also created. The graft was passed from the tibial bone tunnel. Then the patella plug portion of the graft (femoral site) was fixed to the femoral tunnel with an interference screw just grossly near the joint. The tibial plug portion of the graft was fixed with an interference screw under 20 degrees of flexion. The bone from the tibial bone tunnel was impacted into the defect of the patella and tibia. The defect of the patellar tendon was closed by running suture.

Evaluation methods

All patients were examined by X-ray and MRI examination at 3, 6, 12, and 18 months following their surgery. Each patient underwent a standardized anteroposterior (AP) and lateral X-ray in full extension (0 degrees). We put a ruler by the test knee the first time, and in the following period we used the dimension of the tibia plateau as reference to determine the magnification factor. The diameter of the bone tunnel was measured between the sclerotic margins. The width of the tunnel was measured at the bone plug site and the joint site. The bone plug site of the tibial tunnel was defined as a point between the patellar tendon and the tibial bone plug in the graft. The joint site was defined as the point out of the tunnel near the knee joint (Fig. 1). We used linear regression method for comparing tunnel width change between the bone plug site and the joint site. We also used Pearson correlation method for evaluating the relation between the tunnel width change (bone plug and joint site) and the tunnel length. A p-value of less than 0.05 was considered statistically significant.

All patients underwent MRI examination using a 1.5 T MRI unit (Signa; General Electric, Milwaukee, WI, USA). The signal intensity of the patellar tendon and graft were measured in the middle of them by using a circle with radius of 1 mm on T1-weighted image. The thickness of the patellar tendon was measuring on the middle of it. Changes of the sequential signal in ten sity in the patellar tendon, graft, and the thickness of the patellar tendon were measured by MRI.

RESULTS

The MRI signal in ten sity of the patellar tendon increased at 3 and 6 months following surgery and decreased...
to a lower level after one year (Fig. 2). Similarly, the thickness of the patellar tendon increased soon after the operation, but declined after 6 months (Fig. 3). The MRI signal of the ACL graft remained high throughout the follow-up period (Fig. 4). The length of the patellar tendon on MRI decreased in the following period (Fig. 5).

From the AP view of the knee, the average diameters of the bone tunnel at the joint site and bone plug site at 3, 6, 12, and 18 months increased (Table 1). Linear regression method revealed that the diameter of the bone tunnel expanding at the joint site were statistically greater than at the bone plug site (p < 0.05) in all AP and lateral views. The average length of the bone tunnel length (distance between the bone plug and joint site) was 1.6 ± 0.4 mm (mean ± SD). The difference in expansion between the bone plug site and joint sites was not statistically correlated with the distance between them (by Pearson correlation, p = 0.77).

**DISCUSSION**

Bone tunnel enlargement after ACL reconstruction is the result of resorption or osteolysis in the bone tunnel. The etiology of this process is unknown, although various potential causes of bone tunnel enlargement have been previously proposed and discussed. In general, biological and mechanical factors can be distinguished. Biological factors include antigenetic immune response (allografts), toxic effect (ethylene oxide, metal), non-specific inflammatory response (cytokines), cell necrosis from thermal injury during drilling (heat effect), and cell necrosis from graft remodeling (avascularity). On the other hand, mechanical factors in clude local stress applied on the tunnel wall by the donor tendon, motion of the graft within the tunnel, aggressive rehabilitation, and increased graft forces due to improper graft placement.

Due to the fact that the length of the tendinous portion of the bone-patellar tendon-bone graft is generally...
longer than the original ACL, when the femoral site is fixed grossly near the joint, then the tendon-in-bone phenomenon is created over the proximal portion of tibial tunnel. Furthermore, due to the flatness of the patellar tendon graft (approximately 10 mm wide and 4 mm thick), the cross-sectional area of the tendinous graft portion is smaller than the tibia tunnel. As a result, a substantial amount of dead space will exist in the proximal part of the tibial tunnel next to the tendinous portion of the graft. This will allow motion of the graft at the level of the tibial tunnel when the joint is moved throughout the range of motion. This phenomenon has been referred to as the windshield wiper effect. Described by L’Insalata et al. who observed significant bone tunnel enlargement on the tibial site and not such effect on the femoral side when using this technique, the magnitude of this motion can theoretically be increased with the fixation of the graft in a position more distant to the joint line or osseous tunnel entrance.

Due to the windshield wiper effect, the enlarged diameter of the bone tunnel at the joint site should be larger than at the bone plug site. The greater the distance between the joint site and the bone plug site, the greater the expansion on the bone tunnel. By correlation analysis, the difference between the bone tunnel diameter at the joint site and the bone plug site was not statistically correlated with the distance between them. Consequently, we concluded that the windshield wiper effect could not be the only factor in ducing the enlar gement of the bone tunnel, based on our results. The cause of en lar gement of the tibial bone tunnel may be due to multiple factors. More over the greater en lar gement of the tibial tunnel at the joint site compared to that at the bone plug site was no tic ed to occur sig ni ficantly in the first-half year after the operation in our group.

The results of our study showed that in the early post-operative period, the signal in ten sity of the patellar tendon after harvesting was signifi cantly increased relative to that of the pre-operative knee. After 6 months, the signal in ten sity of the patellar tendon reached the highest levels and decreased with time until 1 year after the operation. The signal in ten sity of the patellar tendon even tu ally decreased to near pre-operative con dition after 1 year. On the other hand, the signal in ten sity of the ACL graft was persistently high and slowly decreased on a curve. According to Stockle et al. the signal in ten sity of the neo-ACL ligament persistently increased until 1 year post-operation, where it reached a maximal level and de creased after two years. Con sequently if one patient received ACL reconstruction and incurred a knee injury afterwards, MRI evaluation of the neo-ligament would be misleading.

The in creases in signal in ten sity of the ACL graft after the operation is the result of three common causes, according to Cheung,21 surgical repair, synovial prolifera tion, and revascularization. Furthermore, Boynton suggested that the patellar tendon graft progresses through four stages of transformation: avascular necrosis, revascularization, cellular proliferation, and remodeling. Revascularization of the patellar tendon graft occurs from the synovial fold and endosteal ves sels in the bone tunnels of the ACL graft. Graft revascularization is complete at 20 weeks, progressing from a vascular synovial covering at 6 weeks and in trac tic ves sels for ma tion at 6 to 10 weeks postoperatively.7 Synovial-like membranes that were identified around loose total joint implants were shown to contain a large num ber of macrophages, among other inflammatory cells, which were capable

### Table 1. Sequential width changes of the tibial tunnel

<table>
<thead>
<tr>
<th></th>
<th>N = 27</th>
<th>3 months</th>
<th>Postoperative follow-up</th>
<th>6 months</th>
<th>12 months</th>
<th>18 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint site AP</td>
<td>13.0 ± 2.3</td>
<td>14.6 ± 2.5</td>
<td>14.7 ± 2.7</td>
<td>14.5 ± 2.1</td>
<td></td>
<td></td>
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<tr>
<td>Bone plug site AP</td>
<td>12.1 ± 1.7</td>
<td>13.7 ± 2.3</td>
<td>13.5 ± 2.5</td>
<td>13.1 ± 2.1</td>
<td></td>
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<tr>
<td>Joint site Lateral</td>
<td>14.4 ± 2.0</td>
<td>14.7 ± 1.8</td>
<td>14.5 ± 2.1</td>
<td>14.6 ± 1.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bone plug site Lateral</td>
<td>13.0 ± 1.7</td>
<td>12.9 ± 1.7</td>
<td>12.9 ± 2.4</td>
<td>13.0 ± 1.2</td>
<td></td>
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AP = Bone tunnel width in anteroposterior view of knee. Lateral = Bone tunnel width in lateral view of knee. The unit of the bone tunnel width was mm. Values represent mean ± SD.
of releasing various cytokines such as interleukin I, tumor necrosis factor alpha, and prostaglandin E2. Cytokines are soluble proteins that act as intercellular messengers that can induce cell proliferation and protein synthesis as well as mediate tissue destruction, repair, and remodeling. High levels of these cytokines are known to stimulate ostelclastic activity, resulting in subseuent bone resorption. There are also in hib i tors in the joint fluid. ACL graft remodeling occurs more slowly at the knee Joint than the donor site of the patellar tendon.

A significant increase in the thickness of the patellar tendon was noted at all peri ods of the fol low-up after harvesting. The thick ness of the patellar tendon increased with time and reached its max i mum thick ness at ap prox i mately 6 months after the op e ration. The thick ness seems to per sist, then slowly de creases. In the Coupens se ries, a sig ni ficant increase in the thick ness was noted at all pe ri ods of fol low-up. Why does the thick ness of the pa tella tend on increase after harvesting? According to data of Kartus et al. the central part of the harvested patella tendon had increased cellularity and vascularity compared with both its peri pheral part and a nor mal tendon. The thick ness of the har vested patellar tendon increased after har vesting and de creased with time after 6 months. This reaction appeared to be more marked in the central part than the peripheral part of the tendon 26 months after the harvesting procedure. They believed that the in crease in cellularity and vascularity in the peripheral part was a com pensatory mecha nism in response to the har vest ing of the cen tral portion of the patellar tendon.

Because of the effect of the titanium interference screw in MRI, we could not observe the structural re-modeling of the tunnel. A bioabsorbable interference screw combined with cin ematic resonance imaging would solve this problem. We concluded that the wind shield wiper effect could not be the only factor in ducing the en large ment of the bone tunnel, based on our results. The signal change of the expanded tunnels may also provide further information on the etiology and biology of tunnel expansion following ACL reconstruction.

We con cluded that the wind shield wiper effect could not be the only factor in ducing the en large ment of the bone tunnel, based on our re sults. The sig nal change of patellar tendon was more ob vi ous than that of the bone-patellar tend on-bone graft.

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