

Anterior Cruciate Graft Tensioning

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## **Abstract**

Successful surgical reconstruction of the ACL depends on certain variables which have been recognized as important factors affecting the final outcome. Graft material selection, intra-articular graft position, type of fixation, post-operative rehabilitation, and initial graft tension have all been implicated. Extensive investigation of the biomechanical properties of various graft materials, the ultimate load of fixation devices, isometry and the proper intra-articular placement of grafts, and rehabilitation protocols has taken place over the last two decades. Despite the acknowledgement that the initial tension placed on the anterior cruciate graft tissue is an important variable in anterior cruciate reconstructions, the amount of tension that is optimal has yet to be determined. We have studied the effect of different initial graft tensions in a rigidly fixed doubled semitendinosus and gracilis autograft reconstruction on postoperative side-to-side anterior laxity and knee range of motion. Based on our clinical experience, we feel that tensioning at a force greater than 15 lbs. ( 68 N ) causes excessive constraint of the knee joint and increases the likelihood of greater anterior laxity, reconstruction failure, and more difficulty regaining knee range of motion.

**Key Words:** ACL, tensioning, reconstruction, graft, hamstrings

## Historical Perspective

Successful surgical reconstruction of the ACL depends on certain variables which have been recognized as important factors affecting the final outcome. Graft material selection<sup>1</sup>, intra-articular graft position<sup>2-5</sup>, type of fixation<sup>6,7</sup>, post-operative rehabilitation, and initial graft tension<sup>1-3,8-14</sup> have all been implicated. Extensive investigation of the biomechanical properties of various graft materials, the ultimate load of fixation devices, isometry and the proper intraarticular placement of grafts, and rehabilitation protocols has taken place over the last two decades. During this time, however, relatively few clinical studies have concentrated on initial graft tension.

Early work by Jones<sup>15</sup> stated that tension applied to the ACL graft at the time of surgery should be enough to eliminate an anterior drawer sign but still allow a full knee range of motion. Cadaveric studies by both Burks et al.<sup>10,16</sup> and Grood et al.<sup>17</sup> indicated that a small initial tensioning (20 to 40N) of the graft was required to maintain normal joint kinematics and physiologic laxity of the joint. Burks and Leland<sup>16</sup> later determined that the graft tension needed to restore normal anterior laxity is tissue specific. They further showed that the material (stiffness) and geometrical (size and length) properties of the graft influence the amount of tension that needs to be applied. Brown et al.<sup>6</sup> stated that stiffness and elasticity vary among autograft tissues. In addition, the mechanical behavior of the graft fixation complex affects the amount of tension needed and varies widely between fixation devices. Beynnon et al.<sup>18</sup> reported that the tension initially applied to the graft at the time of fixation immediately decreased by creep elongation of the graft. Therefore, pretension applied to the graft construct to restore normal anterior laxity may be insufficient and result in an increase in postoperative anterior laxity.

In contrast, excessive initial tension has been implicated in graft failure at the midsubstance, fixation failure, loss of knee motion, excessively reduced anterior laxity, and cartilage degeneration.<sup>9,19</sup> In several in-vitro studies, the effects of graft pretension variation on the anteroposterior knee laxity, knee kinematics, and forces on the cartilage and other knee ligaments has been analyzed.<sup>3,11,16,17,20,21</sup> Bylski-Austrow et al.<sup>20</sup> and Fleming et al.<sup>3</sup> found that increasing pretension caused increased posterior shifts of the tibia. Lewis et al.<sup>21</sup> found that the tibia of some of the reconstructed knees was positioned posterior and was rotated externally relative to the femur compared to unreconstructed ACL intact knees. They introduced the term "over-corrected" to describe this phenomenon. Van Heerwaarden et al.<sup>22</sup> and Andersen

et al.<sup>8</sup> found changes in knee kinematics caused predominantly by a posterior shift and external rotation of the tibia relative to the femur. These kinematic alterations result in increased graft forces at all flexion angles, increased forces in the PCL, and alteration of the normal roll-glide mechanism during knee motion. Melby et al.<sup>11</sup> found that graft tension-related posterior tibial subluxation resulted in an increase in quadriceps force needed to achieve full knee extension. They postulated that the difficulty seen clinically in the achievement of full extension after reconstruction may be partially due to an inability of the quadriceps to generate the additional force. Furthermore, if quadriceps atrophy or weakness is present, extensor lag may remain even though full passive motion is attainable.

Although a stimulus is essential for the orientation of newly formed collagen during the remodeling phase<sup>23</sup>, basic science research studying the effect of graft pretension cautions that high initial tension may be detrimental to the remodeling process. Yoshiya et al.<sup>14</sup> found that patellar tendon reconstructions in dogs exposed to high initial graft tension showed focal degeneration within the graft, replacement of collagen fibrils by a myxoid, extracellular matrix, and loss of the normal parallel arrangement of collagen fibers. Thus, overconstraint that results in continuous loading of the graft during knee motion can lead to graft stretching and elongation during the remodeling process<sup>21</sup>.

Despite the acknowledgement that the initial tension placed on the anterior cruciate graft tissue is an important variable in anterior cruciate reconstructions, the amount of tension that is optimal has yet to be determined. We have studied the effect of different initial graft tensions in a rigidly fixed doubled semitendinosus and gracilis autograft reconstruction on postoperative side-to-side anterior laxity and knee range of motion.

### Indications and Contraindications

The natural history of the ACL-deficient knee demonstrates significant variability. Some individuals compensate well without a functioning ACL, but the consequence of chronic ACL deficiency in the young active patient is usually quite different. Recurrent episodes of instability can lead to attenuation of secondary restraints and meniscal and articular cartilage injury, thereby initiating the cascade toward degenerative arthritis.<sup>24</sup>

The purpose of ACL reconstruction is to prevent further knee injury and allow the return to work, sports, and activities of daily living. Without ligament reconstruction, those individuals desiring to participate in pivoting sports to any significant level of proficiency will often experience recurrent episodes of instability and subsequent chondral and meniscal injury. The evolution of more demanding and active lifestyles of our population combined with the technical advances of arthroscopic surgical techniques has made the surgical reconstruction of the ACL the standard of care in the treatment of the unstable ACL-deficient knee.

Because of the well-recognized donor-site morbidity associated with the use of autogenous patellar tendon grafts, four-stranded hamstring tendons have become our graft of choice for ACL reconstruction. Equally tensioned doubled semitendinosus and gracilis grafts are among the strongest and stiffest autogenous ACL replacement graft currently available. Hamstring tendon harvest can be performed through a small, cosmetically acceptable incision. Finally, it has been our experience that hamstring tendon grafts generally result in less postoperative pain and donor site morbidity. Hamstring grafts are especially useful in patients with extensor mechanism problems, patients with a failed patellar tendon autograft, and patients whose activities require an extensive amount of kneeling or crawling. Relative contraindications for use of hamstring autografts include the hamstring-dominant athlete and the patient with generalized ligamentous laxity. Also, previous pes transfer or open medial-sided surgery can result in scarring and alter the normal hamstring anatomy; this can make hamstring tendon harvest difficult and unpredictable.<sup>25</sup>

### Pre-Operative Planning

The diagnosis and surgical planning for ACL deficiency begin with a complete history and clinical examination. Plain radiographs help define the osseous anatomy and are especially important in the skeletally immature patient. Although magnetic resonance imaging is not routinely used, it can help identify meniscal and chondral pathology, in addition to confirming the diagnosis of an ACL tear. Instrument testing can reliably detect ligament laxity, and we routinely obtain KT-1000 arthrometer measurements to quantify knee laxity and document the side-to-side difference.

The final two elements of pre-operative planning include a prepared surgeon and a prepared patient. The surgeon must be prepared to encounter and address associated injuries, including chondral and meniscal damage. The surgeon should also be prepared to use an alternate graft source, should this be dictated by intra-operative findings. Finally, the patient should be ready for surgery: when the knee is no longer swollen and tender, and has reached full extension and sufficient flexion (about 125°), surgery can be performed safely and with minimal risk of post-operative stiffness.

### Technique

After introduction of a spinal or general anesthetic the knee is examined. The status of the ACL as well as the other ligaments is confirmed. A routine diagnostic arthroscopy is then performed without the use of a tourniquet. Anteromedial and anterolateral portals are created for visualization and probing. The ACL is examined and probed to confirm its status. The menisci are then visualized and evaluated for tears. Tears are deemed either repairable or non-repairable. Meniscal repairs are performed with an inside-out technique using a non-absorbable 2-0 suture. Sutures are not tied until completion of the ligament reconstruction. In the case where the meniscal tear cannot be repaired because of vascularity, direction, or degeneration, a partial resection is performed. The articular cartilage is evaluated for full thickness lesions in both the medial and lateral compartments. Abrasion chondroplasty, microfracture, or mosaicplasty is performed as necessary. No treatments are typically performed for softening or fissuring of articular cartilage.

An air tourniquet is inflated after exsanguination of the lower extremity and the semitendinosus and gracilis tendons are harvested using a tendon stripper. The tendons are prepared by removing all excess tissue and muscle. A whip stitch is placed in the tails of each tendon using a #5 non-absorbable suture. The grafts are then doubled and placed on a graft board under tension (Figure 1). The diameter of the doubled semitendinosus and gracilis graft is measured with a sizing system (Acufex, Norwood, Massachusetts). The arthroscope is once again introduced. The remnants of the ACL are completely removed using a motorized shaver. A notchplasty is performed with a motorized abrader, curette, and osteotome to adequately enlarge the intercondylar notch along the roof and anterolateral wall. A tibial

targeting device is then used to direct a guide pin to the posterior aspect of the normal ACL footprint. The targeting point is introduced through the anteromedial portal and the sleeve placed against the anteromedial tibial cortex through the incision made to harvest the hamstring tendons. Once the guide pin is placed, the knee is brought into full extension to evaluate the adequacy of the notchplasty. The tibial tunnel is created with a trephined cannulated drill matching the measured size of the graft or 8mm, whichever is greater. A femoral guide pin is then placed under arthroscopic visualization 3mm from the posterior wall at the 11 o'clock position for the right knee or 1 o'clock position for the left knee. The femoral tunnel is then drilled with a cannulated drill matching that of the tibial tunnel to a depth of 40mm. A 5.5mm Linx reamer is used to drill the anterolateral femoral cortex (Mitek Products, Westwood, Massachusetts). The femoral tunnel is tapped and an 8mm femoral Linx device advanced until it engages in the cortex (Figure 2). The entrances to both tunnels are then contoured using a curette to remove any sharp, potentially abrasive edges. The prepared graft is then attached to the male portion of the Linx device and advanced through the tibial and femoral tunnels until it engages with the female portion of the device (Figures 3,4).

A custom made tibial tensioning device is used for graft tensioning. This is a prototype made by Innovasive Devices, and although it is not commercially available, a similar tensiometer is currently commercially available from Linvatec. The tensiometer is attached to the anteromedial tibial cortex with two smooth pins (Figures 5 and 6). The #5 suture previously placed in the graft tails is then secured to the tensiometer (Figure 7). The knee is preconditioned by setting the tension to 25 lbs. at 30° and cycling the knee through a full range of motion 20 times. The tension is reset and the step repeated until no change in tension noted. The tension is then readjusted to 15 lbs. with the knee maintained in 30° of flexion. The tension reading typically increases by approximately 2 lbs with full extension and decreases by approximately 1-2 lbs in 90° of flexion when compared to the reading at 30° of flexion. The tibial tunnel is then bone grafted, anterior to the graft, with the bone from the trephined tibial tunnel drilling. An absorbable interference screw (Bioscrew, Linvatec) with a diameter 1mm greater than that of the tunnel width and 25mm in length is then placed anterior to the graft (Figure 8). Once the graft is secured, the tensiometer is removed. The remaining distal ends of the graft are further secured with a bicortical Concept screw and spiked soft tissue washer (Linvatec). The excess graft and sutures are then trimmed.

The arthroscope is again introduced into the knee and the intra-articular portion of the graft visualized. The graft is probed to confirm tension. The knee is then extended to confirm that there is no graft impingement. The knee is thoroughly irrigated and all debris removed. A small intra-articular drain is placed and removed on the following morning. The arthroscopic portals are closed in a subcuticular fashion with a 2-0 absorbable suture. The anteromedial tibial skin incision is closed with 2-0 undyed vicryl suture in the subcutaneous layer and a 2-0 PDS subcuticular suture in the skin. The incisions are dressed with an Adaptec and gauze dressing. A cold therapy pad is placed on the knee and the knee placed in a hinged knee brace locked at 10° of flexion.

## Results

A prospective, randomized study has been conducted using 61 patients with isolated ACL tears who underwent arthroscopically assisted ACL reconstructions with autogenous doubled semitendinosus and gracilis tendons. The patients were divided into two groups based on the initial tension applied to the graft fixation complex: Group I (15 lbs., 68 N) and Group II (20 lbs., 88 N). No significant differences were noted between the two groups when comparing background factors and associated operative procedures (Tables I and II). Patients were followed in the post-operative period for an average of 15.1 months (range 8-25). One patient in Group I suffered a fatal cardiac arrhythmia four weeks after reconstruction. This was determined to be unrelated to her surgery or to medications prescribed in the post-operative period. Two patients in each group refused to return for further examinations and were considered lost to follow-up. This left a total of 26 patients in Group I and 30 in Group II who completed follow-up. The patients were examined post-operatively for side-to-side differences in anterior laxity and for progression of knee range of motion during the rehabilitation protocol (Tables III and IV). Post-operatively, the average side-to-side difference in anterior laxity was  $1.7 \pm 1.5$ mm for Group I and  $2.8 \pm 2.0$ mm for Group II. Statistical analysis using a Wilcoxon Rank Sum test for non-parametric data showed that the anterior laxity in Group I was significantly less than that in Group II ( $p=0.047$ ). Spearman's rank-order correlation analysis also demonstrated significant correlation between the initial graft tension and anterior laxity ( $p=0.046$ ).

Patients who desired to participate in rehabilitation at our institution were enrolled into Part II of the study. This involved comparing the postoperative progression of knee range of motion between the groups (Tables V and VI). Knee motion measured at four weeks showed an average range of motion of 3-109° for Group I and 3-88° for Group II. This represented a significant difference in knee flexion ( $p=0.018$ ). The time to achieve 90 degrees flexion was  $3.2 \pm 2.3$  weeks for Group I and  $4.7 \pm 2.8$  weeks for Group II. The time to achieve 120 degrees flexion was  $5.7 \pm 2.9$  weeks for Group I and  $9.8 \pm 8.3$  weeks for Group II. The time to achieve 90 degrees and 120 degrees of flexion for the two groups were not significantly different but did show a trend ( $p=0.137$  and  $p=0.097$ ). Comparison of extension and flexion losses at final examination showed no statistical difference between the two groups.

### Complications

Successful ACL reconstruction is dependent on a number of factors including patient selection, surgical technique, post-operative rehabilitation, and associated secondary restraint ligamentous laxity. Errors in graft selection, tunnel placement, tensioning, or fixation methods chosen may lead to graft failure. Not recognizing or treating a significant secondary restraint instability can place excessive stress on the ACL graft which may lead to failure. In addition, there are factors outside the surgeon's control, such as patient healing potential and compliance, that play a role in graft failure. Infection is rare following ACL reconstruction (0.005%). Infrapatellar contracture syndrome can occur following ACL reconstruction and may require graft removal to return functional motion to the involved knee.<sup>7</sup> Care must be taken to try and prevent graft failure, because revision ACL surgery results are not as predictable as primary reconstruction.

There were two notable complications in the study. One patient suffered a fatal cardiac arrhythmia four weeks post-operatively. As mentioned previously, this was determined to be unrelated to her reconstruction. One patient was diagnosed with a peroneal nerve palsy in the contralateral leg. This resolved completely by her 8 month examination.

### Post-Operative Management

Patients undergo post-operative management according to our ACL protocol. Patients are initially non-weight bearing with crutches, and after the first week are weaned to weight bearing as tolerated over 4 weeks. Immediate isometric and patellar mobilization exercises were performed. Patients are initiated with a formal rehabilitation protocol beginning after 5-7 days. At this point flexion and extension range of motion are started. Stationary cycling is allowed after 8 weeks. A run/jog program is started at 4 months and return to sporting activities allowed at 6 months.

Patients are seen for examination at 5-7 days after reconstruction, 6-8 weeks post-operatively, and then at 4 months, 6 months, 8 months, and 12 months. An objective examination is performed by measuring knee range of motion and the side-to-side difference in anterior laxity at 30<sup>0</sup> of flexion. At the 6-8 week examination the side-to-side anterior laxity is measured under an anterior drawer force of 20 lbs. (88N). All subsequent measurements are performed with an anterior drawer force of 30 lbs. (133N).

Patients undergo rehabilitation at our institution in a supervised, formal atmosphere on a three times per week basis. Range of motion is documented at the beginning of each session (cold range of motion) and after a 15-20 minute warm-up period (warm range of motion). Patients are discharged from therapy when they have achieved extension to 0° and flexion to 140° or flexion within 10° of the contralateral knee. Patients' flexion and extension at 4 weeks post-op, time to achieve 90° flexion, time to achieve 120° flexion, flexion loss at final exam, and extension loss (using 0° as full extension) are all evaluated. In our opinion hyperextension is detrimental to the reconstructed ACL and therefore, no attempt is made to equal any contralateral knee hyperextension.

#### Concerns, Future of the Technique

In descriptions of ACL reconstruction techniques, the initial tension applied to grafts generally has received little attention. When it is recognized, unquantified terms such as "firm tension" or "as much tension as possible" are used to describe the pretension applied. Tensioning techniques vary greatly from one surgeon to another. Through experience and observation, most surgeons develop a technique that works consistently for their specific graft type and fixation device. However, unless the initial tension applied to the graft can be measured accurately and maintained during the reconstruction, a description of

the technique cannot be adequately conveyed to others. The use of a fixed ligament tensiometer addresses this deficiency. By fixing the tensiometer to the bone and the ligament graft to the tensiometer the graft is maintained at an accurate tension during range of motion for preconditioning, bone grafting of the tibial tunnel, and placement of the tibial fixation device. In addition, the behavior of the ligament graft through a complete range of motion can be analyzed.

Of major importance when discussing the pretension level is the knee flexion angle at which the pretension is applied. Markolf et al.<sup>27</sup> measured the tension in the intact ACL and reported that tension decreases with knee flexion from the maximal value at 0° to the minimal value near 30° of flexion and then slightly increases with further flexion. Bylski-Austrow et al.<sup>20</sup> and Fleming et al.<sup>19</sup> have demonstrated that an increase in initial tension applied at any angle of knee flexion increased the graft tension by a constant magnitude at every flexion angle during knee range of motion. Therefore, the shape of the tension versus flexion curve did not change. In addition, the intraarticular portion of the graft is commonly shortest at 30° of flexion and the effect of slight variations in tunnel placement minimized at this angle. Based on this knowledge and previous studies<sup>2,3,10,11-13,16,19,20,22,26-28</sup> we choose a 30° flexion angle for application of the pretension. Many surgeons attempt to obviate the need to measure tension accurately by tensioning the knee in full extension. Although this may prevent posterior tibial subluxation and overconstraint of the knee, it effectively lengthens the intraarticular portion of the graft increasing the amount of anterior laxity. In addition, if the graft is overtensioned this will not prevent further elongation of the graft during remodeling. The tensioner allows us to evaluate the tension pattern of the graft during knee motion. The behavior of the graft usually varies little from full extension to full flexion. Extending the knee from 30° to full extension typically shows an increase in tension of 1-2 lbs. We have not seen more than a 10% change in graft tension throughout a full range of motion. This behavior is consistent with that reported in previous basic science studies.<sup>19,26</sup>

Many in-vitro studies have shown that increasing the amount of pretension alters the kinematics of the knee joint.<sup>8,17,21,28</sup> As tension increases the tibia shifts posteriorly and externally rotates relative to the femur.<sup>3,8,20,21,28</sup> These changes alter the normal roll-glide mechanism in knee range of motion. It has been postulated that this change could result in loss of knee range of motion. In our study, the amount of motion at four weeks post-operatively was significantly different ( $p=0.018$ ) between Group I (109° flexion) and

Group II (88° flexion). This slow progression of motion may have a deleterious effect on the health of the articular cartilage. Although the times to achieve 90° and 120° were not statistically different they did show a strong trend. This trend is important when considering the amount of time and money spent on therapy. With the increasing costs of medical care and care plans often limiting the amount of formal rehabilitation allotted for a patient, outcome in certain circumstances may be affected by the slow progression of knee range of motion. Although both groups of patients had regained full motion at the time of final examination, that motion may have been achieved at the expense of anterior laxity in the over-tensioned patients. In an overconstrained knee, as the knee is flexed there is an increase in the forces placed on the graft. With flexion in the normal knee a rolling of the femur takes place in the first 30° combined with anterior gliding of the femur in a 1:2 ratio. After 30°, the gliding movement increases resulting in a roll to glide ratio of 1:4. In overtensioned knees, flexion of the knee starts at a more anterior part of the tibia due to the posterior subluxation of the tibia. During the first part of flexion, rolling and gliding take place in a ratio similar to that in the normal knee. After 30° of flexion, the graft force increases as the stiff graft arrests the rolling of the femur. From this point on the femur rotates about the femoral attachment of the graft and only gliding of the femur enables further flexion. This gliding requires lengthening of the graft. Furthermore, it has been warned that the increase in the cartilage compression that occurs with overconstraint may lead to a greater degree of degeneration over time. Evaluation of these patients in the future will be necessary to determine the long-term effects of the high pretension on articular cartilage.

Based on our clinical experience, we feel that tensioning at a force greater than 15 lbs. ( 68 N ) causes excessive constraint of the knee joint and increases the likelihood of greater anterior laxity, reconstruction failure, and more difficulty regaining knee range of motion. It should be recognized that, since the mechanical behavior of ligament grafts is determined not only by the mechanical properties of the autogenous tissue but also by the fixations devices used, the tension levels recommended here may not be relevant with other ligament graft types or other fixation devices. However, our findings indicate that careful attention should be paid to the amount of initial tension that is applied as excessive pretension can lead to overconstraint and increased anterior laxity.

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## **Figure Legends**

Figure 1: Hamstring graft on graft board under tension.

Figure 2: Female portion of Linx device being inserted into femur.

Figure 3: Male and female portions of the Linx device.

Figure 4: Male portion being inserted into female portion of Linx device

Figure 5: Two pins placed in anteromedial tibial tibial cortex for tensiometer attachment.

Figure 6: Tensiometer positioned over the two smooth pins.

Figure 7: Suture from graft tails secured to tensiometer.

Figure 8: Interference screw placement.

**Table I**

Demographic preoperative Data

	<b>Group 1</b>	<b>Group 2</b>
Male/Female	20/9	17/15
Left/Right	16/13	18/14
Average Age <sup>a</sup>	28.1 ± 11.4 range 16-63	29.1 ± 12.8 range 16-56

<sup>a</sup> expressed in years

**Table II**

Associated Procedures

<b>Procedure</b>	<b>Group 1</b>	<b>Group 2</b>
Partial Medial Meniscectomy	3	5
Partial Lateral Meniscectomy	5	6
Medial Meniscal Repair	4	6
Lateal Meniscal Repair	6	8
MCL Microperforation	1	1
Lateral Release	3	1
Abrasion Chondroplasty	0	2
Ice Pick Chondroplasty	1	0
Mosaicplasty	3	0

**Table III**

Side-to-side difference in anterior laxity and length at final follow-up for Group I

<b>Patient (N=26)</b>	<b>KT<sup>a</sup> at 6-8 weeks</b>	<b>KT<sup>b</sup> at final exam</b>	<b>Final F/U<sup>c</sup></b>
WA	-2.0	1.0	13/2
EC	0.0	0.5	12/0
JM	0.0	3.5	16/2
JR	1.0	2.0	25/0
DDR	1.0	-2.0	20/0
CE	0.0	0.0	12/0
GT	-1.0	3.5	12/0
KS	1.5	1.0	12/0
NW	-1.0	1.0	19/0
SJ	2.0	4.5	12/3
CM	0.5	2.0	18/1
MH	1.0	0.5	17/2
BA	2.0	-1.5	17/2
SB	2.0	3.0	21/0
SD	2.0	3.5	8/3
CS	3.5	3.5	15/2
MP	0.0	2.0	20/0
LF	2.0	1.0	10/1
JT	-1.0	1.0	20/0
JP	2.0	2.0	11/0
RC	0.0	2.0	18/0
DD	1.0	1.0	17/0
SW	1.0	1.0	15/0
MC	0.5	2.0	8/0
RF	3.0	3.0	20/2
AM	-2.0	3.0	14/0
<b>Average</b>	<b>0.7 ± 1.4</b>	<b>1.7 ± 1.5</b>	<b>15/3</b>

<sup>a</sup> Side-to-side difference measured in millimeters with KT-1000 at 20 lbs. anterior drawer.

<sup>b</sup> Side-to-side difference measured in millimeters with KT-1000 at 30 lbs. anterior drawer.

<sup>c</sup> Final follow-up time given in months/weeks.

**Table IV**

Side-to-side difference in anterior laxity and length at final follow-up for Group II

Patient (N=30)	KT <sup>a</sup> at 6-8 weeks	KT <sup>b</sup> at final exam	Final F/U <sup>c</sup>
PL	0.0	1.0	22/0
EW	4.0	4.0	13/3
RP	1.0	3.0	20/0
XN	-3.5	1.5	23/0
MB	-1.0	2.0	14/0
TR	2.0	2.0	8/2
PB	1.0	2.0	12/3
RV	0.0	2.5	17/2
BH	1.0	2.5	12/0
JA	-1.0	0.0	18/2
JB	1.0	4.0	13/3
IJ	4.0	4.0	9/2
LB	-1.0	1.0	8/0
JR	2.0	2.0	8/0
JB	-3.0	7.0	13/0
MH	0.0	3.0	12/0
CB	5.0	6.0	11/0
AN	3.0	-1.5	17/0
NR	0.0	8.0	15/0
SA	0.0	1.0	12/0
GP	0.0	2.0	19/0
AC	1.0	1.5	12/0
SF	2.5	2.5	19/0
KD	1.0	1.0	14/3
DW	0.0	4.0	25/0
SB	1.0	4.0	13/0
JG	1.0	3.5	15/0
TA	3.0	3.0	9/1
DH	-1.0	5.0	12/3
HH	1.0	1.0	16/0
<b>Average</b>	<b>0.8 ± 1.9</b>	<b>2.8 ± 1.5</b>	<b>14/2</b>

<sup>a</sup> Side-to-side difference measured in millimeters with KT-1000 at 20 lbs. anterior drawer.

<sup>b</sup> Side-to-side difference measured in millimeters with KT-1000 at 30 lbs. anterior drawer.

<sup>c</sup> Final follow-up time given in months/weeks.

**Table V**  
Range of Motion Data for Group I

Patient	4 week ROM	Time to 90 degrees (weeks)	Time to 120 degrees (weeks)	Lost flexion (degrees)	Lost extension (degrees)
EC	15-54 <sup>0</sup>	11	14	10	5
JM	2-115 <sup>0</sup>	3	5	0	0
JR	2-138 <sup>0</sup>	2	3	5	0
CE	7-92 <sup>0</sup>	4	6	5	2
KS	0-124 <sup>0</sup>	2	4	0	0
NW	4-119 <sup>0</sup>	2	4	0	0
SJ	9-105 <sup>0</sup>	4	8	0	2
CM	3-105 <sup>0</sup>	3	6	5	0
MH	0-115 <sup>0</sup>	3	5	0	0
BA	0-108 <sup>0</sup>	3	5	3	0
SB	2-110 <sup>0</sup>	2	5	0	2
JT	10-95 <sup>0</sup>	3	9	0	5
JP	2-121 <sup>0</sup>	2	4	0	0
RC	5-112 <sup>0</sup>	2	5	0	0
MC	0-125 <sup>0</sup>	2	3	10	0
<b>Average</b>	<b>3-109<sup>0</sup></b>	<b>3.2</b>	<b>5.7</b>	<b>2.5</b>	<b>1.1</b>

Patient EC developed post-operative arthrofibrosis, but did not undergo manipulation until 14 weeks after reconstruction.

**Table VI**

Range of Motion Data for Group II

<b>Patient</b>	<b>4 week ROM</b>	<b>Time to 90 degrees (weeks)</b>	<b>Time to 120 degrees (weeks)</b>	<b>Lost flexion (degrees)</b>	<b>Lost extension (degrees)</b>
PL	2-68 <sup>0</sup>	6	11	10	0
EW	0-119 <sup>0</sup>	2	4	0	0
PB	2-101 <sup>0</sup>	3	7	5	0
RV	5-90 <sup>0</sup>	4	6	5	0
JA	9-91 <sup>0</sup>	4	6	0	5
JB	0-101 <sup>0</sup>	3	8	5	0
NR	3-80 <sup>0</sup>	6	8	0	3
SA	1-60 <sup>0</sup>	6	11	5	0
GP	6-110 <sup>0</sup>	3	6	0	2
SF	5-45 <sup>0</sup>	12	34	20	8
ST	0-105 <sup>0</sup>	3	7	0	0
<b>Average</b>	<b>3-88<sup>0</sup></b>	<b>4.7</b>	<b>9.8</b>	<b>3.6</b>	<b>1.6</b>

Patient SF developed post-operative arthrofibrosis, but did not undergo manipulation until 34 weeks after reconstruction.