



Single-Stage Surgical Treatment of Multi-ligament Knee Injuries Results in Lower Cost and Fewer Complications and Unplanned Reoperations Compared With Staged Treatment

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Purpose: To compare complications, unplanned reoperations, and costs between single-stage and 2-stage treatment of multi-ligament knee injuries. **Methods:** The MarketScan database was queried (2007-2016), identifying patients undergoing surgery for a multi-ligament knee injury. The single-stage cohort was defined as having at least 2 Current Procedural Terminology codes for ligament reconstruction at the index procedure without a Current Procedural Terminology code for ligament reconstruction appearing in the database for the following 12 months. The 2-stage cohort was defined as undergoing multiple ligament reconstruction procedures within a 12-month period with subsequent ligament procedure codes that differed from the index ligament reconstruction codes. Propensity score matching was performed using a greedy nearest-neighbor algorithm to match specific injury patterns between the 2 cohorts. Baseline demographic characteristics, medical comorbidities, and the Charlson Comorbidity Index were recorded. Complications, unplanned reoperations, and total health care expenditures were recorded for up to 5-year follow-up. Two-sample *t* tests, χ^2 tests, and Fisher exact tests were used with an α level of .05 set as significant. **Results:** We identified 1,150 patients who underwent surgery for multi-ligament knee injuries (1,080 with single-stage approach and 270 with 2-stage approach). No significant differences in baseline characteristics or medical comorbidities were found between the cohorts. After propensity score matching, the single-stage group had fewer complications at 30, 90, 180, and 365 days ($P < .05$). Two-stage treatment increased the risk of reoperation at 1 year (5.5 times) and 2 years (4.9 times) after the index procedure. Health care expenditures were lower in the first 9 months for the staged cohort, but from 9 months (\$31,210 vs \$22,252, $P < .0001$) through 5 years, total costs were higher in this group. **Conclusions:** Single-stage surgical treatment of multi-ligament knee injuries results in fewer complications and reoperations and lower total costs compared with 2-stage treatment, even after controlling for the number and combination of ligaments injured. **Level of Evidence:** Level III, retrospective cohort study.

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Multi-ligament knee injuries can be among the most challenging orthopaedic injuries to treat.^{1,2} Most surgeons advocate operative management because of poor outcomes with nonoperative management²⁻⁷ and improved patient-reported outcomes and range of motion with operative treatment.⁴ Although operative management is widely accepted as the most successful treatment, there remains controversy in determining the timing of operative intervention and which ligaments to prioritize.^{2,8}

There are 2 general approaches that surgeons may use during operative management of multi-ligament knee injuries: single-stage approach versus 2-stage approach. A single-stage approach involves treating all ligamentous injuries and associated pathology at one surgical

encounter. The workflow for each case is dependent on injury pattern as well as surgeon preference, with the ultimate goal of anatomic reconstruction. A single-stage approach expedites rehabilitation, avoids alteration of joint mechanics, and decreases the risk of graft failure or additional injuries between staged procedures.⁸ Single-stage surgery is, however, technically challenging, requiring longer operative times, and may be associated with an increased risk of arthrofibrosis.⁸

A 2-stage approach calls for addressing some of the ligamentous injuries during an initial surgical procedure, with the remaining injuries treated at a planned later time point. Ohkoshi et al.⁹ described a 2-stage procedure beginning with posterior cruciate ligament (PCL) reconstruction within 2 weeks of the injury. This was followed 3 months later by reconstructions of the anterior cruciate ligament (ACL), medial collateral ligament (MCL), and lateral collateral ligament (LCL).⁹ Lai et al.¹⁰ described a similar protocol, repairing the MCL, meniscus, and posterolateral corner in the initial procedure, followed by ACL and PCL reconstruction in subsequent arthroscopic procedures. The proposed benefits of a multi-stage approach are to avoid risks associated with a prolonged surgical time in the acute setting while allowing range-of-motion therapy between surgical procedures.^{10,11} In addition, patients may report better subjective outcomes after a 2-stage

procedure.⁸ The staged approach, however, prolongs the overall rehabilitation time and may not be suited for younger and more active patients.¹¹

The relative infrequency of multi-ligament knee injuries, as well as their variability, leads to difficulty in performing high-quality studies examining outcome differences between single-stage and 2-stage ligamentous reconstruction procedures. The purpose of this study was to compare complications, unplanned reoperations, and costs between single-stage and 2-stage treatment of multi-ligament knee injuries. Our hypothesis was that a 2-stage approach, after controlling for the number and location of ligamentous injuries, would lead to increased complications, reoperations, and costs as compared with a single-stage approach.

Methods

We obtained our data from the MarketScan Commercial Claims and Encounters database (Truven Health Analytics, Ann Arbor, MI). This database is a collection of commercial inpatient, outpatient, and pharmaceutical claims of more than 75 million persons with an average age of 40.1 years and 61.4% female population. The MarketScan database represents a substantial portion of the US population covered by employer-sponsored insurance. This database contains *International Classification of Diseases, Ninth Revision, Clinical*

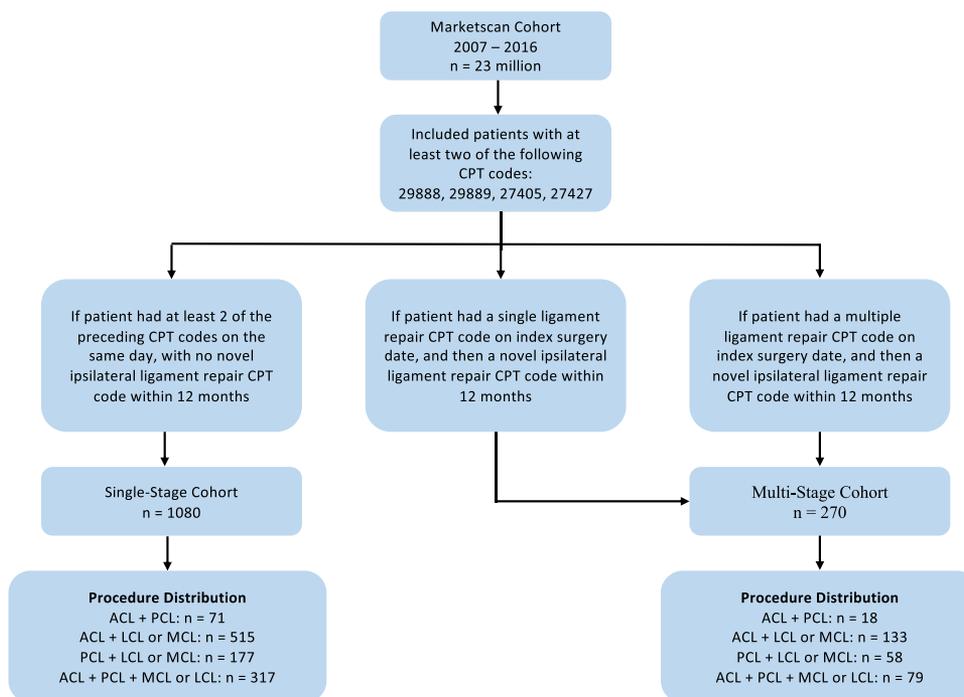


Figure 1. Flowchart depicting formation of single-stage and multi-stage cohorts. (ACL, anterior cruciate ligament; CPT, Current Procedural Terminology; LCL, lateral collateral ligament; MCL, medial collateral ligament; PCL, posterior cruciate ligament.)

Table 1. Demographic Characteristics and Baseline Comorbidities

	Single-Stage Surgery (n = 1,080)	2-Stage Surgery (n = 270)	P Value
Age, mean (SD), yr	27.2 (12.5)	27.8 (12.9)	.4851
Male sex, n (%)	711 (65.8)	176 (65.2)	.8410
Pulmonary disease, n (%)	36 (3.3)	15 (5.6)	.0867
Diabetes, n (%)	19 (1.8)	6 (2.2)	.6138
Hyperlipidemia, n (%)	107 (9.9)	32 (11.9)	.3471
Tobacco use, n (%)	56 (5.2)	17 (6.3)	.4703
Hypertension, n (%)	130 (12.0)	40 (14.8)	.2185
Obesity, n (%)	81 (7.5)	24 (8.9)	.4460
Mean CCI	0.12	0.15	.4131

CCI, Charlson Comorbidity Index; SD, standard deviation.

Modification (ICD-9-CM) codes; *International Classification of Diseases, Tenth Revision, Clinical Modification* (ICD-10-CM) codes; Current Procedural Terminology (CPT) codes; Diagnosis-Related Group codes; and National Drug Codes. The MarketScan database relies on billing codes submitted by providers during routine patient care and has been used for procedure-specific research evaluating surgical complication rates, unplanned reoperation rates, and overall patient cost.¹²⁻¹⁴

Database Query

The data set was queried to identify patients with a multi-ligament knee injury between January 1, 2007, and December 31, 2016, with a minimum of 1 year of follow-up captured in the database (Fig 1). Multi-ligament knee injury was defined as injury to 2 or more of the following ligaments: ACL (CPT code 29888), PCL (CPT code 29889), and MCL or LCL (CPT code 27405 or 27427). A single-stage approach was defined as multiple procedure codes at the index procedure without either related procedural codes or ipsilateral different-ligament procedural codes appearing again within 12 months. The 2-stage approach was defined as a single code at the index procedure and an ipsilateral code for a different ligament within 12 months (excluding the same procedure code). The 2-stage group also included patients who had multiple codes at the index procedure followed by an ipsilateral ligamentous procedure code within 12 months. For example, a patient may have had 2 ligaments addressed during the index surgical procedure, followed by a second operation to address a third ligament. We recorded demographic data including age and sex and comorbidities including pulmonary disease, diabetes, hyperlipidemia, tobacco use, hypertension, and obesity, as well as the Charlson Comorbidity Index (Table 1).

Patient Grouping and Propensity Score Matching

Patients were divided into 2 cohorts based on exposure to a single-stage approach versus a multi-stage approach (Table 1). Within the cohorts, patients were

placed in the following groups based on injury pattern: group 1, ACL and PCL; group 2, ACL and LCL or MCL; group 3, PCL and LCL or MCL; and group 4, ACL, PCL, and MCL or LCL. To minimize the effect of potential confounders, propensity score matching was performed. A greedy nearest-neighbor algorithm was used to match patients with a 4:1 ratio of single-stage patients to multi-stage patients. All baseline and operative characteristics were included in the algorithm.

A propensity score is the probability that a patient may be placed in a group (single-stage group vs 2-stage group) based on the patient's characteristics, injury characteristics, and comorbidity status. When patients are matched on their propensity scores, patients will have statistically insignificant differences in their likelihood to be placed in either group. A greedy nearest-neighbor approach is preferred because it matches patients based on the closest ("nearest") propensity scores within the caliper (maximal difference allowed between a patient's propensity scores to match).

Outcomes and Variables

Our primary outcome was postoperative complications based on those commonly reported after surgical treatment of multi-ligament knee injuries.^{2,15-17} These included knee instability and/or dislocation, infection, nerve injury, arthrofibrosis, wound complications, deep vein thrombosis, and hematoma. Data were obtained by collecting *International Classification of Diseases, Tenth Revision* (ICD-10) codes for the relevant diagnoses from the MarketScan database during the postoperative period. For patients who underwent a single-stage operation, complications were considered for the 30-, 90-, 180-, and 365-day periods after the initial surgical procedure. For patients who underwent a 2-stage operative plan, complications were considered for the 30-, 90-, 180-, and 365-day periods after the second procedure. A secondary outcome consisted of unplanned reoperations, which included irrigation and/or debridement (CPT code 27301 or 27310); manipulation under anesthesia (CPT code 27570); and isolated (not part of ligament procedures) meniscal debridement (CPT code 29881 or 29880), meniscal repair (CPT code 29882, 29883, or 27403), chondroplasty (CPT code 29877 or 29879), and conversion to total knee replacement (CPT code 27447). Complications were tracked for 1 year after the index procedure in the single-stage group and after the second surgical procedure in the multi-stage group. Reoperations were tracked for 2 years after the index procedure in the single-stage group and after the second surgical procedure in the multi-stage group. Costs were calculated from the index procedure for both groups and were evaluated at 9 months, 2 years, and 5 years. Costs included the aggregate value of total spending (combined surgical spending and nonsurgical costs including physical therapy, imaging, and postoperative care).

Table 2. Postoperative Complications Within 30 Days

Variable	Single-Stage Surgery (n = 1,080)	2-Stage Surgery (n = 270)	P Value	OR (95% CI)
Any complication	97 (8.9)	36 (13.3)	.0467*	1.5 (1.0-2.3)
Knee instability	46 (4.3)	19 (7.0)	.0565	1.7 (0.9-2.9)
Infection	8 (0.7)	5 (1.8)	.0945	1.3 (0.1-12.9)
Nerve injury	0 (0.0)	1 (0.4)	.0454*	NA
Wound complication	3 (0.3)	1 (0.4)	.8023	1.3 (0.1-12.9)
Deep vein thrombosis	9 (0.8)	0 (0.0)	.1323	NA
Hematoma	0 (0.0)	1 (0.4)	.0454*	NA

CI, confidence interval; NA, not applicable; OR, odds ratio.

*Statistically significant at α level of .05.

Statistical Analysis

Two-sample *t* tests, χ^2 tests, and Fisher exact tests were used as appropriate. An α level of .05 was used to discern statistical significance. Statistical analysis was conducted in the RStudio program (version 1.0.153; RStudio, Boston, MA).

Results

Cohort Demographic Characteristics

We identified a matched cohort of patients undergoing multi-ligament knee reconstructions with a single-stage approach (n = 1,080) or a 2-stage approach (n = 270). The number of simultaneous ligamentous injuries was also matched between groups. These injuries were classified as group 1 in 6.6%, group 2 in 47.7%, group 3 in 16.4%, and group 4 in 29.4% in the single-stage cohort and as group 1 in 6.3%, group 2 in 46.2%, group 3 in 20.1%, and group 4 in 27.4% in the 2-stage cohort. Matched covariates and demographic characteristics between the single and 2-stage groups showed no statistically significant differences ($P > .05$ for all) (Table 1).

Complications

In the first 30 days after the last planned surgical procedure, there was a higher overall complication rate for staged procedures (13.3% vs 8.9%, $P = .047$) (Table 2). Specific complication differences were seen in nerve injury ($P = .045$) and hematoma ($P = .045$).

At 90 and 180 days, 2-stage procedures were found to have a higher overall complication rate, driven by increased rates of infection, knee instability, and hematoma (Tables 3 and 4). These findings remained significant at 1 year, with the exception that hematoma formation was not significantly different between the 2 groups (Table 5). Rates of nerve injury, arthrofibrosis, wound complications, and deep vein thrombosis were low, with no between-group differences.

Reoperations

The single-stage group had a significantly lower rate of unplanned reoperations at all time points (Table 6). The odds of a reoperation at 1 year and 2 years in patients undergoing a 2-stage approach versus a single-stage approach was 5.5 times (26.7% vs 6.2%) and 4.9 times (28.2% vs 7.4%), respectively (Table 6). The most common reoperations for patients in the single-stage group were manipulation under anesthesia (n = 40, 3.7%) and chondroplasty (n = 35, 3.2%). In the 2-stage cohort, the most common reoperations were chondroplasty (n = 35, 13%) and isolated meniscal repair (n = 30, 11.1%) (Table 7).

Costs

The single-stage approach showed significantly higher index procedure costs. At all other follow-up time points, costs were greatest in the 2-stage group (Table 8).

Table 3. Postoperative Complications Within 90 Days

Variable	Single-Stage Surgery (n = 1,080), n (%)	2-Stage Surgery (n = 270), n (%)	P Value	OR (95% CI)
Any complication	138 (12.8)	58 (21.5)	.0003*	1.9 (1.3-2.6)
Knee instability	48 (4.4)	23 (8.5)	.0073*	2.0 (1.2-3.4)
Infection	11 (1.0)	11 (4.10)	.0004*	4.1 (1.8-9.6)
Nerve injury	1 (0.1)	1 (0.4)	.2885	4.0 (0.3-64.3)
Arthrofibrosis	71 (6.6)	22 (8.2)	.361	1.3 (0.8-2.1)
Wound complication	6 (0.6)	1 (0.4)	.7041	0.6 (0.1-5.6)
Deep vein thrombosis	11 (1.0)	1 (0.4)	.3102	0.4 (0.1-2.8)
Hematoma	0 (0.0)	2 (0.7)	.0046*	NA

CI, confidence interval; NA, not applicable; OR, odds ratio.

*Statistically significant at α level of .05.

Table 4. Postoperative Complications Within 180 Days

Variable	Single-Stage Surgery (n = 1,080), n (%)	2-Stage Surgery (n = 270), n (%)	P Value	OR (95% CI)
Any complication	156 (14.4)	65 (24.1)	.0001*	1.9 (1.4-2.6)
Knee instability	54 (5.0)	26 (9.6)	.004*	2.0 (1.2-3.3)
Infection	15 (1.4)	15 (5.6)	<.0001*	4.2 (2.0-8.6)
Nerve injury	2 (0.2)	1 (0.4)	.5633	2.0 (0.2-22.2)
Arthrofibrosis	81 (7.5)	25 (9.3)	.3364	1.3 (0.8-2.0)
Wound complication	6 (0.6)	1 (0.4)	.7047	0.6 (0.1-5.6)
Deep vein thrombosis	11 (1.0)	1 (0.4)	.312	0.4 (0.1-2.8)
Hematoma	0 (0.0)	2 (0.7)	.0046*	NA

CI, confidence interval; NA, not applicable; OR, odds ratio.

*Statistically significant at α level of .05.

Discussion

Single-stage multi-ligament reconstruction was associated with lower overall cost, fewer surgical complications, and lower reoperation rates when compared with 2-stage reconstruction. Prior studies comparing outcomes of single-stage versus 2-stage approaches reported varying results regarding both objective measures and patient-reported outcomes.^{6,9,18-21} Because of the rarity of these injuries, sample size has been a consistent limiting factor in comparing these protocols.^{6,9,18-21} Mook et al.⁸ performed a systematic review including 24 studies with 396 patients undergoing single and 2-stage reconstructions. They reported similar clinical outcomes in the 2 groups, although the 2-stage patients had a higher frequency of good to excellent scores. Barfield et al.²² followed up with a systematic review of studies from 2009-2014 showing no differences in outcomes for single-stage versus multi-stage patients.

In this study, we used a national database to compare the complication rates and costs associated with a single-stage versus 2-stage approach. The MarketScan database is a large national database of more than 75 million unique patients that allows evaluation of complications and costs from a much larger patient population than can be provided by case studies or a collection of case series. We identified 1,350 patients surgically treated for a multi-ligamentous knee injury. After rigorous matching, we found that patients who

underwent single-stage surgery had lower complication rates and lower reoperation rates than those who underwent a 2-stage approach. Patients who underwent multi-stage treatment had an increased risk of reoperation at 1 year (5.5 times) and 2 years (4.9 times). Although the index procedure was less expensive, the total financial cost associated with a 2-stage approach was increased compared with a single-stage approach at 9 months through 2 years.

Wound complications remain a general concern after surgical treatment of complex multi-ligament knee injuries, particularly in patients with high-energy events and injuries with significant swelling, ecchymosis, and friability.^{2,14-17,23} In our study, a wound complication or hematoma was rare (<1%) regardless of the treatment strategy. However, it is interesting to note that 2-stage treatment had an increased risk of infection beyond 90 days after the last planned procedure. Although obesity (body mass index > 30) has been reported as a risk factor for postoperative infections after surgical treatment of multi-ligament knee injuries, there was no significant difference in the rate of obesity between the single-stage and 2-stage cohorts. The discrepancy between wound complications and infections may represent a propensity for deep infections rather than superficial infections with the re-traumatization of a healing wound bed.

Another commonly discussed complication after a multi-ligamentous injury is arthrofibrosis.^{2,8,15-17} It has

Table 5. Postoperative Complications Within 365 Days

Variable	Single-Stage Surgery (n = 1,080), n (%)	2-Stage Surgery (n = 270), n (%)	P Value	OR (95% CI)
Any complication	172 (15.9)	69 (25.6)	.0002*	1.8 (1.3-2.5)
Knee instability	55 (5.1)	30 (11.1)	.0003*	2.3 (1.5-3.7)
Infection	19 (1.8)	16 (5.9)	.0001*	3.5 (1.8-6.9)
Nerve injury	2 (0.2)	1 (0.4)	.5634	2.0 (0.2-22.2)
Arthrofibrosis	89 (8.2)	26 (9.6)	.4646	1.2 (0.7-1.8)
Wound complication	6 (0.6)	1 (0.4)	.7047	0.6 (0.1-5.6)
Deep vein thrombosis	11 (1.0)	1 (0.4)	.3102	0.4 (0.1-2.8)
Hematoma	2 (0.2)	2 (0.7)	.1331	4.0 (0.6-28.7)

CI, confidence interval; OR, odds ratio.

*Statistically significant at α level of .05.

Table 6. Overall Unplanned Reoperation Rates After Final Planned Surgical Procedure

Timing of Unplanned Reoperation	Single-Stage Surgery (n = 1,080), n (%)	2-Stage Surgery (n = 270), n (%)	P Value	OR (95% CI)
0-30 d	5 (0.5)	5 (1.9)	.0173*	4.0 (1.2-14.1)
0-90 d	41 (3.8)	25 (9.3)	.0002*	2.5 (1.5-4.3)
0-180 d	54 (5.0)	41 (15.2)	<.0001*	3.4 (2.2-5.2)
0-1 yr	67 (6.2)	72 (26.7)	<.0001*	5.5 (3.8-7.9)
0-2 yr	80 (7.4)	76 (28.2)	<.0001*	4.9 (3.5-6.9)

CI, confidence interval; OR, odds ratio.

*Statistically significant at α level of .05.

been postulated that early treatment leads to a greater risk of arthrofibrosis owing to the increased inflammatory milieu present in the knee, which may be exacerbated during early treatment.¹⁶ Previous studies reported a loss of range of motion of 31% versus 0% for single versus staged procedures.⁸ The findings in this study suggest that the rates of arthrofibrosis were similar between the treatment groups. In the first postoperative year, arthrofibrosis was reported in 8.2% and 9.6% of patients who underwent the single-stage and 2-stage operative plans, respectively. The rates of reoperation for manipulation under anesthesia between treatment groups were also similar at 2 years postoperatively (3.7% for single-stage group vs 4.4% for 2-stage group).

An argument against a single-stage surgical plan is that the increased length of surgery may result in an increased likelihood of nerve injury or deep vein thrombosis,²⁴ as well as the known association between increased length of surgery and increased infection risk.²⁵ The findings in our study show that these complications are rare. Throughout the various time points, the rate of nerve injury ranged from 0.0% to 0.4%, with no difference between treatment groups. Likewise, deep vein thrombosis rates were low (0%-1%) and did not differ between groups over the 1-year follow-up period. These results, in conjunction with the decreased postoperative infection rate in the single-stage cohort, suggest there may be less morbidity associated with increased operative times than previously postulated.

Mook et al.⁸ summarized postoperative instability in the anterior, posterior, varus, and valgus directions.

One of the obvious limitations of reporting on general instability and specific directional instability after multi-ligament knee injuries is that instability largely depends on what structures were initially injured, how they were injured (midsubstance vs avulsion), and how they were treated (repair vs reconstruction), in addition to the timing of surgery. Despite these limitations, Mook et al. found no significant differences in instability between single-stage treatment and 2-stage treatment. In our study, the database was not able to distinguish the direction of instability; thus, we are only able to report on general knee instability. We found no differences in continued knee instability in the early phase (30 days), which was expected because many rehabilitation protocols after multi-ligament knee injuries have a period of immobilization or limited weight bearing. At 90, 180, and 365 days postoperatively, however, the patients treated in a 2-stage fashion had a 2.0 to 2.3 times greater risk of continued instability (Tables 2, 4, and 5). The etiology of this difference is difficult to determine with a database study. It should be noted that patients were matched based on comorbidities and the number and combination of ligaments injured, suggesting these factors alone cannot explain the difference.

Although a small percentage of patients in the single-stage group received an unplanned operation at the 1- and 2-year marks, patients treated with a 2-stage treatment plan had a 5.5 times greater risk of a subsequent unplanned operation at 1 year and a 4.9 times greater risk at 2 years than patients with single-stage treatment. This difference was primarily driven by significantly increased rates of subsequent meniscal repairs and chondroplasty in the 2-stage group.

Table 7. Subsequent Procedures Within 2 Years of Final Planned Surgical Procedure

Variable	Single-Stage Surgery (n = 1,080), n (%)	2-Stage Surgery (n = 270), n (%)	P Value
Infection and/or irrigation and debridement	8 (0.7)	5 (1.9)	.0945
Manipulation under anesthesia	40 (3.7)	12 (4.4)	.5716
Meniscal repair	7 (0.7)	30 (11.1)	<.0001*
Meniscal debridement	1 (0.1)	1 (0.4)	.2885
Chondroplasty	35 (3.2)	35 (13.0)	<.0001*
Total knee replacement	6 (0.6)	1 (0.4)	.8668

*Statistically significant at α level of .05.

Table 8. Costs Associated With Treatment

Variable	Single-Stage Surgery (n = 1,080)	2-Stage Surgery (n = 270)	P Value
Average index surgery cost, \$	16,661	12,918	<.0001*
Average total cost, \$			
9 mo	22,252	31,210	<.0001*
2 yr	24,620	37,752	<.0001*
5 yr	26,298	39,237	<.0001*

*Statistically significant at α level of .05.

Although it is not possible to determine causality with the design of this study, a possible explanation is that a period of partial instability between staged procedures may increase the likelihood of additional meniscal and chondral injuries. Although these injuries may be subclinical at the time of the second planned procedure, they may serve as a nidus for continued symptoms. The presence of reoperations in the single-stage group indicates that there is still a risk of reoperation within this group and underlines the significance of this particular injury pattern.

Last, we looked at the financial costs of a single-versus 2-stage treatment strategy. At the time of index surgery, the staged surgery strategy was 22% less expensive. This finding is expected because the surgical times are shorter and less equipment is required. However, at 9 months, 2 years, and 5 years, the cost of care associated with staged treatment was increased compared with single-stage treatment. At 5 years after the last planned surgical procedure, the total cost associated with a 2-stage approach increased from \$12,918 to \$39,237—a 204% increase. In comparison, total costs after the index surgical procedure for the single-stage group increased by 54%. The costs associated with a secondary planned surgical procedure, prolonged physical therapy, and an increased reoperation rate are likely driving the cost difference. The breakdown of costs for the 2 treatment strategies will be the subject of future studies.

Overall, we found that a single-stage procedure resulted in fewer complications and fewer reoperations at reduced costs. The most common complications were knee instability and infections. Other complications including arthrofibrosis, deep vein thrombosis, and nerve injury were rare and showed similar rates between groups. Two-stage treatment had a 5.5 times increased risk of an unplanned second surgical procedure within a year of the last planned surgical procedure compared with single-stage treatment. We controlled for potential limitations with a rigorous matching method that included injury pattern based on our groupings in the algorithm. This matching resulted in a slight trend toward less severe injury scores in the staged cohort. Objective measures such as postoperative

range of motion or patient-reported outcomes were not available in the database. Despite the inherent limitations of a data set review, given the paucity of available data comparing 1-stage and 2-stage approaches to multi-ligament knee injuries, the benefits of looking at a large data set outweigh the limitations inherent in using existing databases.

Limitations

There are several limitations to our study design. A database study allows broad evaluation across a larger cohort of patients but is unable to provide granular data. Multi-ligament knee injuries encompass complex injury patterns with variability in the number of injured ligaments and the type of injury (midsubstance vs avulsion). Individual patient records are not able to be reviewed, and the decision model for choosing between single-stage and 2-stage approaches is not able to be determined. Patients with more complex injuries may be more likely to be offered 2-stage approaches. We are unable to comment on or account for the role surgeon experience plays in the decision to offer a single-stage or 2-stage approach. Outside of surgeon preference, there may have been patient- or injury-specific indications for staging that were not captured by this study. Moreover, surgical techniques vary greatly and are individualized to each patient and injury pattern, as is the choice between autograft and allograft. In addition, surgeons who perform a single-stage technique may be biased and, as a result, be less likely to return to the operating room for a required second stage. Our study design is unable to differentiate between these injury patterns and techniques. Peroneal nerve injuries may have been present preoperatively and likely under-coded and, as such, may have been falsely coded as operative complications. We do not have access to information regarding time of injury relative to surgery, which may alter the incidence of arthrofibrosis or other complications. Finally, the MarketScan database relies on accurate coding of diagnoses and procedures. Inaccurate coding via clerical errors including miscoding or noncoding is a possibility.

Conclusions

Single-stage surgical treatment of multi-ligament knee injuries results in fewer complications and reoperations and lower total costs compared with 2-stage treatment, even after controlling for the number and combination of ligaments injured.

References

1. Klimkiewicz JJ, Petrie RS, Harner CD. Surgical treatment of combined injury to anterior cruciate ligament, posterior cruciate ligament, and medial structures. *Clin Sports Med* 2000;19:479-492.

2. Cook S, Ridley TJ, McCarthy MA, et al. Surgical treatment of multiligament knee injuries. *Knee Surg Sports Traumatol Arthrosc* 2015;23:2983-2991.
3. Gauffin H, Rockborn P. Knee dislocations: Is reconstruction of the posterior cruciate ligament crucial? *Eur J Orthop Surg Traumatol* 2014;24:371-377.
4. Levy BA, Dajani KA, Whelan DB, et al. Decision making in the multiligament injured knee: An evidence based systematic review. *Arthroscopy* 2009;25:430-438.
5. Li X, Liu T. Surgical management of multiple knee ligament injuries. *Eur J Orthop Surg Traumatol* 2013;23:691-697.
6. Shelbourne KD, Haro MS, Gray T. Knee dislocation with lateral side injury: Results of an en masse surgical repair technique of the lateral slide. *Am J Sports Med* 2007;35:1105-1116.
7. Subbiah M, Pandey V, Rao SK, Rau S. Staged arthroscopic reconstructive surgery for multiple ligament injuries of the knee. *J Orthop Surg (Hong Kong)* 2011;19:297-302.
8. Mook WR, Miller MD, Diduch DR, Hertel J, Boachie-Adjei Y, Hart JM. Multiple-ligament knee injuries: A systematic review of the timing of operative intervention and postoperative rehabilitation. *J Bone Joint Surg Am* 2009;91:2946-2957.
9. Ohkoshi Y, Nagasaki S, Shibata N, Yamamoto K, Hashimoto T, Yamane S. Two-stage reconstruction with autograft for knee dislocations. *Clin Orthop Relat Res* 2002;398:169-175.
10. Lai Z, Liu ZX, Yang JL, Zhang ZF, Chang YL. Clinical effect of staged repair and reconstruction of multiple ligament injuries in knee joints [in Chinese]. *Zhongguo Gu Shang* 2016;29:404-407.
11. Sun L, Wu B, Tian M, Luo YZ. Results of multiple ligament injured knees operated by three different strategies. *Indian J Orthop* 2016;50:43-48.
12. Mabud T, Norden J, Veeravagu A, et al. Complications, readmissions, and revisions for spine procedures performed by orthopedic surgeons versus neurosurgeons: A retrospective, longitudinal study. *Clin Spine Surg* 2017;30:E1376-E1381.
13. Hansen EN, Ong KL, Lau E, Kurtz SM, Lonner JH. Unicompartmental knee arthroplasty has fewer complications but higher revision rates than total knee arthroplasty in a study of large United States databases. *J Arthroplasty* 2019;34:1617-1625.
14. Traven SA, Brinton D, Simpson KN, et al. Preoperative shoulder injections are associated with increased risk of revision rotator cuff repair. *Arthroscopy* 2019;35:706-713.
15. Freychet B, Kennedy NI, Sanders TL, et al. No difference between single and staged posterolateral corner surgical procedures in the multiligament injured/dislocated knee. *Knee Surg Sports Traumatol Arthrosc* 2020;28:2170-2176.
16. Hegyes MS, Richardson MW, Miller MD. Knee dislocation: Complications of nonoperative and operative management. *Clin Sports Med* 2000;19:519-543.
17. Medina O, Arom GA, Petrigliano FA, McAllister DR. Vascular and nerve injury after knee dislocation. *Clin Orthop Relat Res* 2014;472:2621-2629.
18. Fanelli GC, Orcutt DR, Edson CJ. The multiple-ligament injured knee: Evaluation, treatment, and results. *Arthroscopy* 2005;21:471-486.
19. Noyes FR, Barber-Westin SD. Reconstruction of the anterior and posterior cruciate ligaments after knee dislocation. Use of early protected postoperative motion to decrease arthrofibrosis. *Am J Sports Med* 1997;25:769-778.
20. Werier J, Keating JF, Meek RN. Complete dislocation of the knee: The long-term results of ligamentous reconstruction. *Knee* 1998;5:255-260.
21. Fanelli GC, Edson CJ. Arthroscopically assisted combined anterior and posterior cruciate ligament reconstruction in the multiple ligament injured knee: 2- to 10-year follow-up. *Arthroscopy* 2002;20:339-345.
22. Barfield WR, Holmes RE, Slone H, Walton ZJ, Hartsock LA. Acute versus staged surgical intervention in multiligamentous knee injuries: A review of literature since 2009. *Curr Orthop Pract* 2015;26:530-535.
23. Rios A, Villa A, Fahandezh H, de Jose C, Vaquero J. Results after treatment of traumatic knee dislocations: A report of 26 cases. *J Trauma* 2003;55:489-494.
24. Arthur JR, Spangehl MJ. Tourniquet use in total knee arthroplasty. *J Knee Surg* 2019;32:719-729.
25. Leong G, Wilson J, Charlett A. Duration of operation as a risk factor for surgical site infection: Comparison of English and US data. *J Hosp Infect* 2006;63:255-262.