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Evaluation of Graft Tensioning Effects in Anterior Cruciate Ligament Reconstruction Between Hamstring and Bone-Patellar Tendon Bone Autografts

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Abstract

Purpose: To investigate clinical, functional, and radiographic outcomes in ACL reconstruction patients over 7 years to determine the effects of initial graft tension on outcomes when using patellar tendon (BTB) and hamstring tendon (HS) autografts.

Methods: Ninety patients, reconstructed with BTB or HS, were randomized using two initial graft tension protocols; 1) normal anteroposterior laxity ("low-tension"; n=46) and 2) AP laxity over-constrained by 2 mm ("high-tension"; n=44). 72 patients had data available at 7 years, with 9 excluded for graft failure. Outcomes included the Knee osteoarthritis Outcome Score, Short-Form-36, and Tegner activity scale. Clinical outcomes included KT-1000S, IKDC examination score; and functional outcomes included 1-leg hop distance, and peak knee extensor torque. Imaging outcomes included medial Joint Space Width, Osteoarthritis Research Society International radiographic score, and Whole Organ Magnetic Resonance Score.

Results: There were significantly improved outcomes in the high-tension compared to the low-tension HS group for SF-36 subset scores for bodily pain (p=.012), social functioning (p=.004) and mental health (p=.014) 84-months post-surgery. No significant differences in any outcome were found within the BTB groups. Tegner activity scores were also significantly higher for the high-tension HS group compared to the low-tension (6.0 versus 3.8, p=.016).

Conclusions: Patients with hamstring autografts placed in high-tension had better outcomes relative to low-tension for Tegner activity score and SF-36 subset scores for bodily pain, social functioning and mental health. For this reason, we recommend that graft fixation be performed

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with the knee at 30° flexion ("high-tension" condition) when reconstructing the ACL with HS autograft.

Keywords

ACL; graft selection; graft tensioning

Introduction

Anterior cruciate ligament (ACL) reconstruction surgery is commonly performed to reestablish joint stability and knee function. Although functional stability is achieved in many patients, there remains an elevated risk for posttraumatic osteoarthritis (PTOA) in the injured knee even with reconstruction surgery.[1] One surgeon-controlled variable that may potentially influence the development of PTOA is the initial tension applied to the graft at time of graft fixation. The initial graft tension modulates knee laxity and joint contact forces at the time of surgery, which in turn may influence the risk for knee PTOA.[2] We previously published data from a randomized control trial (NCT00434837) evaluating short-term (36-month) and mid-term (84-month) outcomes between two initial graft tension groups.[3,4] In this trial both bone-patellar tendon-bone (BTB) and four-stranded hamstring tendon (HS) autograft were randomized to receive either a low- or high-initial graft tension condition using a "laxity-based" approach to set the initial graft tension. The short-term results showed no detectable differences in clinical, functional, patient-reported and osteoarthritis (OA) imaging outcomes between the initial graft tension groups. The mid-term results showed minimal differences in the clinical, functional and patient-reported outcomes between the two groups, though some differences were emerging. There were differences related to the patient-reported outcomes scores and trends suggesting superior results in high-tension group for clinical outcomes. Specifically, the low-tension group performed significantly worse than the control group on the KOOS pain subscale, SF-36 general health and social functioning, although no significant clinical outcomes were found.[4] This original study did not examine tension group differences within graft types (BTB vs. HS).

The objective of this retrospective analysis was to compare clinical, functional, patient-reported and OA imaging outcomes between the two randomized laxity-based graft tension protocols within the BTB and HS cohorts at 84-month follow-up. The two laxity-based tension protocols under investigation were aimed (1) to restore normal anteroposterior (AP) laxity at the time of surgery to that of the contralateral uninjured knee (the "low-tension" condition) or (2) to over constrain AP laxity by 2 mm relative to the uninjured contralateral leg (the "high-tension" condition). We hypothesized that (1) there would be no difference in the high-tension BTB group compared to the low-tension BTB group, and (2) that the high-tension HS group would have improved clinical, functional, patient-reported and OA outcomes compared to the low-tension HS group.

Materials and Methods:

Study design

This retrospective cohort study is an analysis of the mid-term (84 months) results from a prospectively collected randomized control trial (NCT00434837) evaluating the effects of graft tensioning on outcomes.[4] The current analysis is unique, as a comparison of outcomes between the two tension groups within graft types was not previously performed.

We prospectively reviewed all patients who presented with an isolated unilateral ACL injury from February 2004 through February 2007 in the office of three surgeons as described in the prior studies[3,4] Inclusion criteria consisted of male and female patients 15 to 50 years of age with a unilateral ACL injury. These patients were offered ACL reconstruction with either BTB or 4-stranded HS autograft. The graft type was not randomized as patients could choose between these two options following discussion with the operative surgeon. Exclusion criteria were: 1) ACL injury greater than 12 months prior to surgery, 2) a significant concomitant injury to the meniscus, articular cartilage or other ligamentous structure, 3) evidence of existing osteoarthritis or 4) a previous knee injury. Of the 557 patients screened, 355 were excluded for not meeting inclusion criteria, and 112 declined to participate.[3] Of the 90 remaining patients, only 18 (20%) were lost to follow up at 84 months, and of the remaining 72 patients, 100% completed the questionnaire and 86% returned to the clinic for an on-site examination.[4] There were 23 patients in the low-tension BTB group, 22 patients in the high-tension BTB group, 13 patients in the low-tension HS group and 14 patients in the high-tension HS group.

ACL Reconstruction/Initial Graft Tension Protocol

Autograft ACL reconstruction consisted of either ipsilateral central one-third bone-patellar tendon-bone (BTB) or a 4-stranded semitendinosus and gracilis hamstring (HS).[3] All surgeons performed the same operative procedure and all grafts were preconditioned with 20 manual tension cycles prior to fixation. Femoral tunnel drilling was performed via an accessory low anteromedial portal in all cases. The bone blocks of the BTB grafts were fixed with titanium interference screws.[4] The HS grafts were fixed with suspensory button fixation on the femur and a biodegradable interference screw on the tibia, backed up at the surgeon’s discretion with a screw and spiked soft tissue washer.[4] The initial graft tension condition was randomized in the operating room at the time of surgery. Following femoral fixation, the low-tension group had their grafts tensioned by firmly pulling on the distal graft with the knee at 0 degrees of knee flexion, while the high-tension group had their grafts firmly tensioned with the knee at 30 degrees of flexion.[3–5] Tibial fixation was partially engaged for both graft types and anteroposterior (AP) knee laxity at 20 degrees was checked using the KT-1000S arthrometer (MEDmetric Corp, San Diego CA) and compared with that of the contralateral knee, which was also measured under anesthesia. If the targeted laxity value was not achieved within 1 mm, tension on the fixation was released, and the tensioning process was repeated. The final laxity value was rechecked once the fixation procedure was completed.[4] Post-operatively, all patients participated in a standardized rehabilitation protocol designed to have them return to sports at 6 months.[6]

Patient Reported Outcomes

The Knee osteoarthritis Outcome Score (KOOS)[7], the Short-Form-36 (SF-36)[8] and Tegner activity scale[9] were utilized to assess patient-reported outcomes. The KOOS evaluates 5 domains: 1) quality of life (KOOS-QOL), 2) sports and recreation (KOOS-sport), 3) activities of daily living (KOOS-ADL), 4) symptoms (KOOS-symptoms), and 5) pain (KOOS-pain). The SF-36 evaluates general health related to role limitations, bodily pain, vitality, social functioning, mental health, health transitioning and physical functioning.[8] The Tegner activity scale quantified the activity levels of the participants. All patient-reported outcome questionnaires were assessed both pre-operatively and at the subsequent follow up visits.

Clinical Outcomes

AP knee laxity was assessed preoperatively and postoperatively using the KT-1000 Knee Arthrometer (MEDmetric Corp, San Diego CA).[10] A trained sports physical therapist performed three manual maximum tests utilizing the KT-1000 and the displacement readings were averaged. Clinical outcomes were assessed using the 2000 IKDC examination score.[11] The IKDC evaluates 4 categories: 1) function, 2) symptoms, 3) range of knee motion, and 4) clinical examination. The IKDC score rates knees as A) normal, B) near normal, C) abnormal, D) severely abnormal within each category, with the final IKDC rating based on the score from the worst category. Subsequent surgical procedures or knee injuries were determined by a review of the medical record and patient questioning. All clinical exams were administered by a trained sports physical therapist.

Functional Outcomes

Patients performed the 1-leg hop test for distance on each leg three times and the trials were averaged.[12] The mean hop distance of the injured leg was normalized to that of the uninjured contralateral leg. Isokinetic strength testing (Biodex 2; Biodex Medical Systems, Inc. Shirley NY) was performed at 60°/sec to assess the strength of the extensor muscles of each knee.[13] Peak torques for five repetitions were averaged and normalized with respect to bodyweight and height.

PTOA Imaging Outcomes

Medial joint space width (JSW) measurements were obtained radiographically as previously described using a standardized posteroanterior view of the semiflexed knee.[3,4,14] The overall condition of the joint was assessed preoperatively and postoperatively using the modified Osteoarthritis Research Society International (OARSI) radiographic grading scale.[15] OA was also assessed using the Whole Organ Magnetic Imaging Score (WORMS).[16]

Statistical Analysis

Analyses of variance and chi square tests were used to compare groups on patient characteristics. Analyses of covariance were used to compare the two randomized tension groups (high versus low) on 84-month outcomes within each of the autograft types. For each outcome, patients' pre-surgical values were used as a covariate when evaluating 84-month outcomes. Because participants' baseline values of peak torque and WORM scores were not collected for the majority of participants, their values were not used as covariates for these outcome and comparisons of the 84-month outcomes between graft types were based on analyses of variance. IKDC scores at 84-months were compared between high and low tension groups within each graft type using chi square tests. All statistical analyses were performed using SAS statistical software Version 9.4 (SAS Institute, Cary, NC). Statistical significance was determined based on α =.05.

RESULTS

Patient Characteristics

At the 84-month follow-up visit, there were 72 patients (23 low-tension BTB group, 22 high-tension BTB group, 13 low-tension HS group, and 14 high-tension HS). Nine patients were excluded due to graft failure (2 low-tension BTB, 2 high-tension BTB, 2 low-tension HS, and 3 high-tension HS). Outcomes were evaluated for 63 patients after excluding these 9 patients with failed grafts. Patient age, weight, KT-1000 difference, and time to surgery were not significantly different at baseline among BTB high-tension (n=20), BTB low-tension (n=21), HS high-tension (n=11), and HS low-tension (n=11). Patient sex was significantly different among the four groups (p=0.001) with a higher percentage of males in the BTB low-tension group and a higher percentage of females in the HS low-tension group (Table 1).

Clinical Outcomes

Mean KT-1000 values at the 84-month follow up within the BTB and HS groups were not significantly different (Table 2). The distribution of IKDC scores at 84-months for the two tension groups within BTB and HS grafts type are displayed in (Table 3) There was no significant difference between the low-tension and high-tension for either of the graft types.

Functional Outcomes

The mean hop distances and peak torques in the low-tension and the high-tension group were not significantly different in either BTB groups or HS groups (Table 4).

Patient-Reported Outcomes

There were no significant differences between low and high-tension groups in mean Tegner activity scores, KOOS scores, or SF-36 sub scores within the BTB graft group (Table 5).

Within the HS graft group (Table 6), a significantly greater mean Tegner activity score was observed for the high-tension group compared to the low-tension group at 84-months (p =.016). There were no significant differences between the two tension groups in mean KOOS values within the BTB group. Examination of SF-36 sub scores indicated superior outcomes in the high-tension HS group relative to the low-tension group. The high-tension protocol resulted in significantly higher 84-month scores compared to the low-tension group in SF-36 scores relating to bodily pain (86.9 versus 68.3, p=.012), social functioning (100 versus 76.1, p=.004) and mental health (85.5 versus 73.2, p<.014).

PTOA Imaging Outcomes

There were no significant differences in medial JSW, OARSI radiographic scores or WORMS when comparing high-tension vs. low-tension BTB. There were also no significant differences in these outcomes between high-tension and low-tension HS groups (Table 7).

Discussion

The results of this study support the first hypothesis that there would be no differences between high-tension BTB vs. low-tension BTB groups in terms of clinical, functional, patient-reported and OA outcomes. The results also supported the second hypothesis comparing the outcomes of the high-tension versus low-tension HS groups. While the results from the BTB groups showed no difference in improved clinical, functional, patient-reported and OA outcomes regardless of tension, the results from the HS group were mixed. There were significantly improved outcomes for the high-tension HS group compared to low-tension HS group, with improved Tegner activity scores and SF-36 subset scores for bodily pain, social functioning and mental health, but no difference in any of the KOOS subsets. There were no significant differences for functional or PTOA outcomes for the high-tension vs. low-tension HS groups. Clinical outcomes for HS showed no difference for IKDC score outcomes for high-tension vs. low-tension HS and no difference between KT-1000 testing. Additionally, there were trends toward better outcomes in the high-tension group for SF-36 physical functioning (96.8 versus 89.5, p=.085), role physical (99.4 versus 91.5, p=.064) and vitality (72.7 versus 61.9, p=.087) (Table 5).

Our study did not show differences in the KT-1000 testing between either high-tension and low-tension BTB or HS groups. Sajovic recently showed an increase in instrumented anteroposterior translation of long term follow up for HS grafts compared to BTB grafts when measured with KT-1000 arthrometer at 17 year follow up.[17] They hypothesized that greater translation in the HS group was likely due to the greater progression of OA in the BTB group. However, other studies have showed no difference in instrumented AP translation and postoperative clinical instability at long term follow up.[18–20]

Several randomized control trials evaluating the effect of initial graft tension on clinical outcomes following ACL reconstructions for both HS grafts and BTB grafts have been performed. Yasuda et al found a significant difference in mean side-to-side AP laxity difference in a doubled hamstring tendon when comparing a low-tension (20N) group compared to a high-tension (80N) group two years after surgery.[21] On the contrary, Kim et al found no difference in knee laxity 1 year after surgery when HS grafts were tensioned at 78, 117 and 146N respectively.[22] It is worth considering that both of these studies are less than the 7 year follow up considered in our currently study. At 7 years, the HS group had significantly improved outcomes for Tegner activity scores and SF-36 subset scores for bodily pain, social functioning and mental health in high-tension compared to low-tension. The results in the literature regarding BTB grafts are also mixed for post-operative AP side-to-side laxity. Nicholas et al found significantly worse side-to-side differences when BTB grafts were tensioned at low-tension (45N) compared to high-tension (90N) at follow up.[23] However, Yoshiya et al showed no significant difference at 2 years when tensioning BTB grafts at 25 and 50 N.[24] Van Kampen et al also found no significant difference at 1 year when tensioning BTB grafts at 20N and 40N.[25]. Once again, these studies had shorter follow up than the present study, in which no significant differences were noted in clinical outcomes for either tension state in the BTB cohort. Kirwan et al performed a systematic review of the literature addressing initial graft tension with respect to post-operative functional outcomes.[26] The authors limited inclusion to both HS, and BTB grafts in which side to side difference in AP laxity was the primary outcome measure. This review included 5 papers, and found that grafts tensioned at 78.5–90 N displaced less side to side difference at 2 weeks and 1 year that those tensioned at 20 or less, however no significant clinical differences were found.[26] Ultimately, the results of this study, as well as our own, highlight the need for longer follow ups to truly determine what effects initial graft tension may have on both overall knee laxity, as well as overall patient reported clinical outcomes.

There are several limitations to this investigation. Patient loss to follow up is inherent to any long-term follow up study. Of the original 90 patients in our study, we lost 8 patients from the low-tension BTB group, 5 patients from the high-tension BTB group, 2 patients from low-tension HS group and 3 patients from high-tension HS at 7 years (18 patients). Nonetheless, the loss to follow-up was only 20%. Significant differences between groups with respect to their baseline sex characteristics were found. Since graft type was not randomized this could have confounded the results. The largest difference can be seen when comparing HS high-tension to HS low-tension as there were no male subjects in the HS low-tension group compared to 11 females. In the HS high-tension group there were 4 males and 7 females. Thus the differences related to the SF-36 and KOOS could be due to either graft type or sex. There is evidence that males score higher than women on the SF-36, particularly those most related to mental health. This could explain our small but significant difference between the low-tension and high-tension HS groups. Lastly there is a potential source of inherent bias as 3 different surgeons performed the surgeries. To help minimize bias, the same drill guide system and anatomical landmarks were used by all of the surgeons. Ultimately, further research is required to determine the effect of graft selection and tension on clinical, functional, and radiographic outcomes.

Conclusion

The initial graft tension set at the time of surgery using a laxity based tensioning protocol did not significantly affect the clinical, functional, patient reported and imaging outcomes for BTB autografts. However, HS autografts placed in high-tension performed better in terms of the Tegner activity score as well as SF-36 subset scores for bodily pain, social functioning and mental health. All other outcome metrics for HS grafts were equivocal. Based on these findings, we recommend that if HS autografts are used, firmly tensioning the graft at 30 degrees of flexion (the high-tension condition used in this study) would be preferable.

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References

1. Ajuied A, Wong F, Smith C,.et al. Anterior cruciate ligament injury and radiologic progression of knee osteoarthritis: a systematic review and meta-analysis. Am J Sports Med. 2014;42(9):2242–2252. doi:10.1177/0363546513508376. [PubMed: 24214929]
2. Brady MF, Bradley MP, Fleming BC, Fadale PD, Hulstyn MJ, Banerjee R. Effects of initial graft tension on the tibiofemoral compressive forces and joint position after anterior cruciate ligament reconstruction. Am J Sports Med. 2007;35(3):395–403. doi:10.1177/0363546506294363. [PubMed: 17218659]
3. Fleming BC, Fadale PD, Hulstyn MJ,.et al. The Effect of Initial Graft Tension After Anterior Cruciate Ligament Reconstruction. Am J Sports Med. 2013;41(1):25–34. doi:10.1177/0363546512464200. [PubMed: 23144370]
4. Akelman MR, Fadale PD, Hulstyn MJ,.et al. Effect of Matching or Overconstraining Knee Laxity During Anterior Cruciate Ligament Reconstruction on Knee Osteoarthritis and Clinical Outcomes. Am J Sports Med. 2016;44(7):1660–1670. doi:10.1177/0363546516638387. [PubMed: 27159308]
5. Fleming BC, Brady MF, Bradley MP, Banerjee R, Hulstyn MJ, Fadale PD. Tibiofemoral Compression Force Differences Using Laxity- and Force-Based Initial Graft Tensioning Techniques in the Anterior Cruciate Ligament-Reconstructed Cadaveric Knee. Arthrosc - J Arthrosc Relat Surg. 2008;24(9):1052–1060. doi:10.1016/j.arthro.2008.05.013.
6. Beynnon BD. Rehabilitation After Anterior Cruciate Ligament Reconstruction: A Prospective, Randomized, Double-Blind Comparison of Programs Administered Over 2 Different Time Intervals. Am J Sports Med. 2005;33(3):347–359. doi:10.1177/0363546504268406. [PubMed: 15716250]
7. Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynnon BD. Knee injury and osteoarthritis outcome score (KOOS) - Development of a self-administered outcome measure. J Orthop Sport Phys Ther. 1998;28(2):88–96. doi:10.2519/jospt.1998.28.2.88.
8. Ware JJ, Sherbourne C. The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. Med Care. 1992;30(6):473–483. doi:10.1097/00005650-199206000-00002. [PubMed: 1593914]
9. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. Clin Orthop Relat Res. 1985;(198):43–49. doi:10.1097/00003086-198509000-00007.
10. Daniel DM, Malcom LL, Losse G, Stone ML, Sachs R, Burks R. Instrumented measurement of anterior laxity of the knee. J Bone Joint Surg Am. 1985;67(5):720–726. [PubMed: 3997924]
11. Irrgang JJ, Ho H, Harner CD, Fu FH. Use of the International Knee Documentation Committee guidelines to assess outcome following anterior cruciate ligament reconstruction. Knee Surgery, Sport Traumatol Arthrosc. 1998;6(2):107–114. doi:10.1007/s001670050082.
12. Reinke EK, Spindler KP, Lorring D,.et al. Hop tests correlate with IKDC and KOOS at minimum of 2 years after primary ACL reconstruction. Knee Surgery, Sport Traumatol Arthrosc. 2011;19(11):1806–1816. doi:10.1007/s00167-011-1473-5.
13. Patel RR, Hurwitz DE, Bush-Joseph CA, Bach BR, Andriacchi TP. Comparison of Clinical and Dynamic Knee Function in Patients with Anterior Cruciate Ligament Deficiency. Am J Sports Med. 2003;31(1):68–74. doi:10.1177/03635465030310012301. [PubMed: 12531760]
14. Buckland-Wright JC, Wolfe F, Ward RJ, Flowers N, Hayne C. Substantial superiority of semiflexed (MTP) views in knee osteoarthritis: A comparative radiographic study, without fluoroscopy, of standing extended, semiflexed (MTP), and schuss views. J Rheumatol. 1999;26(12):2664–2674. doi:10.1136/ARD.2005.039115. [PubMed: 10606380]
15. Altman RD, Gold GE. Atlas of individual radiographic features in osteoarthritis, revised. Osteoarthr Cartil. 2007;15(SUPPL. 1):1–56. doi:10.1016/j.joca.2006.06.017.
16. Peterfy C, Guermazi A, Zaim S, et al. Whole-Organ Magnetic Resonance Imaging Score (WORMS) of the knee in osteoarthritis. Osteoarthr Cartil. 2004;12(3):177–190. doi:10.1016/j.joca.2003.11.003.

17. Sajovic M, Stropnik D, Skaza K. Long-term Comparison of Semitendinosus and Gracilis Tendon Versus Patellar Tendon Autografts for Anterior Cruciate Ligament Reconstruction: A 17-Year Follow-up of a Randomized Controlled Trial. Am J Sports Med. 2018;46(8):1800–1808. doi:10.1177/0363546518768768. [PubMed: 29741911]
18. P-M KL, S H, R KE,.et al. Long-Term Outcomes in Anterior Cruciate Ligament Reconstruction: A Systematic Review of Patellar Tendon Versus Hamstring Autografts. Orthop J Sport Med. 2017. doi:10.1177/2325967117709735.
19. Thompson SM, Salmon LJ, Waller A, Linklater J, Roe JP, Pinczewski LA. Twenty-Year Outcome of a Longitudinal Prospective Evaluation of Isolated Endoscopic Anterior Cruciate Ligament Reconstruction with Patellar Tendon or Hamstring Autograft. Am J Sports Med. 2016. doi:10.1177/0363546516658041.
20. Webster KE, Feller JA, Hartnett N, Leigh WB, Richmond AK. Comparison of Patellar Tendon and Hamstring Tendon Anterior Cruciate Ligament Reconstruction: A 15-Year Follow-up of a Randomized Controlled Trial. Am J Sports Med. 2016. doi:10.1177/0363546515611886.
21. Yasuda K, Tsujino J, Tanabe Y, Kaneda K. Effects of initial graft tension on clinical outcome after anterior cruciate ligament reconstruction: Autogenous doubled hamstring tendons connected in series with polyester tapes. Am J Sports Med. 1997;25(1):99–106. doi:10.1177/036354659702500120. [PubMed: 9006702]
22. Kim SG, Kurosawa H, Sakuraba K, Ikeda H, Takazawa S. The effect of initial graft tension on postoperative clinical outcome in anterior cruciate ligament reconstruction with semitendinosus tendon. Arch Orthop Trauma Surg. 2006;126(4):260–264. doi:10.1007/s00402-005-0045-x. [PubMed: 16193302]
23. Nicholas SJ, D’Amato MJ, Mullaney MJ, Tyler TF, Kolstad K, McHugh MP. A Prospectively Randomized Double-Blind Study on the Effect of Initial Graft Tension on Knee Stability After Anterior Cruciate Ligament Reconstruction. Am J Sports Med. 2004;32(8):1881–1886. doi:10.1177/0363546504265924. [PubMed: 15572316]
24. Yoshiya S, Kurosaka M, Ouchi K, Kuroda R, Mizuno K. Graft tension and knee stability after anterior cruciate ligament reconstruction. Clin Orthop Relat Res. 2002;(394):154–160.
25. van Kampen a, Wymenga a B, van der Heide HJ, Bakens HJ. The effect of different graft tensioning in anterior cruciate ligament reconstruction: a prospective randomized study. Arthroscopy. 1998;14(8):845–850. doi:10.1016/S0749-8063(98)70022-2. [PubMed: 9848597]
26. Kirwan GW, Bourke MG, Chipchase L, Dalton PA, Russell TG. Initial Graft Tension and the Effect on Postoperative Patient Functional Outcomes in Anterior Cruciate Ligament Reconstruction. Arthrosc J Arthrosc Relat Surg. 2013;29(5):934–941. doi:10.1016/j.arthro.2013.01.021.

Table 1.

Baseline demographics

Pre-Op Demographic	BTB Low N=21	BTB High N=20	HS Low N=11	HS High N=11
Age	26±10.1	20±6.3	25±10.4	27±8.1
Sex*	16M/5F	8M/12F	0M/11F	4M/7F
% Male	76%[a]	40%[c]	0%[b]	36%[c]
Weight	79±16	70±16	66±8	70±17
KT-1000[1]	4.3±2.4	3.8±2.2	5.1±2.1	3.8±3
Time to Sx	109±82	108±70	143±97	138±79

Tabled values are Mean ± SD unless otherwise indicated.# denotes significant difference among groups (chi square test, p <.05). Groups not sharing a common superscript are significantly different based on pairwise comparisons.

[1]Surgical-Contralateral control (mm).

Table 2:

KT-1000 AP laxity for bone-patellar tendon bone and hamstring cohorts

	Low-Tension Group	High-Tension Group	P-Value
BTB: KT-1000	1.13 (−0.27–2.5) N=17	1.06 (−0.26–2.40) N=15	0.946
HS: KT-1000	1.61 (−4.97–8.20) N=7	2.49 (−0.09–5.07) N=10	0.742

Values expressed as mean (95% CI)

Table 3:

Distribution of IKDC scores by graft type and initial tension.

	Low-Tension Group	High-Tension Group
BTB: WORMS		
A	9 (19.2)	6 (15.4)
B	24 (51.0)	24 (61.5)
C	13 (27.7)	9 (23.1)
D	1 (2.1)	0 (0.0)
HS: WORMS		
A	1 (4.4)	3 (12.5)
B	13 (56.5)	17 (70.8)
C	9 (39.1)	2 (8.3)
D	0 (0.0)	2 (8.3)

Values are expressed as n (%)

Table 4:

Hop distance and peak torque for bone-patellar tendon bone and hamstring cohorts

	Low-Tension Group	High-Tension Group	P-Value
BTB: Hop distance	91.7 (84.5–99.0) N=17	92.9 (89.3–96.5) N=15	0.773
HS: Hop distance	95.5 (86.7–104.2) N=9	98.5 (88.4–108.7) N=10	0.612
BTB: peak torque	94.0 (86.4–101.6) N=16	101.4 (93.8–109.0) N=12	0.20
HS: peak torque	116.6 (77.4–155.8) N=5	100.7 (89.5–111.9) N=9	0.48

Table 5:

Patient reported outcomes for bone-patellar tendon bone: Knee injury and Osteoarthritis Outcome Score, Short-form-36, and Tegner activity scale.

Subscale	Low-Tension Group N=21	High-Tension Group N=20	P-Value
KOOS: Symptoms	82.1 (74.8–89.5)	83.8 (74.9–92.6)	0.771
KOOS: Pain	88.9 (79.8–98.0)	90.28 (79.9–100.6)	0.834
KOOS: Activities of daily living	94.1 (89.3–98.9)	94.9 (89.4–100.3)	0.834
KOOS: Sports and recreation	77.6 (68.5–86.7)	87.5 (78.6–96.4)	0.114
KOOS: Quality of life	76.5 (65.6–87.4)	85.3 (74.4–96.3)	0.240
SF-36: Physical functioning	93.1 (88.5–97.7)	94.5 (89.0–100.0)	0.068
SF-36: Role physical	94.6 (89.5–99.8)	96.6 (91.1–102.1)	0.600
SF-36: General health	79.3 (71.9–86.8)	83.2 (75.4–91.0)	0.459
SF-36: Bodily pain	80.7 (74.7–86.7)	84.3 (75.3–93.2)	0.493
SF-36: Vitality	69.6 (60.5–78.7)	70.9 (62.2–79.6)	0.831
SF-36: Social functioning	95.2 (90.7–99.8)	94.4 (88.2–100.5)	0.814
SF-36: Emotional role	96.4 (91.8–101.0)	94.2 (87.2–101.1)	0.569
SF-36: Mental health	81.2 (74.2–88.2)	83.5 (76.6–90.4)	0.627
Tegner activity scale	5.0 (4.2–5.9)	5.5 (4.6–6.4)	0.446

Values expressed as mean (95% CI)

Table 6:

Patient reported outcomes for hamstring: Knee injury and Osteoarthritis Outcome Score Results, Short-form-36, and Tegner activity scale.

Subscale	Low-Tension Group N=11	High-Tension Group N=11	P-Value
KOOS: Symptoms	82.8 (72.2–93.4)	89.6 (81.3–98.0)	0.274
KOOS: Pain	89.9 (79.6–101.2)	97.7 (95.4–100.1)	0.158
KOOS: Activities of daily living	94.7 (88.7–100.6)	98.8 (97.6–100.0)	0.158
KOOS: Sports and recreation	84.1 (70.8–97.4)	90.9 (84.6–97.3)	0.321
KOOS: Quality of life	76.1 (67.2–85.1)	79.0 (62.0–96.0)	0.745
SF-36: Physical functioning	89.5 (81.5–97.6)	96.8 (93.4–100.3)	0.085
SF-36: Role physical	91.5 (83.0–99.9)	99.4 (98.2–100.7)	0.064
SF-36: General health	80.3 (71.7–88.8)	84.2 (75.3–93.1)	0.488
SF-36: Bodily pain	68.3 (55.3–81.3)	86.9 (80.3–93.5)	0.012
SF-36: Vitality	61.9 (51.2–72.6)	72.7 (64.7–80.6)	0.087
SF-36: Social functioning	76.1 (61.9–90.4)	100.0 (100.0–100.0)	0.004
SF-36: Emotional role	90.9 (81.7–100.1)	97.0 (90.2–103.7)	0.250
SF-36: Mental health	73.2 (65.3–81.0)	85.5 (79.0–91.9)	0.014
Tegner activity scale	3.8 (2.9–4.7)	6.0 (4.4–7.6)	0.016

Values expressed as mean (95% CI)

Table 7:

Post traumatic osteoarthritis outcomes of Bone-patellar tendon bone and Hamstring: JSW,OARSI, and WORMS.

	Low-Tension Group	**High-Tension Group**	**P-Value**
BTB: JSW	0.0 (−0.3–0.4) N=11	−0.4 (−1.1–0.4) N=9	0.256
HS: JSW	0.2 (−0.6–0.9) N=4	0.2 (−0.4–0.8) N=6	0.900
BTB: OARSI	1.4 (−0.4–3.2) N=17	0.5 (−0.3–1.2) N=15	0.322
HS: OARSI	0.3 (−0.1–0.7) N=7	1.1 (−0.3–2.5) N=8	0.246
BTB: WORMS	10.0 (1.8–18.2) N=19	4.6 (0.5–8.7) N=16	0.26
HS: WORMS	2.9 (−0.2–6.0) N=9	5.8 (0.0–5.8) N=9	1.00