The Effect of Early Motion on Tibial Tunnel Widening After Anterior Cruciate Ligament Replacement Using Hamstring Tendon Grafts

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Purpose: The purpose of this study was to evaluate the hypothesis that early motion increases tibial tunnel enlargement in patients who underwent anterior cruciate ligament (ACL) replacement with hamstring autograft. **Type of Study:** Cohort analytic study. **Methods:** All patients in this study had received a doubled semitendinous and gracilis graft. Grafts were secured in place with an implant–free technique. Two groups of patients were evaluated. Group A consisted of 35 patients who underwent isolated ACL replacement and whose rehabilitation protocol included early motion. Group B consisted of 20 patients who underwent combined arthroscopic meniscal repair and ACL replacement. Partial weight bearing and restriction of range of motion for 6 weeks was recommended for these patients. The only 2 variables between the groups were the meniscal repair and the postoperative rehabilitation. Patients were evaluated clinically and radiographically at 3, 6, and 12 months postoperatively. After correction for radiographic magnification, the tibial tunnel was measured at distal (T1), middle (T2), and proximal (T3) locations on both anteroposterior and lateral views. **Results:** At 1-year follow-up evaluations, tunnel enlargement was significantly higher in the group with early motion, in both the anteroposterior and lateral views, in all but one location (anteroposterior, T1). The enlargement was greater in the mid-portion (T2) of the tunnel in both groups. The mean percentage was 45.92% for group A and 23.34% for group B ($P < .05$) in the anteroposterior view, and 48.14% for group A and 24.47% for group B ($P < .05$) in the lateral view. No correlation was found between tunnel enlargement and clinical results or between tunnel enlargement and joint laxity measured by a KT-1000 arthrometer. **Conclusions:** Our study confirms that early motion increases the amount of tibial tunnel enlargement after anterior cruciate ligament replacement with hamstring autograft. This may have an impact on future rehabilitation protocols. **Level of Evidence:** Level II. **Key Words:** Tibial tunnel enlargement—ACL reconstruction—Hamstring autograft.

Reconstruction of the anterior cruciate ligament (ACL) with an autogenous quadrupled hamstring graft has recently become a popular and common procedure among orthopaedic surgeons. Good short- and medium-term clinical results have been reported with this technique.[1-4]

Tunnel widening, especially of the tibial bone tunnel, after this surgical technique has been reported during the past few years by many authors.[5-11] In fact, tunnel enlargement has been initially described with allograft tissues[12,13] and bone–patellar tendon–bone autografts after ACL reconstruction.[14-16] However, comparative studies have shown that tunnel widening is significantly greater after ACL reconstruction using hamstring autograft than in those using bone–patellar tendon–bone autografts.[5,7,10] Nevertheless, from the

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current literature, tunnel widening does not appear to correlate with a poor clinical result.

The etiology of this phenomenon is unknown and probably multifactorial. Hoher et al.[17] proposed that both biologic and mechanical factors are associated with tunnel widening. They hypothesized that a potential mechanical cause contributing to this radiographic observation could be aggressive rehabilitation after ACL reconstruction. The same authors suggested that comparative studies are necessary to evaluate whether aggressive rehabilitation is indeed associated with bone tunnel enlargement. To our knowledge, a comparative study to test this hypothesis has not been published.

Therefore, we designed a study to evaluate the amount of tibial tunnel enlargement after ACL replacement, with hamstring autograft in an implant-free technique (fixation without screws, pins, or other implants) developed by the senior author (H.H.P). Comparison regarding the amount of tibial tunnel widening was performed between a group of patients with a rehabilitation protocol that includes early motion (isolated ACL replacement) and a group of patients with a restriction in the range of motion for the first 6 weeks (ACL replacement and meniscal repair).

METHODS

Study Design

The inclusion criteria for the study were (1) an isolated primary arthroscopic ACL replacement (no concurrent meniscus or cartilage surgery) or a combined arthroscopic meniscal (medial or lateral) repair and ACL replacement simultaneously; (2) no previous knee ligament surgery; (3) a normal contralateral knee; and (4) radiographic evidence of physeal closure of the distal femur and the proximal tibia. Patients were excluded from the study if they showed additional ligament injuries, osteoarthritic changes of the knee joint, presence of a collagen disease, or skeletal immaturity.

In our department, patients with a combined ACL replacement and meniscal repair are treated with a slower rehabilitation protocol than patients with an isolated ACL reconstruction. Therefore, patients were assigned to 2 different groups according to the rehabilitation protocol.

Fifty-five consecutive knees in 55 patients who met the inclusion criteria were included in the study. These patients were divided into 2 groups: group A consisted of 35 patients with an isolated ACL replacement and group B consisted of 20 patients with a combined ACL replacement and meniscal repair. Comparison of the data showed that the 2 groups were well matched for age, gender, time to surgery, preoperative instability, and International Knee Documentation Committee (IKDC) and Lysholm knee scores (Table 1).

TABLE 1. *Patient Data From the 2 Study Groups*

	Group A	Group B	*P* Value
Age (y)	37.29 ± 8.75	32.23 ± 10.27	NS
Gender (men/women)	19/16	11/9	NS
Side (right/left)	20/15	12/2	NS
Time to surgery (mo)	17.9 ± 5.73	10.15 ± 7.67	NS
Lysholm knee score	51.4 ± 17	46.7 ± 13	NS
KT-1000 (132 N)	6.64 ± 2.78*	7.09 ± 1.64*	NS
IKDC			
Abnormal	22 (62.8%)	12 (60%)	NS
Severely abnormal	13 (37.2%)	8 (40%)	NS

Abbreviations: IKDC, International Knee Documentation Committee; NS, not significant.

*Measurements with the KT-1000 arthrometer as side-to-side difference.

Surgical Technique

All patients were treated between October 1998 and September 1999 by the senior author (H.H.P). The surgical technique for ACL replacement was identical in all patients.

Harvesting of the semitendinosus and gracilis hamstring tendons is performed through a 3-cm oblique incision. The ends of each tendon are tied in a simple knot, which is tightened under cyclic load and fixed with 3 No. 2 sutures (Fig 1). The diameter of the knot of the semitendinosus (which is thicker) and the diameter of both tendon loops are measured using a measuring device with 0.5-mm increments. A 5-mm Mersilene tape (Ethicon, Norderstedt, Germany) is placed at the loop of each tendon.

The femoral tunnel is drilled using an inside-out technique through the anteromedial portal with the knee flexed to 120°. The diameter of the drill corresponds to the diameter of the tendon loops. A cannulated impactor corresponding to the diameter of femoral tunnel is placed 10 to 12 mm into the femoral tunnel through the anteromedial portal. A K-wire is passed through the impactor and a 10-mm skin incision is made in the lateral aspect of the thigh where the K-wire perforates the skin. Overdrilling of the K-wire with a drill bit corresponding to the diameter of the

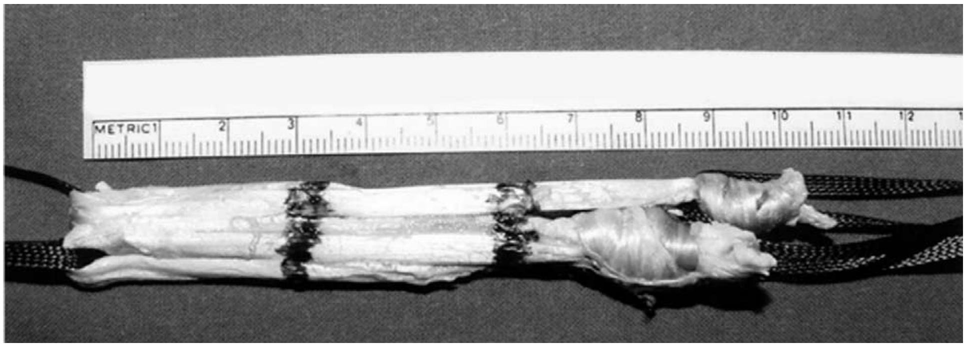

Figure 1. The hamstring tendons are tied and knotted. The knots are secured with Ethibond No. 2 sutures and held with Mersilene tape.

semitendinosus knot is performed until it reaches the tip of the cannulated impactor. By these means, a "bottleneck" femoral tunnel is created. A special cannulated impactor corresponding to the "bottleneck" femoral tunnel is placed from outside-in and is used to impact the remained cancellous bone (Fig 2). This will guarantee that the knot of the graft will be placed on cortical bone only.

After confirmation of correct placement of the guide pin, the tibial cortex is pierced with a reamer (the diameter is equal to the tendon loops of the hamstring tendons). This is followed by compaction drilling with a dilator of the same diameter, to compact the cancellous bone surrounding the tibial tunnel. The cortex of the tibial plateau is drilled under arthroscopic visualization.

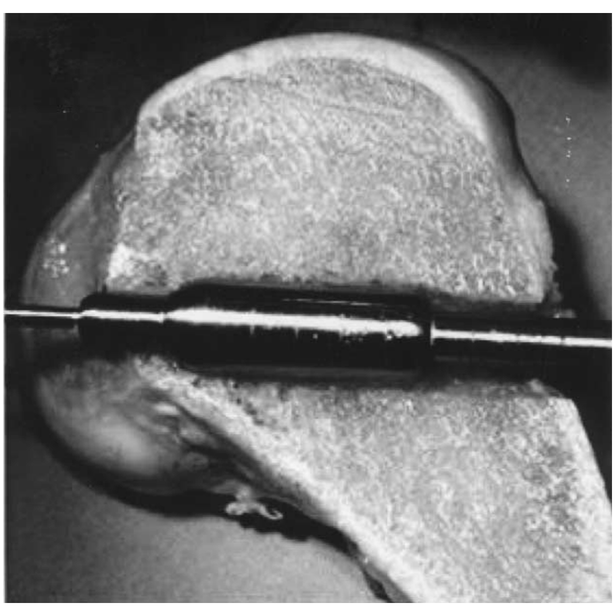

Figure 2. Demonstration of the femoral tunnel ("bottleneck" configuration) in a cadaver knee with the cannulated impactor in place.

Tendon loops are introduced from the lateral side of the femur into the femoral and tibial tunnels with the semitendinosus first, by pulling the Mersilene tapes. A sudden jolt indicates that the loops are settled in the "bottleneck." The gracilis follows the semitendinosus. The graft is conditioned under maximal manual loading by moving the knee through a full range of motion 20 times. Tibial fixation over a bone bridge is achieved by drilling a 4.5-mm drill hole 1-cm distal to the exit of the tibial tunnel. With a curved clamp, a bone tunnel is created in the underlying cancellous bone resulting in a cortical bone bridge over which the ends of the Mersilene tape from each tendon will be tied with the knee at 5° to 10° of flexion (Fig 3).

Meniscal repair was performed arthroscopically when indicated. Only longitudinal lesions in the red/red or red/white zone greater than 8 mm were repaired. The arthroscopic inside-out technique was used using a series of specifically prebent cannulas (zone specific) to access the posterior, middle, and anterior regions of the meniscus (Linvatec, Largo, FL). Absorbable polydiaxanone stitches (2-0), vertically orientated and 4 to 5 mm apart, were used to suture the tear.

Rehabilitation Protocol

The rehabilitation protocol for the patients with an isolated ACL arthroplasty includes an unrestricted range of motion of the knee immediately after surgery without a brace. Full weight bearing was allowed for these patients, and they were also allowed to discard their crutches as soon as they felt able to do it.

In the ACL-meniscal repair group, a knee brace allowing a range of motion of 0° to 60° and partial weight bearing was used for the first 3 weeks. Motion was limited for another 3 weeks to a range of motion of 0° to 90°, and full weight bearing was allowed by the end of the sixth postoperative week.

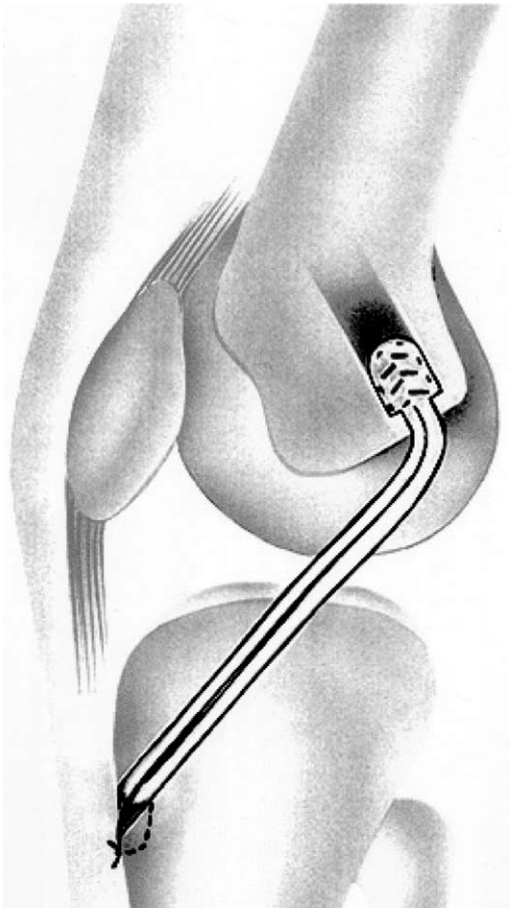

FIGURE 3. Final position of the hamstring ACL graft after tibial fixation.

Evaluation Protocol

Preoperative and postoperative evaluation of patients was performed using the Lysholm knee score[18] and the IKDC Standard Evaluation Form.[19] Joint laxity was assessed with the KT 1000 arthrometer (Medmetric, San Diego, CA).

Radiographic evaluation using anteroposterior (AP) and lateral (L) views of the treated knee was performed immediately after surgery and then at 3, 6, and 12 months postoperatively. The diameter of the tibial tunnel was measured at proximal (T3), middle (T2), and distal (T1) locations on both the AP and L view according to Peyrache et al.[14] To calculate the magnification factor, a metal ball of known diameter (10 mm) was taped on the film plate. The radiographic magnification factor was calculated from the ratio of the ball diameter on the radiograph to the actual ball diameter. The magnification factor was determined separately for the AP and L radiographs. The films were taken in the same manner in all patients. All measurements were performed by one examiner (M.E.H). A subset of 15 radiographs was randomly selected and reviewed by a second observer to determine interobserver variability.

Statistics

The non-paired *t*-test was used for comparison between the 2 groups and the amount of tunnel widening between time intervals. Pearson's correlation coefficient was used to determine the relationship between tunnel widening and clinical results. To determine interobserver variability, an interclass correlation coefficient was calculated. Significance was set at $P < .05$.

RESULTS

Two (6%) of 35 patients from group A were lost to follow-up and their data were excluded from the study. The rest of the patients from both groups (33 patients from group A, and 20 from group B) were available for the serial radiographic and clinical follow-up evaluations and constitute the subjects of this report.

Radiographic Results

The margins of the tunnels on the tibial side were well detected and easily identified on both AP and L views at 3 months, 6 months, and 1 year follow-up. In contrast, postoperatively (at time 0) the margins of the tibial tunnel were not detectable, and measurements at that time period were not made. Similarly, on the femoral side the diameters of the "bottleneck" tunnel were difficult to identify and therefore measurements were not made.

Analysis of radiographs revealed that tunnel enlargement was significantly higher in group A than in group B, on both the AP and L views, at all but one location (AP view, T1 location) and at all stages of follow-up evaluation (Table 2). Figs 4 and 5 show a typical example of tunnel configuration in 2 patients (one from each group) 1 year after surgery.

The percentage of tunnel widening was greater in both groups at the middle (T2) tunnel location on both the AP and L views at all stages of follow-up. This was 45.92% for group A versus 23.34% for group B ($P < .05$) in the AP view, and 48.14% for group A versus 24.49% for group B ($P < .05$) in the L view at 1 year follow-up.

TABLE 2. *Tibial Tunnel Enlargement at Different Time Intervals on Anteroposterior and Lateral Views at Proximal, Middle, and Distal Locations Between the 2 Groups*

	T1(AP)	T1(L)	T2(AP)	T2(L)	T3(AP)	T3(L)
3 mo follow-up						
Group A	19 ± 16	20 ± 9	35 ± 30	37 ± 28	27 ± 18	32 ± 17
Group B	14 ± 13	11 ± 10	18 ± 6	19 ± 6	14 ± 8	17 ± 12
P value	.350	.045	.031	.014	.031	.018
6 mo follow-up						
Group A	21 ± 8	22 ± 15	41 ± 27	40 ± 32	31 ± 16	34 ± 15
Group B	16 ± 19	12 ± 8	20 ± 9	21 ± 5	16 ± 9	19 ± 11
P value	.263	.037	.01	.008	.03	.02
1 y follow-up						
Group A	24 ± 14	26 ± 14	45 ± 33	48 ± 30	36 ± 18	36 ± 18
Group B	18 ± 11	14 ± 10	23 ± 8	24 ± 7	21 ± 11	23 ± 10
P value	.175	.03	.02	.006	.028	.026

NOTE. All measures are percentage difference.
Abbreviations: AP, anteroposterior; L, lateral; T1, distal; T2, middle; T3, proximal.

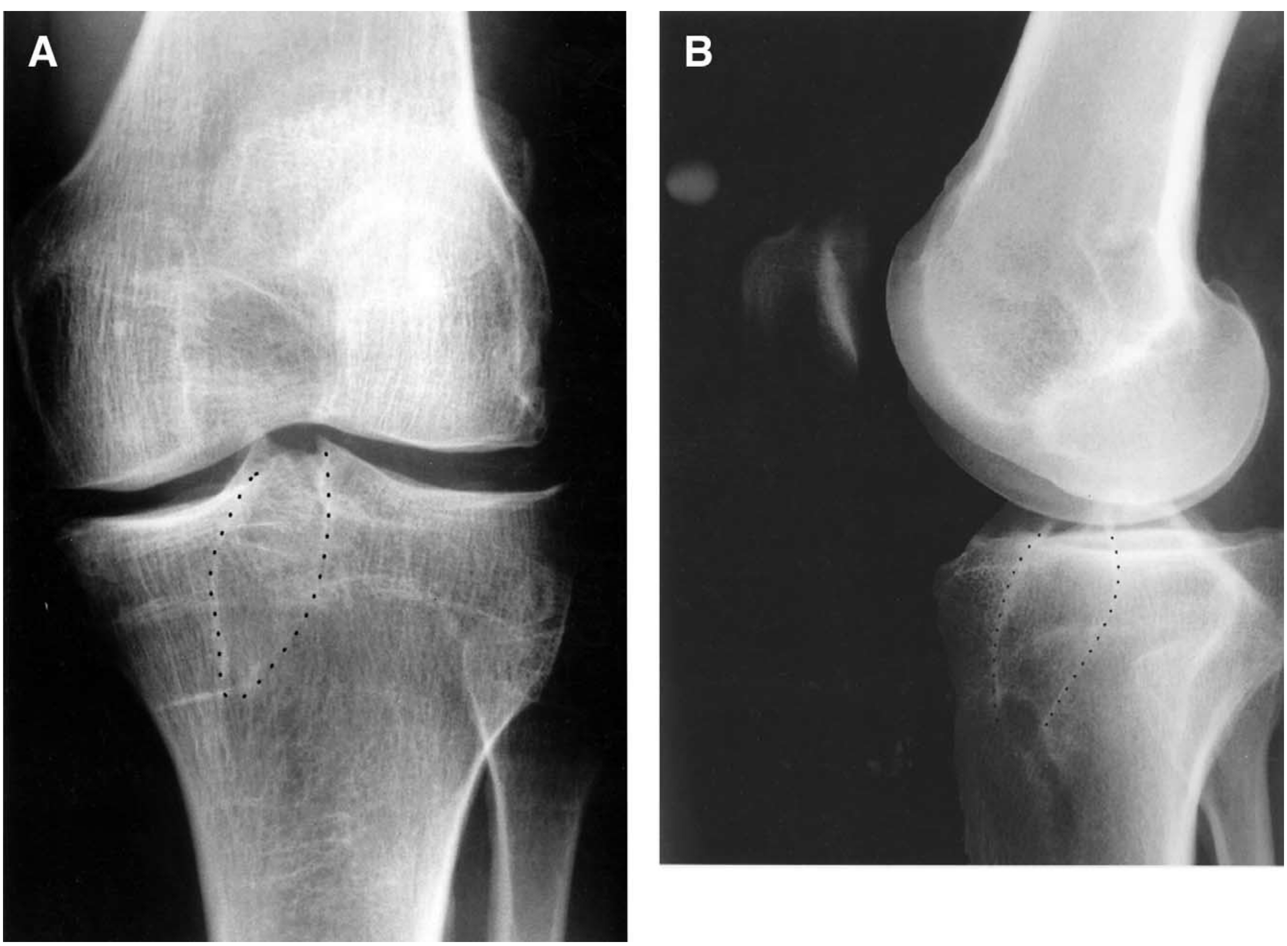

FIGURE 4. Anteroposterior (A) and lateral (B) radiographs 1 year after ACL replacement. Cavity type configuration and tunnel enlargement of the tibial tunnel (dotted line), in a patient with isolated ACL reconstruction (early motion group).

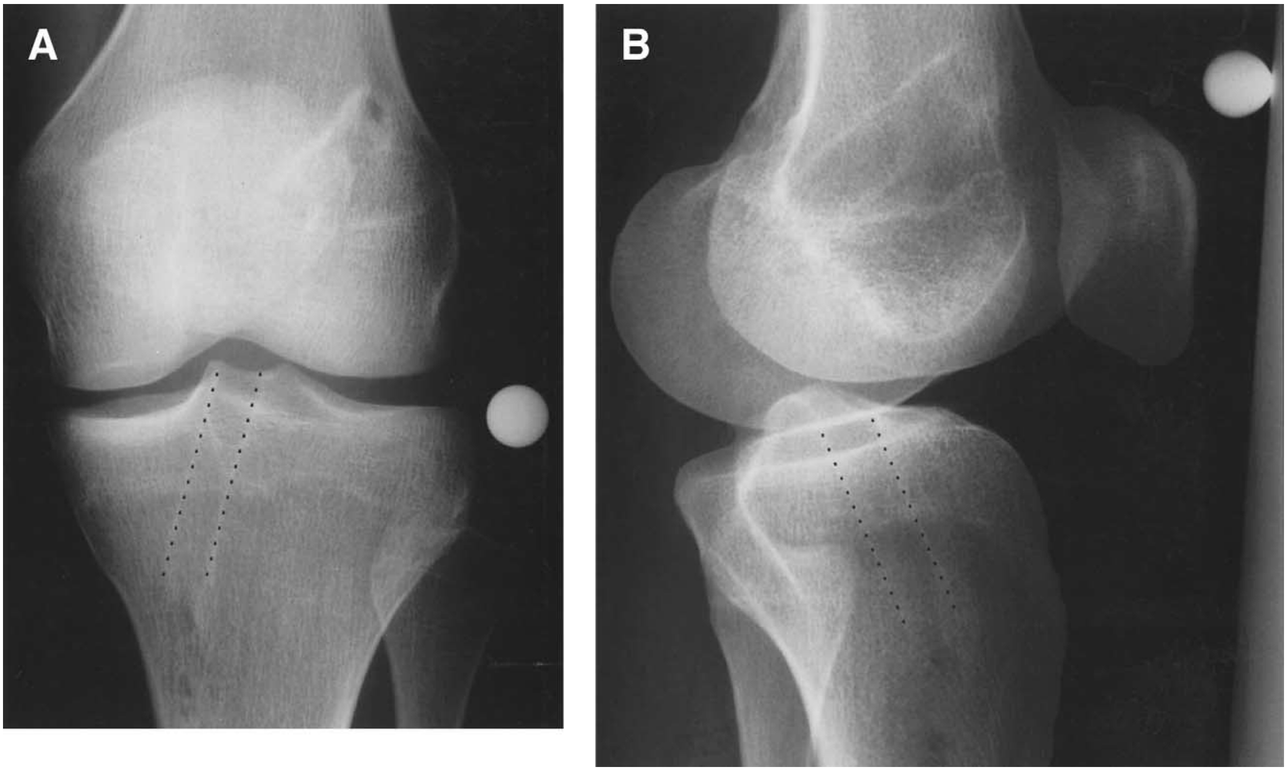

FIGURE 5. Anteroposterior (A) and lateral (B) radiographs 1 year after ACL reconstruction. Linear type configuration, with small amount of tunnel enlargement of the tibial tunnel (dotted line), in a patient with a combined isolated ACL reconstruction and meniscal repair (slower rehabilitated group).

More than 75% of tunnel widening occurred in the first 3 months postoperatively for both groups. Tunnel widening did not significantly increase from 3 months to 6 months, or from 3 months to 1 year. The interobserver variability for measurement of tunnel widening was excellent, and intra-class correlation coefficient was 0.93 with a confidence interval of 0.89 to 0.96.

Clinical Outcome and Clinical Correlation

All patients in group A discarded the crutches before week 3, and they had full range of motion at the sixth week follow-up evaluation. Eighteen of 20 patients showed a full range of motion at the 3-month follow-up evaluation. The remaining 2 patients showed 15° and 20° flexion deficits, which were restored subsequently.

However, no statistically significant differences were found between the A and B groups with respect to clinical findings at the latest 1-year follow-up evaluation (Table 3). We also found no significant correlation ($P > .05$) between the tibial bone tunnel enlargement and the KT-1000 results, the Lyshom Score, or the IKDC score.

DISCUSSION

Tunnel widening after ACL reconstruction is today a well known phenomenon, and it has been recognized by many authors during the past decade. Nevertheless,

TABLE 3. *Results in IKDC, KT-1000, and Lysholm Knee Score 1 Year Postoperatively*

	Group A (n = 33)	Group B (n = 20)	*P* Value
Lysholm knee score	93.43 ± 8.6	90.78 ± 5.7	NS
KT-1000	1.82 ± 1.1*	1.43 ± 0.9*	NS
Pivot-shift			
0 (absent)	23	17	NS
1 (glide)	5	2	NS
2 (clunk)	3	1	NS
IKDC			
Normal	19 (57.5%)	11 (55%)	NS
Nearly normal	12 (36.3%)	8 (40%)	NS
Abnormal	2 (6%)	1 (5%)	NS
Severely abnormal	0	0	

Abbreviations: IKDC, International Knee Documentation Committee; NS, not significant.

*Measurement with the KT-1000 arthrometer as side-to-side difference at manual maximum.

the etiology of this phenomenon remains unknown. Many authors[8,10,17] hypothesized that aggressive rehabilitation protocol may be a potential factor for tunnel enlargement, especially in hamstring autografts, but this suggestion has not been validated.

To do this, we designed a comparative study between 2 groups of patients with different rehabilitation protocols. The results of our study confirmed that early motion significantly increases the amount of tibial tunnel enlargement after ACL replacement with hamstring autograft. The percentage of tibial tunnel enlargement in the early motion group was almost double in comparison to the slower rehabilitated group at the middle (T2) and proximal (T3) tunnel locations on both the AP and L views at all stages of follow-up evaluation.

We found a maximum increase of approximately 45% for the early motion group versus 23% for the slower rehabilitated group on the AP view and 48% versus 24% on the L view at 1 year follow-up. Tunnel dilation occurred with an almost equal expansion throughout the length of the tibial tunnel in the slower rehabilitation group. In contrast, an asymmetric expansion of the tibial tunnel in the group with early motion was seen. Direct comparison regarding the percentage of tunnel enlargement with other series cannot be made because of many differences in surgical technique and tunnel widening calculation.

As has been shown in many studies,[20,21,22] tendon to tunnel healing (in ACL reconstruction) using soft tissue grafts requires at least 10 to 12 weeks. Liu et al.[20] and Rodeo et al.[21] showed that a period of 6 weeks is necessary for the organization of the scar tissue and the development of Sharpey's fibers in the tendon–bone interface. Furthermore Grana et al.[22] showed that biomechanically the tendon–bone interface is weak the first 9 weeks with an improvement in strength beyond 12 weeks. Aggressive rehabilitation exercises during this critical period before graft incorporation probably results in increased graft–tunnel motion (up and down piston motion) and subsequently increases the amount of tunnel widening, as has been shown by our study.

Greater tunnel enlargement in hamstring than patellar tendon grafts has been reported in comparative studies.[5,7,10] Some authors[5,6] proposed that suspensory fixation that is commonly used in hamstring grafts is responsible for these results. However, other studies[10,11,23] have proved that fixation does not itself appear to be the principal cause of tunnel enlargement. Webster et al.[10] have shown that when suspensory fixation (endobutton) was used for both graft types in the femoral side, tunnel enlargement was greater in hamstring grafts than bone–patellar tendon–bone grafts. Conversely, Clatworthy et al.[23] and Buelow et al.,[11] comparing different fixation methods for hamstring grafts, found that suspensory fixation caused less tunnel enlargement than anatomic fixation. Based on these findings and our results, we believe that early and unrestricted motion is the main reason for this difference.

Healing of the bone block of the patellar tendon grafts is much faster than hamstring grafts, and early stabilization is achieved, resulting in less motion between the graft and the surrounding bone tunnel with aggressive rehabilitation. In contrast, graft–tunnel motion and, subsequently, tunnel enlargement is much more pronounced in hamstring grafts because of a delayed incorporation. Apparently, the difference in biologic incorporation between the 2 grafts is the reason for complete obliteration of the femoral tunnel in 32% of patellar tendon graft patients reported previously.[10] In contrast, no hamstring graft patient showed similar tunnel obliteration.[10]

Tunnel enlargement has not been reported before 1990. We believe there are 2 major reasons for that. First of all, the patellar tendon was the graft of choice for the majority of surgeons. The other major difference for patients who underwent ACL reconstruction in the 1980s was the rehabilitation protocol. Postoperatively, these patients were immobilized for a prolonged period of time (4 to 6 weeks) with a brace or a cast.[24] This treatment allowed enough time for graft incorporation. The philosophy of rehabilitation changed dramatically in the 1990s, and the hamstring graft increased in popularity.[25] Probably, the combination of these 2 changes in ACL surgery resulted in the increased number of papers about tunnel enlargement.

According to our results, the major percentage (75%) of tunnel widening occurred during the first 3 months, with no significant increase after this period. These results are in accordance with other series[10,11] that described the course of bone tunnel enlargement over time with hamstring grafts. Patellar tendon grafts have also the same behavior. Peyrache et al.[14] reported that tunnel enlargement did not increase after 3 months, and Fink et al.,[16] using computed tomography, showed that more than 50% of tunnel widening occurred in the first 6 weeks. In other words, tunnel enlargement develops before biologic incorporation for both types of graft. As Webster et al.[10] stated, "if slower rehabilitation were to have an effect (in tunnel enlargement) it would clearly need to be implemented during the first three months." Our serial radiographic follow-up clearly supports this statement.

We believe that mechanical and biological factors are associated with tunnel enlargement. Two studies[7,16] have shown the presence of synovial fluid between the graft and tunnel wall. Cytokines that are contained in synovial fluid may result in osteolysis and may further disrupt healing, as has been proposed.[7] Furthermore, the process of graft necrosis and revascularization may also be a trigger for bone resorption.[17]

Unfortunately, we were unable to measure the femoral tunnel in this study. It was very difficult to identify the diameters of the "bottleneck" femoral tunnel on both the AP and L views, specially the diameter of the distal part of the tunnel close to the Blumesant's line. Therefore, we decided to make the measurements only on the tibial tunnel. The interobserver variability for this technique was excellent, as determined by the intraclass correlation coefficient.

No relationship was found between tunnel widening and clinical outcome in our study like all previous reports.[5-16] However, all these studies, as with our study, have a short-term follow-up period. We do not know yet if a graft within an enlarged tunnel can maintain its structural and functional integrity over time. The widened tunnels will cause many problems in revision surgery. Many graft failures with large tunnel widening in our department need a 2-stage procedure for the reconstruction of the ACL. Thus, further studies with long-term follow-up are needed to determine if this "radiographic complication" is of important significance or not.

In conclusion, our results suggest that tunnel enlargement after ACL replacement with hamstring autograft is significantly increased by an accelerated rehabilitation protocol. Aggressive rehabilitation results in graft-tunnel motion during the prolonged phase of hamstring incorporation. The implication of aggressive rehabilitation, in terms of tunnel enlargement, is less pronounced in patellar tendon grafts because the incorporation of the bone blocks is much faster. In light of these findings, we may have to re-evaluate the role of accelerated rehabilitation after ACL reconstruction in patients with hamstring autografts and rehabilitate them differently than patients with patellar tendon grafts. A more conservative rehabilitation program, which will allow enough time for graft healing without causing problems in range of motion, will be probably more appropriate for these patients, at least during the first 6 weeks.

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