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Cost-Effectiveness Analysis of Early Reconstruction versus Rehabilitation and Delayed Reconstruction for ACL Tears

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Abstract

Background—An initial anterior cruciate ligament (ACL) tear can be treated with surgical reconstruction or focused rehabilitation. The KANON (Knee Anterior cruciate ligament, NON-surgical versus surgical treatment) randomized control trial compared rehabilitation plus early ACL reconstruction (ACLR) to rehabilitation plus optional delayed ACLR and found no difference at two years by intention to treat analysis of total KOOS scores. The purpose of this study was to compare the cost-effectiveness of early versus delayed ACLR.

Methods—A Markov decision model was constructed for a cost-utility analysis of early reconstruction (ER) versus rehabilitation plus optional delayed reconstruction (DR). Outcome probabilities and effectiveness were derived from two sources: the KANON Study and the Multicenter Orthopaedic Outcomes Network (MOON) database. Collectively, these two sources provided data from 928 ACL patients. Utilities were measured by the SF-6D. Costs were

estimated from the societal perspective in 2012 U.S. dollars. Costs and utilities were discounted in accordance with the United States Panel on Cost-Effectiveness in Health and Medicine. Effectiveness was expressed in quality-adjusted life years gained (QALYs). Principal outcome measures were average incremental costs, incremental effectiveness (as measured by QALYs), and net health benefits. Willingness-to-pay was set at \$50,000, the currently accepted standard in the U.S.

Results—In the base case, the ER group resulted in an incremental gain of 0.28 QALYs over the DR group with a corresponding lower overall cost to society of \$1572. Effectiveness gains were driven by the low utility of an unstable knee and the lower utility for the DR group. The cost of rehabilitation and the rate of additional surgery drove the increased cost of the DR group. The most sensitive variable was the rate of knee instability after initial rehabilitation. When the rate of instability falls to 51.5%, rehabilitation plus optional delayed ACLR is less costly and when it falls below 18% it becomes the preferred cost-effective strategy.

Conclusions—An economic analysis of the timing of ACLR using data exclusively from the KANON trial, MOON cohort, and national average reimbursement revealed that early ACLR was more effective (improved QALYs) at a lower cost than rehabilitation plus optional delayed ACLR. Therefore, early ACLR should be the preferred treatment strategy from a societal health system perspective.

Keywords

ACL reconstruction; rehabilitation; cost effectiveness; QALY

Introduction

The two primary treatments that exist for anterior cruciate ligament (ACL) tears are surgical reconstruction or focused rehabilitation. Early reconstruction is utilized more commonly in the United States to facilitate return to sport and to protect the meniscus and articular cartilage. Focused rehabilitation is reserved for lower demand and older patients. While ACL reconstruction (ACLR) outcomes are well documented and generally excellent,^{23,24} until recently, a direct comparison of the two treatments did not exist. A recent randomized controlled trial reported by Frobell et al, the Knee Anterior cruciate ligament, NON-surgical versus surgical treatment (KANON) study, compared rehabilitation plus early ACLR to rehabilitation plus optional delayed ACLR using the primary outcome measure of the Knee injury and Osteoarthritis Outcome Score (KOOS) by intention to treat analysis.⁷ The rehabilitation plus optional delayed ACLR group demonstrated a high crossover rate (39%) and clinical instability (32%) at two years compared with very little clinical instability (3%) in the ACLR group. Nearly two-thirds of the patients underwent knee arthroscopy to treat meniscus tears without ACLR. As a result, they found no significant difference between the early and delayed reconstruction groups at two years as determined by total KOOS.

Frobell et al concluded the treatment strategy of rehabilitation with optional delayed reconstruction could reduce the utilization of ACLR. This trial and conclusion has the potential to alter the treatment paradigm for this common acute knee injury, as there are estimates of up to 250,000 new ACL injuries occurring annually.¹⁰ Furthermore, since early

osteoarthritis has been linked to ACL tears,¹³ the future effects to individuals and society could be substantial. A treatment shift such as this requires complete evaluation of societal impact, which must include economic analysis.²² However, the KANON trial⁷ lacked comprehensive economic evaluation. Cost-effectiveness analysis is the primary tool of economic analysis. The purpose of this study was to compare the cost-effectiveness of early ACLR to rehabilitation plus optional delayed ACLR.

We had two principal aims in this cost-effectiveness analysis. First was to compare the incremental quality-adjusted life years (QALYs) between early reconstruction (ER) versus delayed reconstruction (DR), and second, to compare the direct costs between these two groups from a societal viewpoint. We hypothesized that the ER group would result in both improved QALYs and less direct expenses.

Methods

General Model Overview

We investigated the cost-effectiveness of early ACLR (less than 10 weeks; ER group) compared to rehabilitation plus optional delayed reconstruction (DR group) using a Markov cohort decision model, presented in Figure I. Cost-effectiveness is estimated from the societal perspective. After obtaining IRB approval, outcome and state transition probabilities were obtained from two primary sources, the prospective cohort of primary ACLRs from the Multicenter Orthopaedic Outcomes Network (MOON) (unpublished SF-36 outcomes) and the KANON study.⁷ In Markov models, patients move through the model to various health states at defined intervals or cycle lengths and probabilities. The cycle length for this model was 1 year and the model was run for 6 years, consistent with the mean follow-up in the MOON cohort. All transition probabilities up to 2 years were taken from the KANON trial. Only long-term conversion to ACLR and ACLR re-tear rates were taken from MOON. The primary effectiveness outcome was expressed in QALYs and costs were estimated in 2012 U.S. dollars. Both costs and utilities were discounted at 3% to reflect their present value. The model and analysis were performed in accordance with the consensus-based recommendations for the conduct of cost-effectiveness analysis advocated by the Panel for Cost-Effectiveness in Health and Medicine^{20,21,26} and using a general decision analysis software package (TreeAge Pro Suite 2011; TreeAge Software Inc., Williamstown, MA).

Model Structure

Our decision tree consisted of two primary treatment arms (ER and DR) as described above. Patients in the ER group entered a post-procedure state for 1 year while those in the DR group entered an initial rehabilitation state for 1 year. All patients in the ER arm were assumed to have a stable knee at the end of year one. In the DR group they could undergo arthroscopy without ACLR for meniscus treatment. Thereafter, patients could be in 1 of 3 health states, 1) stable knee with surgery, 2) stable knee with rehabilitation, or 3) symptomatic instability. Patients could undergo additional surgeries consisting of 1) meniscectomy, 2) meniscus repair, 3) manipulation under anesthesia, 4) removal of hardware or 5) basic knee arthroscopy. These reoperation rates were taken from the

KANON trial. Patients were estimated to re-tear their ACL graft at rates consistent with the MOON cohort.²⁷

In the DR arm, patients could have a stable or unstable knee at the end of year one based on rates from the KANON trial. If initially successful with rehabilitation, they were assumed not to develop instability in the next 5 years of the model. Conversely, once symptomatic, patients remained symptomatic until they chose to undergo ACLR.

Model Parameters (Table I)

As mentioned above, the two primary input sources came from the MOON group database and KANON study. The MOON cohort consisted of 807 primary ACL tears with a minimum follow-up of 6 years, while the KANON study had 121 patients (n=62 in the ER group; n=59 in the DR group), with a minimum follow-up of 2 years (unpublished data, in preparation).

Utilities—Utilities in this model were derived from the SF-36 with use of the SF-6D. The SF-6D uses the SF-36 to generate utility by adding patient preferences. It was developed by British health economist John Brazier and has been validated in many disease states.² SF-36 values were taken from the MOON cohort. A clinically stable knee ascertained through rehabilitation was assigned the same utility as a stable knee after surgical reconstruction, 0.82 at 2 years and 0.82 at 6 years and beyond, although the surgical reconstruction patient was assumed to experience a disutility of surgery to account for the time in a worse health state than an unstable knee when recovering from surgery. These values were relatively low due to the low morbidity of arthroscopic knee surgery and were estimated by expert opinion. Unfortunately, there is little objective data to estimate disutility and required estimation by expert opinion. The experts were the clinician authors of this study. They are all fellowship trained in sports medicine and would be considered high volume ACL surgeons. The general approach is to assume 2 weeks in a health state worse than baseline which accounts for postoperative pain followed by 10 weeks at the preoperative utility. We assumed the improved utility from surgery would be reached at 12 weeks postoperatively. This assumption is for ACL reconstruction. Knee arthroscopy is assumed to be exactly half of this recovery (1 week for postop, 5 more weeks of recovery, reaching improved utility at 6 weeks postop). A clinically unstable knee was assigned the utility for a preoperative knee undergoing reconstruction in MOON (Table I). Unstable knees are those with findings of either subjective instability by the patient or objective instability by the clinician (positive pivot shift). Stable knees are those without either of these findings.

Knee Stability—From KANON, 71% of patients with an ACL tear either chose to undergo ACLR (39%) or had clinically detectable or symptomatic instability at 2 years (32%). This value was used in our model to estimate the number of patients undergoing rehabilitation that were stable and unstable. A sensitivity analysis was performed on the progression to instability beyond 2 years. From MOON, 3% of patients 2 years from reconstruction experienced a re-tear so an annual re-tear rate of 1.5% was used in the model (all 6 years).²⁷

Procedure Rates—The rate of primary ACLR in the DR group was taken from KANON. Thirty-nine percent (39%) of the initial cohort or 55% of the unstable patients chose to undergo surgical reconstruction by the 2-year follow-up in the KANON trial. This assumption clearly leaves patients in the symptomatic instability health state in the final 4 years of the model. Ten percent (10%) of the remaining unstable patients were assumed to choose reconstruction for the remainder of the model. This is consistent with the MOON cohort in which 11% of all patients underwent ACLR 2 years or more after their initial injury. Other ACLR series in the literature support this assumption and it was subjected to rigorous sensitivity analysis.^{1,5,6} The rates of re-operation were taken from KANON. The specific numbers of physical therapy visits for both post-operative and non-operative rehabilitation were not available in the KANON trial manuscript or appendix. As such, best practices of the authors were used to estimate this variable – 2 visits per week for 16 weeks were used for post-operative rehabilitation after ACLR. KANON reports the structured rehabilitation treatment program lasted 24 weeks. We assumed 2 visits per week for the first 12 weeks and 1 visit per week for the final 12 visits. Two visits for 6 weeks were used for rehabilitation following subsequent knee surgeries.

Costs—Since this model is performed from a societal perspective, as is recommended by the Panel for Cost-Effectiveness, the costs used in the model are those that are accrued to society rather than an individual hospital or practice. Although this method may not account for all the itemized differences in cost seen by an individual hospital or surgical practice, it permits a more global comparison between the treatment strategies and avoids the pitfalls of regional cost differences. Therefore, the costs for rehabilitation, ACLR, knee arthroscopy and revision procedures were estimated starting with the national average Medicare reimbursements for the procedures in 2012 U.S. dollars. Reimbursement for the outpatient facility and professional fees for each procedure were summed to create the total reimbursement. Facility fees were assumed to be 60% ambulatory surgery center and 40% hospital-based outpatient reimbursement. Current Procedural Terminology (CPT) codes were used to estimate the professional costs.

Cost estimates based on Medicare payment rates may underestimate payments made by private insurers and overestimate payments made by Medicaid, self-insured, and uninsured patients. To reconcile these differences, we adjusted our estimates of direct medical costs using payment rates of other insurers (as a percentage of the Medicare rate) and then weighted by the national distribution of payers for treatment of ACLR. The payment rate of Medicaid and self-pay patients was set as 80% and 50% of the Medicare rate, respectively. For private insurers, the payment rates reported in the literature were used.⁹ Ginsburg reported private insurer payments as a percentage of Medicare rates for outpatient services in selected areas, ranging from 193% in Cleveland to 368% in San Francisco in 2008. The median of the reported range (280%) was used to adjust costs of outpatient services.⁹ The Medicare Payment Advisory Committee (MedPAC) estimated that the private rate for physician services was, on average, 123% of the Medicare rate across all services and areas in 2003.¹⁷ For all other patients, including those paid by Workers' Compensation, we assumed their rate was the same as the average rates of Medicare and private insurers. These costs are shown in Table I.

Cost-Effectiveness Analysis

The Markov cohort model was used to conduct a cost-effectiveness analysis of the present-day value of the expected costs and QALYs gained over the lifetime of a theoretical patient cohort for each treatment strategy. Outcome measures included average costs, effectiveness (QALYs), as well as the cost-effectiveness (C/E) ratio for each strategy. A QALY is an outcome measure equal to the expected gains in life expectancy associated with a treatment option, downwardly adjusted for any limitations in quality of life. A year in perfect health is worth one QALY, and a year of imperfect health is worth some fraction of one QALY.

The incremental costs and effectiveness were also calculated and represent the relative difference between the two alternative strategies. The principal outcome measurement calculated was the incremental cost-effectiveness ratio (ICER), which is the ratio between the difference in costs and difference in QALY of each strategy. In terms of this model, the ICER is expressed as:

$$\text{ICER} = (\text{CostEarly ACLR} - \text{CostRehab+Opt Delayed ACLR}) / (\text{QALYEarly ACLR} - \text{QALYRehab+Opt Delayed ACLR}).$$

ICERs less than \$50,000 per QALY gained were considered to be cost-effective based on a willingness of the health-care system to pay (WTP) value of \$50,000. In this cost-effectiveness analysis, the preferred treatment strategy was the more effective strategy if $\text{ICER} < \text{WTP}$.

One, two and three-way sensitivity analyses were performed on all variables in the model. Sensitivity analysis is a process in which model results are repeatedly estimated using modified versions of the model. The ranges of values taken by the output provide a measure for how sensitive a finding is to the model's underlying assumptions. Variables deemed "sensitive" were those who when changed across a reasonable range also changed the preferred strategy. If the preferred strategy did not change, then the variable was termed "robust." Data from MOON was available in distributions and, therefore, probabilistic sensitivity analysis was used to identify the impact of uncertainty in utility on the preferred outcome. These distributions were normal and defined by a mean and standard deviation. These values are found in Table I. Monte Carlo analysis using microsimulation and probabilistic sensitivity analysis was used to generate 95% confidence intervals for the outcomes. Monte Carlo analysis involves running the model a specified number of times and randomly selecting a value from the distribution as opposed to using the mean as is done in Markov Cohort analysis.

Results

The model was internally validated against the results of the KANON trial, but external validation was not possible due to the lack of availability of similar studies. Results of the base case are shown in Table II. For this cohort, over 6 years, the ER group resulted in an average incremental cost of \$1,572 *less than* the DR group, while providing an incremental QALY *gain* of 0.28 compared to the DR group. The cost-effectiveness ratio associated with the ER group was \$3,881 per QALY versus \$4,434 per QALY for the DR group. In cost-

effectiveness analyses, a treatment strategy is “dominated” when analysis indicates that it is more costly *and* less effective than the alternative. Based on the outcomes of the base case analysis, the DR treatment strategy was dominated by the ER strategy, and no ICER value was necessary to compare the two.

Sensitivity Analyses

Probabilistic Sensitivity Analysis—Monte Carlo simulation utilizing probabilistic sensitivity analysis to assess the impact of parameter uncertainty and microsimulation to represent individual patient variability reported a mean cost for early ACLR was \$19,883 (SD=\$158), with a median of \$19,880. The mean cost of rehabilitation plus optional delayed ACLR was \$21,454 (SD=\$398) with a median of \$20,432. The utility of each strategy showed less variability with a mean of 5.12 (SD=0.42) and median of 5.16 for early ACLR and a mean of 4.84 (SD=0.33) and a median of 4.85 for rehabilitation plus optional delayed ACLR. Early ACLR was the preferred cost-effective strategy for 78% of patients while rehabilitation plus optional delayed reconstruction was preferred for 22% of patients. The incremental cost and benefit of early ACLR compared to rehabilitation plus optional delayed ACLR for each trial is shown in Figure II. The ellipse captures the 95% confidence interval for the differences between each strategy.

Threshold Analysis—One, two and three-way sensitivity analyses were performed on all variables in the model. With cost-effectiveness as the outcome measure, one-way sensitivity analyses of the base case input variables identified only one “sensitive” variable: the rate of instability after initial rehabilitation. With cost only as the outcome, three additional variables were found to be sensitive: (1) the proportion of physical therapy visits for rehabilitation compared to surgical recovery, (2) the number of patients choosing delayed reconstruction, and (3) the cost of ACLR. The threshold values for these variables are reported in Table III. Robust variables, or those which variation of the inputs did not affect the outcomes of the model, were utility of an unstable knee, costs of rehabilitation and ACLR, disutility of surgery, and the discount rate.

Knee Stability and Choice to Undergo ACLR—The most sensitive variable in the model was the rate of instability following initial rehabilitation. When the rate of instability falls to 51.5%, rehabilitation plus optional delayed ACLR is less costly and when it falls below 18% it becomes the preferred cost-effective strategy (Table III). The proportion of patients that choose ACLR after initial rehabilitation is not sensitive with cost-effectiveness as the outcome, but does influence cost alone, especially beyond 2 years. At the conclusion of the KANON trial 32% of the initial group had clinical instability. If none of these patients choose ACLR, early ACLR costs \$115 more, but if all of them eventually choose ACLR, the rehabilitation plus optional delayed ACLR strategy results in an average of nearly \$6,000 additional cost per patient. The number of physical therapy visits has important effects at the margin with cost only as the outcome. If the number of physical therapy visits for structured rehabilitation is equal to or below that for rehabilitation following ACLR, then structured rehabilitation is less costly.

Costs—The cost of ACLR is robust with cost-effectiveness as the outcome. With cost as the outcome, early ACLR becomes less costly below \$17,931. The model is highly sensitive to cost for the assumptions made to payer mix and the facility where the ACLR is performed. These results are put into context under different assumptions of payer mix and facility type in Figure III.

Discussion & Conclusions

Conclusions from the KANON trial suggest that rehabilitation plus optional delayed ACLR can achieve equal KOOS outcomes while avoiding surgical reconstructions, thus suggesting this strategy would utilize fewer resources – however, a complete economic analysis was not performed to support these conclusions. In this study, an economic analysis of the timing of ACLR using data exclusively from the KANON trial, MOON cohort and national average reimbursement, we found that early ACLR was both less costly and more effective than rehabilitation plus optional delayed ACLR. These findings suggest that when considering optimal societal health care delivery, early ACLR is the preferred treatment strategy.

Close examination of the specific values in the base case reveal that there is a substantial difference in utility, while the costs of each strategy are only slightly different. The difference in utility over the six years of the model is largely driven by two factors, the lower utility of an unstable knee and the lower utility of a surgically stabilized knee the further from the injury that the ACLR occurs. With cost-effectiveness as the outcome, variation in these utility values has little effect on outcome. In fact, variation across the distribution does not change the preferred outcome. Additionally, the proportion of ACL tears with symptomatic instability after rehabilitation needing to fall below 18% to make rehabilitation with optional delayed ACLR the preferred cost-effective strategy.

KANON did not report specific utility values, but did report no difference in mean KOOS scores, concluding rehabilitation with optional delayed reconstruction is a viable strategy to decrease utilization of ACLRs without an appreciable decrease in outcomes. This is in contrast to the current study and data from the MOON cohort, which noted decreased utility in the rehabilitation plus delayed reconstruction group. Two factors may explain this: 1) the MOON cohort has a sample size nearly 10-fold that in KANON, and 2) the initial number of meniscus tears in the ER group in KANON was substantially higher than in their DR group, indicating more severe disease in the ER group. Other authors report worse outcomes in patients with ACL tears and meniscus tears compared to no meniscus tear.^{3,4,8,11,12,14,15,18,19,25,28} This may be a confounding variable affecting the KOOS in the KANON study. Second, data from the MOON cohort suggests inferior outcomes for delayed ACLR compared to early ACLR both at 2 and 6 years from the injury with outcomes from ACLR being worse the further their ACLR occurs after the initial injury (Table I; SF-6D scores decreasing from 0.03 to 0.06 over time). This finding may actually be confirmed by KANON, with 48% of patients in the DR group experiencing severely decreased knee-related quality of life compared to 18% in the ER group and 14% in the rehabilitation only group. This last finding combined with a trend toward a greater number of subsequent meniscus symptoms in the DR group raises substantial concerns about long-term outcomes.

Cost differences between the two strategies are affected by several variables as reported in Table III. Attention should be paid to the most uncertain variables. As the KANON trial ended at two years, an important assumption in the model was the proportion of patients with unstable knees who ultimately chose ACLR (39%) by their 2-year follow-up. This variable is highly sensitive to early ACLR being more expensive if no patients chose ACLR, but saving nearly \$6,000 per patient if all of these patients eventually chose ACLR. This “worst case scenario” represented an increased annual cost in the U.S. of 1.2 billion dollars based on 200,000 annual ACLRs. The particular payer and facility where the surgery is performed is also very sensitive and was addressed in Figure III. With ambulatory surgery centers being reimbursed at 56% of hospital based outpatient units, early ACLR saves \$1,977 per patient if the surgery is performed at an ASC while actually costing \$965 more if performed at a hospital based outpatient unit. The greatest cost savings for either strategy is \$2,417 saved per patient for early ACLR if the ACLR is performed at an ASC at national average Medicare rates. Frobell et al specifically mentioned in their manuscript that rehabilitation techniques and results may be variable.⁷ We attempted to address this with a two-way sensitivity analysis seen in Figure IV. If providers can achieve similar or better results to the baseline with fewer visits, rehabilitation is preferred for more patients. This graph also highlights that cost effectiveness is influenced by both the success of rehabilitation and the number of visits, with a stronger effect from the former. This figure allows economic analysis of future innovations in rehabilitation or specific provider or patient variations.

We recently published another economic analysis which found a substantial societal burden of ACL tears ranging from \$10-18 billion annually in the United States.¹⁶ In that study we found ACL reconstruction was cost saving. There are clear fundamental differences between that study and this one. First, this study is a specific economic analysis of a randomized controlled trial. The KANON trial was a powerful study with policy implications, yet it lacked economic analysis. Second, this study only examined direct costs, not indirect costs as our previous study included. Third, this study examines only the 6 years following injury, while the JBJS study had a lifetime perspective. Lastly and maybe most importantly, the JBJS study modeled the counterfactual, as the rehabilitation arm in that study could not cross over to ACLR. The current study models a more realistic clinical scenario, assuming the crossover rate in the KANON trial. Modeling the actual clinical pathway is critical to applying economic analysis to policy and practice. Each manuscript is distinct and addresses specific aspects of economic analysis.

One of the strengths of decision analysis is its ability to focus future research. By identifying variables with the greatest impact on cost and effectiveness, we can streamline potentially time consuming and expensive clinical research to clarify specific critical factors affecting outcomes. Both of these treatment strategies are likely to yield high quality, low cost care when performed for the appropriate patient. This is evidenced by 78% of patients achieving better outcomes with early ACLR and 22% of patients doing better with rehabilitation plus optional delayed ACLR in the microsimulation. Opportunities for improvement in ACL tear treatment decision-making, therefore, lie in better understanding patient preferences and patient-centered care. For example, a patient that is at risk of low utility with an unstable

knee might be better treated with early ACLR, whereas a low-demand patient that has a lower than average risk of symptomatic instability could undergo rehabilitation first.

There are several limitations to this study. First, we do not model long-term outcomes including meniscus status. Clearly, the effects of ACL tears extend beyond 6 years; however, the understanding of those effects is less certain. We chose to err on the side of using high-level inputs, which resulted in a stronger conclusion in the base case. Second, we did not account for differences in patient or provider variability. The inputs in this model came from a controlled study and a cohort with experienced fellowship trained sports surgeons. These values may not be representative of the larger population. Next, the MOON ACLR cohort does not have a non-operative counterpart for comparison. In order to combine data from MOON and KANON we assumed the utility for patients with unstable knees was equal to the preoperative utility of patients with *chronic* ACL deficiency from MOON. That is, we did not use the preoperative utility for anyone undergoing ACLR within 10 weeks of the initial injury. All utility values were from patients living with symptomatic ACL deficiency. Lastly, while we attempted to estimate costs based on an all payer populations, limited data exists to precisely estimate actual reimbursement as a percentage of Medicare reimbursement. Furthermore, while using reimbursement as a measure of cost is widely accepted as the preferred technique to estimate costs in economic analysis, it has its limitations. Reimbursement is a surrogate for costs and does not reflect actual costs. However, obtaining actual costs is currently not possible for any procedure or disease at a state or national level. Actual costs can only be measured at the health system or institutional level. This methodology has substantial limitations in that it may not be generalizable. We recognize the limitations of our approach but do feel we have executed the best available method of cost estimation.

Economic evaluation is integral to clinical trials, however – the KANON trial lacked comprehensive economic evaluation despite a conclusion that could substantially affect access to care for ACL tears. We provided an economic analysis using level I data from two major, respected sources. At the mean, early ACLR is slightly less costly and substantially more cost effective for the patient. Greater study in patient-centered care is necessary to determine the optimal treatment strategy for individual patients and providers, but this study demonstrates that early ACLR is a viable treatment strategy when optimal societal health care is the outcome.

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What is known about this subject? An initial ACL tear can be treated with surgical reconstruction or focused rehabilitation. The purpose of this study was to compare the cost-effectiveness of early versus delayed ACLR.

What this study adds to existing knowledge. Early ACLR should be the preferred treatment strategy from a societal health system perspective.

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* Meniscus repair or meniscectomy, synovectomy, hardware removal, etc

Figure I.

Health State Diagram. The diagram demonstrates the clinical pathway of patients within the decision model. Health states include either a stable or unstable knee while patients can undergo reoperation consisting of meniscus repair, meniscectomy, manipulation under anesthesia or hardware removal.

Figure II.

Incremental cost and effectiveness of early ACLR compared to rehabilitation plus optional delayed ACLR. Each dot represents an individual patient trial and the spread of the trials demonstrates the variability due to parameter uncertainty and individual patient variability. Incremental QALYs are found on the x-axis while cost is on the y-axis. The numbers consider the baseline of early ACLR compared to rehabilitation plus optional delayed ACLR.

Figure III.
Costs for each strategy across different payers and facilities.

Figure IV.

The effect innovation and/or variability in the structure and success of rehabilitation of ACL tears. The number of necessary physical therapy (PT) visits is on the y-axis while success of rehabilitation is on the x-axis.

Table I
Model Parameter Inputs

Health State Utility (QALY)	SF-6D (MEAN $\pm$ SD)	SF-36 MCS/PCS (MEAN)	Sensitivity Analysis ^{^^}	Source
Unstable Knee	0.71 $\pm$ 0.12 [◆] 0.72 $\pm$ 0.11 ^{◆◆}	53.0/42.5 51.0/44.8	Distribution	MOON
Stable Knee within 10 weeks of injury	0.82 $\pm$ 0.10, 0.82 $\pm$ 0.10 [*]	52.5/54.2 53.1/54.8	Distribution	MOON
Stable Knee within 2 years of injury	0.80 $\pm$ 0.11, 0.80 $\pm$ 0.13 [*]	51.8/53.8 51.7/54.1	Distribution	MOON
Stable Knee within 6 years of injury	0.79 $\pm$ 0.10, 0.76 $\pm$ 0.11 [*]	50.2/53.8 50.8/52.4	Distribution	MOON
Disutility of ACL Reconstruction	0.05		0-0.10	expert opinion
Disutility of Knee Arthroscopy	0.02		0-0.50	expert opinion
Transition Probabilities				
Clinical or Symptomatic Instability		71 $\pm$ 6%	Distribution	KANON
Delayed ACLR After Initial Rehabilitation (first 2 years)		55 $\pm$ 8.6%	Distribution	KANON
Delayed ACLR 2-6 years		10 $\pm$ 2.9%	0-100%	KANON
Initial knee arthroscopy [^] – rehab		33 $\pm$ 11%	Distribution	KANON
Reoperation ^{**} – early ACLR		32 $\pm$ 6%	Distribution	KANON
Reoperation ^{**} – delayed ACLR		36 $\pm$ 10%	Distribution	KANON
Reoperation [^] – rehabilitation only		26 $\pm$ 7%	Distribution	KANON
Ratio of PT visits Rehab/ACLR		1.125	0.5-1.5	Expert Opinion
Costs				
Rehabilitation for ACL Tear		\$4,993	\$0-\$10,000	Medicare+
ACL Reconstruction (includes rehab)		\$17,160	\$15,000-\$30,000	Medicare+
Knee Arthroscopy		\$5,644	\$2,500-\$10,000	Medicare+
Miscellaneous				
Discount Rate		3%	0-10%	

[^] Includes meniscectomy or meniscus repair

^{^^} For variables listed as distribution, random samples were taken from the distributions listed

^{*} Values represent outcome at 2 and 6 years, respectively

^{**} Includes meniscectomy, debridement or hardware removal

[◆] 0-2 years from the initial ACL tear

^{◆◆} 2-6 years from the initial ACL tear

Table II

Results of Analysis for Base Case

	Average Cost	Average QALYs Gained	Average Cost Difference	Average Difference in QALYs Gained	Cost-Effectiveness Ratio	Incremental Cost-Effectiveness Ratio
ER Group	\$19,883	5.12	-	+0.28	\$3,881/QALY	-
DR Group	\$21,454	4.84	\$1,572	-	\$4,434/QALY	DOMINATED*

The DR Group resulted in a lower number of average quality-adjusted life-years (QALYs) gained while also at a higher average cost to the payer and is therefore “DOMINATED” by the early ACLR strategy for the treatment of an ACL tear in the base case.

Table III
Results of the Threshold Analyses

	KANON/MOON	Cost Threshold	Cost-Effectiveness Threshold
Rate of Instability after Rehab	71%	51.5%	18%
Proportion of PT visits Rehab/ACL *	1.125	0.75	Robust
Rate of conversion to ACLR after Rehab at 2 years	39%	31.7%	Robust
Rate of conversion to ACLR from 2-6 years ^^	10%	1%	Robust
Utility of Unstable Knee	0.71	Robust	Robust ^
Cost of ACLR	\$12,713	\$17,931	\$65,055

* If rehabilitation for ACL tears can be accomplished with a more efficient program compared to post-op rehabilitation after ACLR, it can be less costly.

^ The utility of an unstable knee would have to be higher than that of a stable knee for the rehabilitation plus optional delayed reconstruction strategy to be the preferred cost-effective strategy. Because this is unlikely, it is effectively considered robust.