Original Article

Harvest of All-Soft Tissue Quadriceps Tendon Autograft for Anterior Cruciate Ligament Reconstruction With or Without Closure of Resulting Defect Has No Effect on Patellar Height

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Purpose: To evaluate the radiographic effect of quadriceps tendon harvest on patellar height and to determine whether closure of a quadriceps graft harvest defect resulted in a significant change in patellar height compared to nonclosure. **Methods:** We conducted a retrospective review of prospectively enrolled patients. The institutional database was queried and all patients who underwent quadriceps autograft anterior cruciate ligament reconstruction between 2015 and March 2020 were included. Graft harvest length in millimeters and final graft diameter after preparation for implantation were obtained from the operative record and demographic data were obtained from the medical record. Radiographic analysis was performed of eligible patients using standard ratios of patellar height: Insall–Salvati (IS), Blackburn–Peele (BP), and Caton–Deschamps (CD). Measurements were performed using digital calipers on a digital imaging system by 2 postgraduate fellow surgeons. Preoperative and postoperative radiographs were performed at 0° according to a standard protocol. Postoperative radiographs were performed 6 weeks postoperatively in all cases. Preoperative patellar height ratios were compared with postoperative patellar height ratios for all patients using *t*-tests. Subanalysis was then performed to compare the effect of closure of with nonclosure on patellar height ratios using repeated-measures analysis of variance. Interrater reliability between the 2 reviewers was assessed using an intraclass correlation coefficient calculation. **Results:** In total, 70 patients met final inclusion criteria. There were no statistically significant changes from pre- to postoperative values for either reviewer for IS (reviewer 1, $P = .47$; reviewer 2, $P = .353$), BP (reviewer 1, $P = .98$; reviewer 2, $P = .907$), or CD (reviewer 1, $P = .107$; reviewer, 2 $P = .188$). The closure and nonclosure groups were adequately powered and no statistically significant demographic differences between the closure and nonclosure groups was identified for sex ($P = .066$), age ($P = .343$), weight ($P = .881$), height ($P = .42$), laterality ($P = 1$), meniscal repair ($P = .332$), graft diameter ($P = .068$), or graft length ($P = .183$). According to the repeated measures analysis of variance, closure of the quadriceps defect had no significant impact on any of the knee ratios. However, reviewer identity had a significant influence on the CD ratio. Intraclass correlation coefficient analysis revealed excellent agreement between reviewers for the IS (0.982) and BP (0.954) ratios, but only moderate-to-good agreement for the CD (0.751) ratio. **Conclusions:** Harvest of quadriceps tendon graft does not result in radiographic changes in patellar height. Furthermore, closure of the quadriceps defect does not appear to result in radiographic changes in patellar height. **Level of Evidence:** III, retrospective comparative trial.

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Quadriceps tendon autograft has become an increasingly popular graft choice for anterior cruciate ligament reconstruction (ACLR) as the result of its biomechanical and histologic properties and clinical success. All soft-tissue quadriceps autograft has been especially appealing because it appears to combine the advantages of soft-tissue handling, similar to hamstring autograft, and at the same time achieving mechanical stability and clinical results, similar to bone−tendon−bone (BTB) autografts.[1]

Anterior knee pain is a well-documented complication of BTB harvest, and harvest of BTB grafts has been shown to shorten the remaining tendon length.[2-4] The effect of all-soft tissue quadriceps harvest on patellar height and its relation to outcomes remains less clear. Furthermore, during harvest of quadriceps tendon autograft, a full-thickness or partial-thickness graft may be harvested. In some cases, partial graft harvest is complicated by unintentional iatrogenic violation of the capsule, resulting in a full-thickness graft harvest. When a partial-thickness graft is harvested, the defect may be left alone. However, in the case of full-thickness graft harvest, the defect must be closed to effectively repair the joint capsule. A recent systematic review demonstrated no clinically or statistically significant effect on outcomes between closure and nonclosure of a BTB harvest defect, although the quality of literature was poor.[5] By contrast, the effect of closure of a quadriceps harvest defect has not been well described.

The purposes of this study were to evaluate the radiographic effect of quadriceps tendon harvest on patellar height and to determine whether closure of a quadriceps graft harvest defect resulted in a significant change in patellar height compared with nonclosure. Our hypothesis was there would be no radiographic change in patellar height after quadriceps graft harvest and no effect of closure versus nonclosure of the resulting defect.

Methods

We conducted a retrospective review of prospectively enrolled patients. Institutional review board approval was obtained for completion of this study (University of Nevada, Reno Institutional Review Board: 1733426-1, Quad Tendon harvest in Anterior Cruciate Ligament Reconstruction: Measuring Patella Height). The institutional database was queried and all patients who underwent quadriceps autograft ACLR between 2015 and March 2020 were included. Exclusion criteria were contralateral-side graft harvest, history of previous surgery to the extensor mechanism, revision ACLR, concomitant osteotomy, multiligamentous knee reconstruction, and patients lacking radiographic or clinical follow-up. Concomitant meniscal surgery was not an exclusion criterion.

Demographic information including sex, age, height, weight, laterality, history of previous surgical procedures, and associated pathology were recorded from the medical record. Graft harvest length in millimeters and final graft diameter after preparation for implantation (millimeters) as well as presence of meniscal tears and associated pathology and related surgical treatments were obtained from the operative record. The index procedure was performed at a single center by 1 of 2 fellowship-trained orthopaedic sports medicine surgeons (T.S.C. and B.B.G) with greater than 7 years' experience in quadriceps tendon ACLR.

Surgical Technique

Quadriceps ACLR was performed through a standard technique as previously described in the literature.[2] In brief, a 2- to 3-cm midline longitudinal incision was made starting at the superior pole of the patella. A 10-mm box blade (Arthrex, Naples, FL) was introduced, and the graft was harvested just medial to the lateral border of the vastus medialis muscle belly in line with the longest portion of the tendon. After initial scoring with the box cutter, a 15 blade was used to elevate the graft from the superior pole of the patella. In every case, the goal was to avoid iatrogenic injury to the superior joint capsule. Once initially elevated, a minimally invasive harvesting device (Arthrex) was used for proximal dissection and truncation of the graft. The senior author's aim was to achieve a graft length of 70 mm and a prepared tendon diameter of 10 mm in all cases. The completed graft was prepared with adjustable loop fixation devices (BTB TightRope and TightRope ABS Implant and Button; Arthrex) on the femoral and tibial sides and was pretensioned on the back table. Final graft dimensions were obtained at this point prior to implantation.

ACLR was performed with independent femoral tunnel drilling and tibial tunnel drilling (FlipCutter III; Arthrex) consistent with all-inside technique.[6] All patients underwent standard ACL rehabilitation protocols with early physical therapy for range of motion and quadriceps tendon activation regardless of closure technique for the graft harvest site.

To detect iatrogenic capsular violation, the harvest site was inspected grossly and by inserting the arthroscope into the incision and following the harvest site proximally. According to the preference of the senior author cases where there was iatrogenic injury to the joint capsule resulting in full-thickness graft harvest, regardless of the size of capsular rent, closure was performed with interrupted 0 VICRYL sutures (Ethical, Somerville, NJ) to seal the joint and reapproximate the tendon edges in side-to-side fashion along the entire length of harvest. This was done using an open technique and mobile window. Increasing the flexion angle of the knee allows access to the more distal defect,

whereas gradual extension progressively exposes the more proximal harvest site. The full length of the closure can be performed using standard open instruments, and no specialized instruments are required when using a longitudinal incision. In cases in which full-thickness graft harvest did not occur, the resulting defect was left in place without closure. Figure 1 demonstrates examples of partial- and full-thickness graft harvests.

Radiographic Analysis

Radiographic analysis was performed of eligible patients using standard ratios of patellar height: Caton–Deschamps (CD), Blackburn–Peele (BP), and Insall–Salvati (IS). Measurements were performed using digital calipers on a digital imaging system, IntelliSpace PACS (Phillips Healthcare Amsterdam, Netherlands). Preoperative and postoperative radiographs were performed according to a standard protocol at 0° of extension with control of magnification to prevent alterations in radiographic technique and angle of knee flexion. Postoperative radiographs were performed 6 weeks postoperatively in all cases. All lateral radiographs were obtained in non–weight-bearing fashion. Patients unable to achieve 0° were excluded under the category of inadequate radiographic follow-up. The radiographic examiners were orthopaedic sports medicine fellows (H.L and S.O.) with the same level of training and experience. Each underwent preoperative instruction in measurement technique for each of the radiographic ratios. Both examiners were blinded to the closure status of the defect, to each other, and were not involved in the surgical cases in question.

Statistical Analysis

Demographic data were summarized. Mahalanobis distances were used to detect patients with anomalous patella ratios to detect outliers in the multivariate ratio data. After assessment for outliers in several groups, the decision was made to include all individuals for further analysis.

Power analysis was performed to determine the number of patients needed to confidently detect a difference in the mean of pre- versus postoperative ratios using a *t*-test, with an effect size of 0.2, power of 0.8, and significance level (alpha) of 0.5. The results indicated a minimum of 54 patients were needed. With the patients currently included in the study (N = 70), effect size of 0.2, and significance level (alpha) of 0.5. the power was calculated as 0.850. Power analyses were conducted using the *pwr* package in R (R Foundation for Statistical Computing, Vienna, Austria).

To determine whether patellar height ratios should be analyzed as a multivariate dataset, or individually, linear regression was used to test for multicollinearity by each reviewer separately, and as pre- and postoperative groups. Because IS, CD, and BP were significantly correlated with one another, in all cases they were treated separately in all subsequent analyses.

For each patella ratio, it was confirmed the data were normally distributed using Shapiro–Wilks tests and Holm *P*-value corrections. Normality was assessed in 8 groups, identified as preoperative versus postoperative, closure versus nonclosure, and reviewer 1 versus reviewer 2. All variables were normally distributed. Differences in the mean IS, BP, and CD ratio for pre- versus postoperative groups were assessed using *t*-tests.

Demographic data for closure versus no-closure groups were compared using *t*-tests (for continuous variables: age, weight, height, completed graft length, completed graft diameter) or χ^2 tests (for categorical variables: sex, laterality). To compare closure versus nonclosure, a repeated-measures analysis of variance (RM ANOVA) was used.

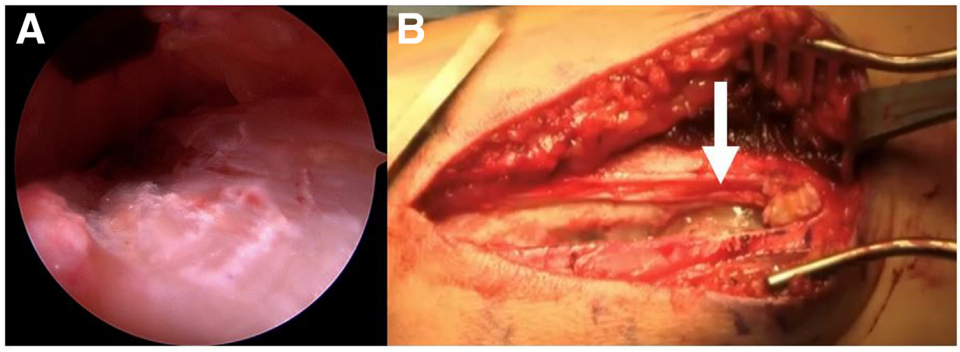

Fig 1. Examples of partial- and full-thickness graft harvest. (A) Arthroscopic view from the incision at the superior pole of the patella demonstrates intact capsular layer after quadriceps graft harvest consistent with partial-thickness graft harvest. (B) Open view with proximal portion of graft harvest to the left and patella to the right of image demonstrating a rent in the quadriceps tendon (white arrow) consistent with full-thickness graft harvest. Of note, the open image is a representative example but was not among the included patients in the study because of the difference in harvest technique through a more extensile open approach.

Table 1. Summary of Patient Demographics for All Patients Analyzed After Exclusion Criteria Were Applied

Sex, n, female/male	41/29
Age, y, mean (range)	28.03 (12-45)
Weight, kg, mean (range)	84.33 (50-190)
Height, cm, mean (range)	170.92 (152-195)
Laterality, n, left/right	36/34
Meniscal repair, n, no/yes	35/35

To assess interrater reliability between the 2 reviewers, an intraclass correlation coefficient was calculated. All statistical analyses were conducted in the R Program for Statistical Computing (GNU Operating Systems, Boston, MA).

Results

The study group was composed of 86 patients. Ultimately, 16 patients were excluded from final analysis, 10 for lack of or inadequate postoperative radiographs and 6 for concomitant ligament reconstruction. Thus, 70 patients were available for final analysis: 41 patients were female and 29 were male. Mean age was 28.03 years (12-45 years), weight (kilograms) was 84.33 (50-190), height (centimeters) was 170.92 (152-195), 36 knees were left, and 34 knees were right. A total of 35 patients underwent concomitant meniscal repair. There were 41 patients in the nonclosure group and 29 patients in the closure group (Table 1).

Change in Patellar Height After Quadriceps Graft Harvest

Differences in the mean IS, BP, and CD ratio for pre- versus postoperative groups using *t*-tests are demonstrated in Figure 2. There was no significant change in any of the 3 pre- versus postoperative radiographic ratios at a significance level of $P = .05$. IS mean change being .01 (±0.12) for reviewer 1 and 0.02 (±0.12) for reviewer 2 ($P = .529$ and 0.391, respectively). BP mean change was 0.01 (±0.12) for reviewer 1 and 0.00 (±0.12) for reviewer 2 ($P = .856$ and 0.902, respectively). CD mean change was 0.06 (±0.13) for reviewer 1 and 0.09 (±0.12) for reviewer 2 ($P = .054$ and 0.137, respectively).

Effect of Closure of Quadriceps Defect on Patellar Height

Demographic analysis of closure versus nonclosure group is summarized in Table 2. There were no statistically significant demographic differences between the closure and nonclosure groups for sex ($P = .066$), age ($P = .343$), weight ($P = .881$), height ($P = .42$), laterality ($P = 1$), meniscal repair ($P = .332$), graft diameter ($P = .068$), or graft length ($P = .183$).

According to the RM ANOVA, closure versus nonclosure had no significant impact on any of the patellar height ratios. Mean postoperative IS for closure = 1.06 (±0.13 SD) (reviewer 1 and reviewer 2) versus nonclosure = 1.09 (±0.11 SD) (reviewers 1 and 2) (RM ANOVA $P = 0.42$). Mean postoperative BP for closure = 1.06 (=- 0.13 SD) (reviewers 1 and 2) versus nonclosure = 1.09 (±0.11 SD) (reviewers 1 and 2) (RM ANOVA $P = .279$). Mean postoperative CD for closure = 0.89 (= -0.19 SD) (reviewer 1), 0.97 (±0.13 SD) (reviewer 2) versus nonclosure = 0.89 (±0.17 SD) (reviewer 1), 0.97 (±0.13 SD) (reviewer 2) (RM ANOVA $P = .70$).

Reviewer identity had no significant impact for BP and IS ratios (IS RM ANOVA $P = .38$, BP RM ANOVA $P = .30$) but was significantly different for the CD ratio (RM ANOVA $P < .001$). Graphs demonstrating the changes in individual ratios for each reviewer are demonstrated in Figure 3.

Interrater Reliability

Intraclass correlation coefficient calculation demonstrated excellent agreement between reviewers for the IS and BP ratios, but only moderate-to-good agreement for the CD ratio. This shows reviewer identity had a significant influence on the CD ratio, indicating reviewer 1 and reviewer 2 had significantly different measurements for CD ratio (Table 3).

Discussion

The primary finding in this study was harvest of quadriceps tendon autograft had no effect on radiographic measurements of patellar height. Furthermore, closure of a defect due to harvest of full-thickness graft resulted in no difference in subsequent patellar height compared with nonclosure of a partial-thickness graft harvest.

Both patella alta and baja have been associated with development of chondromalacia of the patella but do not appear to effect outcomes in total knee arthroplasty. This suggests changes in patella height effect biomechanics resulting in abnormal wear patterns of the native knee.[7,8] Normally, contact surface area of the patella increases with deeper knee flexion and the contact area moves proximally where the chondral surface is thicker.[9] Iatrogenic change in patellar height can disrupt this balance resulting in increasing contact force and pressure in the setting of patella alta.[10,11]

Effect of Graft Harvest on Patellar Height

Harvest of BTB grafts have demonstrated a reduction in patellar height, although this has not consistently demonstrated an effect on outcomes.[12-14] Nonetheless, anterior knee pain after BTB harvest is reported in approximately 25% of cases.[15] More recently, quadriceps tendon grafts have emerged as a graft harvest technique with a lower rate of anterior knee pain with similar clinical outcomes.[16-18]

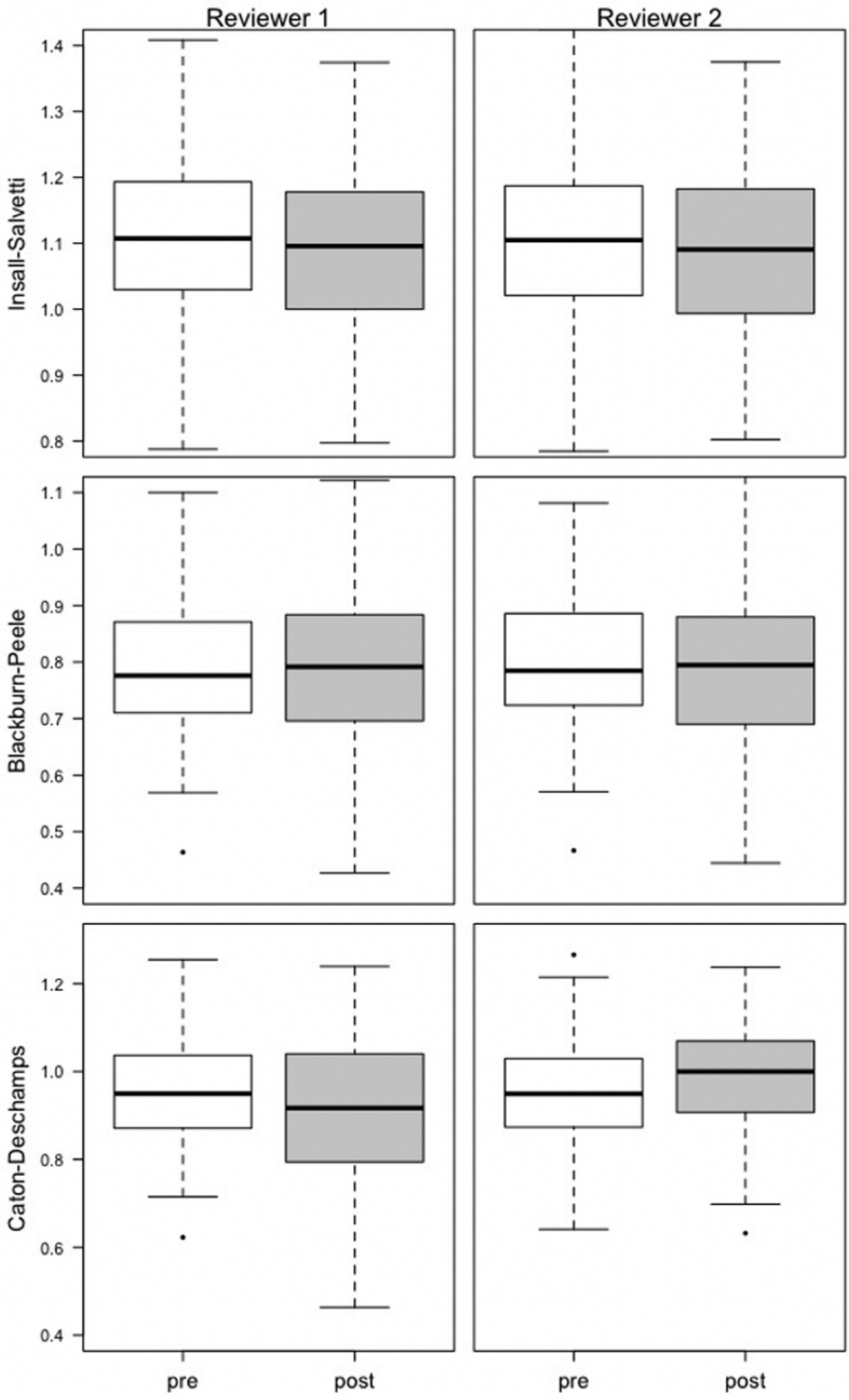

Fig 2. Patella ratios pre- versus postoperative, divided by reviewers 1 and 2.

Harvest of a central third quadriceps tendon graft results in removal of approximately 50% of the total volume of the quadriceps tendon.[19] The effect of patellar height after quadriceps tendon harvest is currently not well described. Intuitively, it may be that the quadriceps muscle tendon unit is better able to compensate for a closure of width which reduces the overall length because the reduction of length can be offset by increasing the resting length of the muscle sarcomeres. In contrast, the patellar tendon is attached to bone on both sides.

Table 2. Summary of Demographics for Patients in the Closure Versus Nonclosure Groups

	Nonclosure	Closure	*P* Value
Sex, n, female/male	21/20	22/7	.066
Age, y, mean (range)	27.22 (12-45)	29.17 (16-43)	.343
Weight, kg, mean (range)	84.9 (50-190)	83.52 (52-180)	.881
Height, cm, mean (range)	171.64 (152.41-195)	169.89 (152-182)	.42
Laterality, n, left/right	41/41	15/14	1
Meniscal repair, n, left/right	18/23	17/12	.332
Graft diameter, cm, mean (range)	9.45 (8-10.5)	9.71 (9-11)	.068
Graft length, cm,: mean (range)	67 (10-70)	69.61 (65-73)	.183

The quadriceps tendon graft may be harvested as a full-thickness or partial-thickness graft, and several minimally invasive harvest techniques have been described.[20] Our study demonstrated no significant change in patellar height on plain radiographs using commonly employed clinical ratios. This may be because the quadriceps tendon is attached to the quadriceps muscle and can accommodate changes more readily than the patellar tendon, which is attached to bone on both sides or simply because the methods were not adequate to detect a change. These results suggest surgeons may feel comfortable with quadriceps graft harvest, and this may be a potential benefit over BTB reconstruction.

Effect of Harvest Site Closure Versus Nonclosure on Patellar Height

The resulting defect in the quadriceps tendon after harvest may be left in situ or closed with a side-to-side repair. Theoretically, closing this defect may result in alterations of patellar height or mechanics.[21] Although surgeons may attempt to harvest a partial-thickness

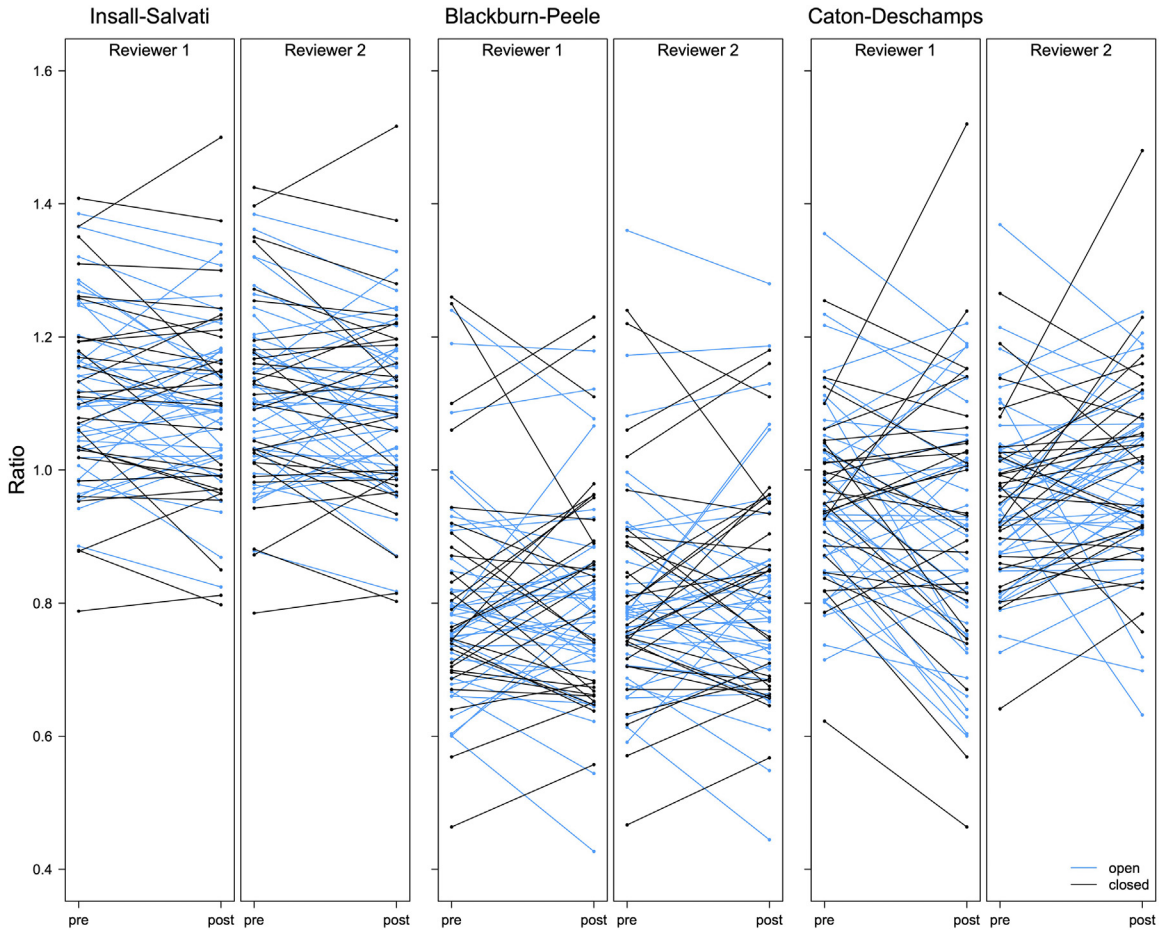

Fig 3. Comparison of closure with nonclosure groups, postoperative radiographs. There were no significant differences for any of the measured ratios.

Table 3. ICC Calculations

Patellar Ratio	ICC − Agreement, Mean (95% CI)	ICC − Consistency, Mean (95% CI)
IS	0.982 (0.975-0.987)	0.982 (0.975-0.987)
CD	0.751 (0.644-0.826)	0.771 (0.695-0.831)
BP	0.954 (0.936-0.967)	0.954 (0.936-0.967)

BP, Blackburn−Peele; CD, Caton−Deschamps; CI, confidence interval; ICC, intraclass correlation coefficient; IS, Insall−Salvati.

graft, they may inadvertently violate the superior capsule of the knee, and this might prompt a repair of the defect. The senior author (B.B.G.) routinely harvests partial-thickness grafts but performs a primary closure in side-to-side fashion in cases of violation of the capsule. Our results demonstrated no difference in patellar height regardless of closure of the defect or not.

Since multiple patellofemoral ratios have been described, and all these ratios have been validated with various benefits and limitations to each, to mitigate the risk of error due to a single ratio we utilized three commonly used patellofemoral measurement ratios.[10] The interrater reliability of the common patellofemoral indices has been evaluated previously, and a high degree of reliability with low variability has been described.[22] All soft-tissue quadriceps tendon grafts were harvested, and these results may not be extrapolated to harvest of a quadriceps graft with bone block. The link between patellar height and symptomatic anterior knee pain is not clear, thus, the absence of change in patellar height does not necessarily mean patients will not experience anterior knee pain.

Limitations

The closure group was smaller because the senior authors' practice is to avoid full-thickness graft harvest, and this may alter the results. The sample size is small; however, power analysis was conducted and determined the study population to be adequate for statistical comparison. Radiographic measurements were conducted on plain radiographs at 6 weeks postoperatively. It is possible patellar height could change after this time point; however, we felt this time period allowed for a reduction in swelling after the initial postoperative period, which could alter results. It is possible measurement error or errors in radiographic technique could affect results.

Conclusions

Harvest of quadriceps tendon graft does not result in radiographic changes in patellar height. Furthermore, closure of the quadriceps defect does not result in radiographic changes in patellar height.

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