Societal and Economic Impact of Anterior Cruciate Ligament Tears

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Background: An anterior cruciate ligament (ACL) tear is a common knee injury, particularly among young and active individuals. Little is known, however, about the societal impacts of ACL tears, which could be large given the typical patient age and increased lifetime risk of knee osteoarthritis. This study evaluates the cost-effectiveness of ACL reconstruction compared with structured rehabilitation only.

Methods: A cost-utility analysis of ACL reconstruction compared with structured rehabilitation only was conducted with use of a Markov decision model over two time horizons: the short to intermediate term (six years), on the basis of Level-I evidence derived from the KANON Study and the Multicenter Orthopaedic Outcomes Network (MOON) database; and the lifetime, on the basis of a comprehensive literature review. Utilities were assessed with use of the SF-6D. Costs (in 2012 U.S. dollars) were estimated from the societal perspective and included the effects of the ACL tear on work status, earnings, and disability. Effectiveness was expressed as quality-adjusted life years (QALYs) gained.

Results: In the short to intermediate term, ACL reconstruction was both less costly (a cost reduction of $4503) and more effective (a QALY gain of 0.18) compared with rehabilitation. In the long term, the mean lifetime cost to society for a typical patient undergoing ACL reconstruction was $38,121 compared with $88,538 for rehabilitation. ACL reconstruction resulted in a mean incremental cost savings of $50,417 while providing an incremental QALY gain of 0.72 compared with rehabilitation. Effectiveness gains were driven by the higher probability of an unstable knee and associated lower utility in the rehabilitation group. Results were most sensitive to the rate of knee instability after initial rehabilitation.

Conclusions: ACL reconstruction is the preferred cost-effective treatment strategy for ACL tears and yields reduced societal costs relative to rehabilitation once indirect cost factors, such as work status and earnings, are considered. The cost of an ACL tear over the lifetime of a patient is substantial, and resources should be directed to developing innovations for injury prevention and for altering the natural history of an ACL injury.

Anterior cruciate ligament (ACL) tears are common in the U.S. population, particularly among younger, physically active individuals, and can result in impaired function[1]. Many authors report an increased lifetime risk of knee osteoarthritis with ACL tears, particularly when associated with meniscal damage[2]. Patients with no meniscal tear had a 0% to 13% risk of developing knee osteoarthritis at ten years after injury, whereas those with a meniscal tear had a 21% to 48% risk[2]. Although the short and long-term societal effects of ACL tears are not well understood, these aspects highlight the potential importance of effective treatments.

Two primary treatments exist for ACL tears: surgical reconstruction and structured rehabilitation. ACL reconstruction is utilized more commonly in the U.S. to facilitate return to sports and to attempt to protect the menisci and articular cartilage. Structured rehabilitation is often reserved for lower-demand and older patients, although a recent randomized controlled trial suggested that this strategy may also be appropriate for younger

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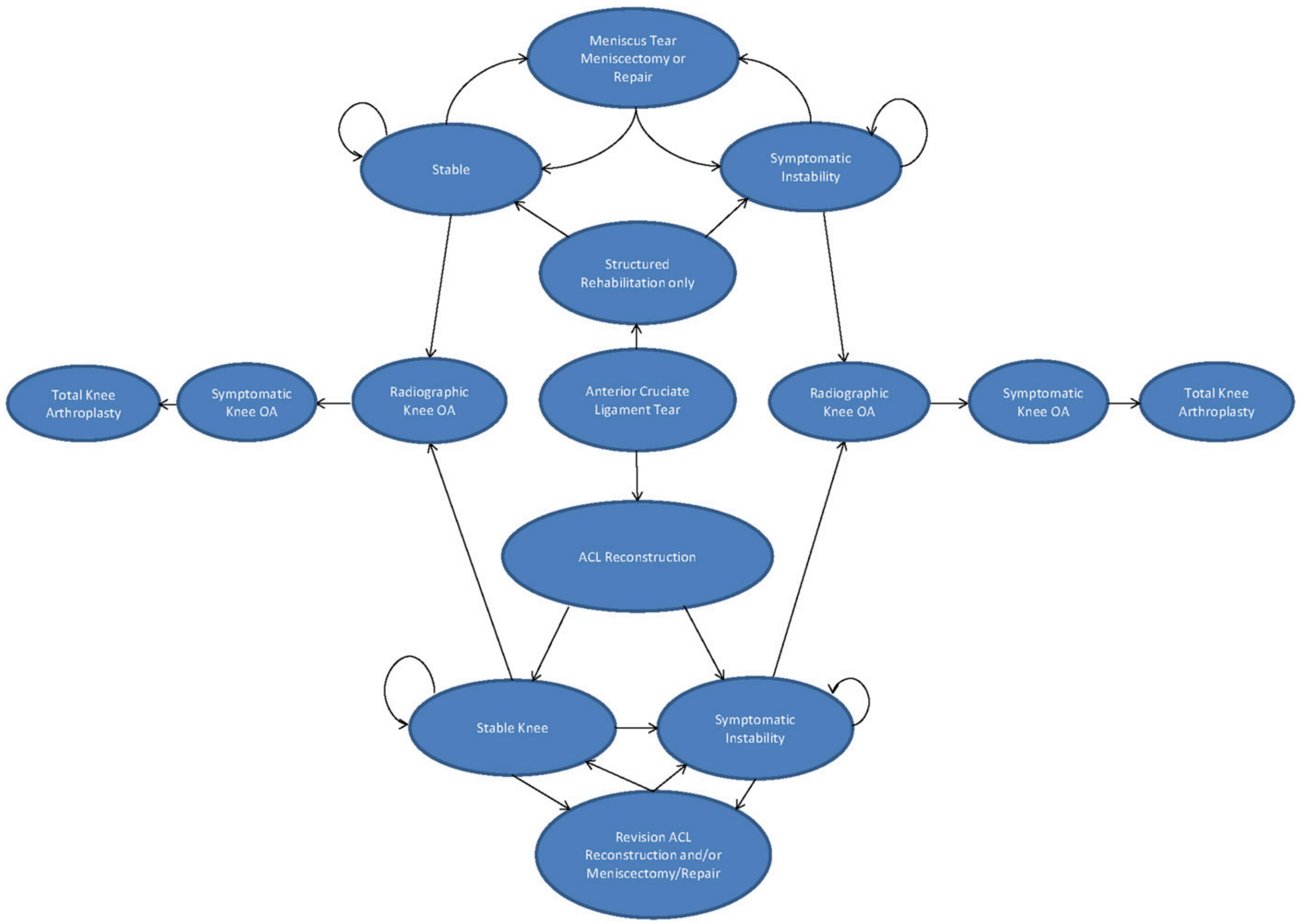

Fig. 1

Health state diagram. The diagram demonstrates the clinical pathway of patients within the decision model. Patient health states include either a stable or an unstable knee, and patients can undergo reoperation consisting of meniscal repair, meniscectomy, manipulation under anesthesia, or hardware removal. OA = osteoarthritis.

patients[3]. Short to intermediate-term outcomes for both treatments are well documented with Level-I and II evidence[3,4]. Although a link between knee osteoarthritis and ACL tears has been established, the specific details of the pathologic process are unclear[2].

The purpose of this study was to examine the societal and economic impact of ACL tears and treatment. We approached this issue from two perspectives: (1) short to intermediate-term outcomes (up to six years), and (2) long-term outcomes (lifetime). Knowledge of the shorter-term outcomes can help to direct treatment decisions immediately, whereas knowledge of the long-term outcomes can help to better understand the entire impact of ACL injuries.

Methods

General Model Overview

We investigated the cost-effectiveness of ACL reconstruction performed at ten weeks or less after the injury compared with rehabilitation. We applied a Markov decision model, presented in Figure 1[1], to a cohort representative of the population in the MOON (Multicenter Orthopaedic Outcomes Network) database (mean age [and standard deviation], 26 ± 11 years). Cost-effectiveness was estimated from the societal perspective.

For the short to intermediate-term model, outcome and state transition probabilities were obtained from the prospective cohort of primary ACL reconstructions in the MOON database (unpublished data) and the KANON (Knee Anterior cruciate ligament, NON-surgical versus surgical treatment) study[3]. The MOON cohort consisted of patients with 988 primary ACL tears with a minimum follow-up of six years, and the KANON study had 121 patients with a minimum follow-up of two years[3]. The length of a cycle in the model was one year and the length was six years for the short to intermediate-term model, consistent with the mean follow-up duration in the MOON cohort. For the long-term (lifetime) model, we used a model structure, outcomes, and state transition probabilities from Losina et al.[5].

Treatment effectiveness was expressed as quality-adjusted life years (QALYs), and costs were estimated in 2012 U.S. dollars. Both costs and utilities were discounted at 3% per year. Secondary outcomes included the rates of radiographically evident osteoarthritis, symptomatic osteoarthritis, and total knee arthroplasty, as well as the estimated burden to the U.S. based on the annual incidence of ACL tears (200,000). The modeling and analysis were performed in accordance with the consensus-based recommendations for the conduct of cost-effectiveness analysis advocated by the Panel on Cost-Effectiveness in Health and Medicine[6-8] and with use of a general decision-analysis software package (TreeAge Pro Suite 2011; TreeAge Software, Williamstown, Massachusetts).

TABLE I Model Parameter Inputs

Parameter*	Base Value†	Sensitivity Analysis‡	Source
Health state utility, in QALYs			
Unstable knee	0.71 ± 0.12	Distribution	MOON
Stable knee within 10 wk of injury	0.81 ± 0.10, 0.82 ± 0.10§	Distribution	MOON
Disutility of ACLR	0.05	0-0.10	Expert opinion
Disutility of knee arthroscopy	0.02	0-0.05	Expert opinion
Transition probability, in percent			
Clinical or symptomatic instability	37 ± 6	0-100	KANON
Initial knee arthroscopy#, rehab. arm	33 ± 11	Distribution	KANON
Early reoperation**, ACLR arm	32 ± 6	Distribution	KANON
Delayed reoperation**, ACLR arm	36 ± 10	Distribution	KANON
Reoperation#, rehab. arm	26 ± 7	Distribution	KANON
Risk of radiographic OA			
No meniscal injury	6.5	0-13	Ref. 2
Meniscal injury	34.5	21-48	Ref. 2
Progression of OA	3.0	1-10	Refs. 13 and 14
TKA for symptomatic OA	2.5	0-10	United Healthcare data
Cost, in 2012 U.S. dollars			
Rehab. for ACL tear	6630	0-10,000	Medicare+
ACLR, including rehab.	19,342	15,000-30,000	Medicare+
Knee arthroscopy	4559	2500-10,000	Medicare+
Knee instability	See Appendix	0-25,000	MOON
Knee OA	See Appendix	0-25,000	See Appendix
TKA	See Appendix	See Appendix	See Appendix
Miscellaneous			
Ratio of PT visits, rehab./ACLR	1	0.5-1.5	Expert opinion
Cost discount rate, per yr	3%	0%-10%	

*ACLR = ACL reconstruction, PT = physical therapy, OA = osteoarthritis, TKA = total knee arthroplasty, and Medicare+ = Medicare rates adjusted for all payers. †Values are given as the base value or as the mean and the standard deviation from a previous study. ‡For variables for which the sensitivity analysis is listed as "Distribution," random samples were taken from the distributions listed. §Values represent outcome at 2 and 6 yr, respectively. #Includes meniscectomy or meniscal repair. **Includes meniscectomy, debridement, or hardware removal.

Model Structure

The decision tree consisted of two primary treatment arms (ACL reconstruction and rehabilitation). Patients in the ACL reconstruction arm entered a post-procedure state for six months, and those in the rehabilitation arm entered an initial rehabilitation state for six months. All patients in the ACL reconstruction arm were assumed to have a stable knee at six months. Thereafter, they could transition to one of six health states: (1) stable knee, (2) unstable knee, (3) radiographic osteoarthritis, (4) symptomatic osteoarthritis, (5) total knee arthroplasty, or (6) death. The health states were the same for the rehabilitation treatment arm. Patients in the rehabilitation arm could undergo arthroscopy without ACL reconstruction for meniscal treatment, but at no point in the model could they cross over to ACL reconstruction. All patients could undergo additional surgical procedures, consisting of (1) meniscectomy, (2) meniscal repair, (3) manipulation under anesthesia (ACL reconstruction arm only), (4) removal of implants (ACL reconstruction arm only), or (5) basic knee arthroscopy. Reoperation rates were taken from the KANON study. Patients were estimated to retear the ACL graft at rates consistent with the MOON cohort.

In the rehabilitation arm, patients could have a stable or an unstable knee at the end of year one, with the rates of these outcomes based on the KANON study. Consistent with the KANON study, patients who chose ACL reconstruction or who were determined to have clinical instability at two years were categorized as having an unstable knee. If rehabilitation was initially successful, patients were assumed to relapse at rates consistent with those of patients with an ACL retear in the MOON cohort. Conversely, once symptomatic, patients remained symptomatic for the remainder of the model unless they transitioned to osteoarthritis.

Short to Intermediate-Term Model Parameters (Table I)

Utilities

Utilities were derived from the Short Form-36 (SF-36) values from the MOON cohort with use of the SF-6D, which generates utility values from SF-36 values by adding patient preferences[9]. A clinically stable knee after rehabilitation was assigned the same utility as a stable knee after surgical reconstruction: 0.81 at two years and 0.82 at six years and beyond. On the basis of expert opinion, patients were assumed to experience a disutility of 0.05 for additional ACL surgery and 0.02 for other arthroscopic knee surgery. A clinically unstable knee was assigned a utility of 0.71, equal to that of a knee prior to reconstruction in the MOON study.

Transition Probabilities

Knee Stability: According to the KANON study, 71% of patients with an ACL tear either chose to undergo ACL reconstruction or had clinically detectable or symptomatic instability at two years. Thirty-seven percent of the rehabilitation-only cohort chose ACL reconstruction by two years. These two values represent

TABLE II Mean Societal Impact of ACL Reconstruction Relative to Rehabilitation in the Base Case

	Net Societal Savings *($)*		QALY Gain		Incremental Cost-Effectiveness Ratio, Savings/QALY	
Age Group	Short to Intermediate Term	Long Term	Short to Intermediate Term	Long Term	Short to Intermediate Term	Long Term
MOON cohort	4503	50,417	0.18	0.72	Dominant	Dominant
20-29 yr	4165	55,138	0.18	0.66	Dominant	Dominant
30-39 yr	7313	46,527	0.17	0.60	Dominant	Dominant
40-49 yr	10,782	27,114	0.19	0.60	Dominant	Dominant
50-59 yr	−262	25	0.15	0.57	$1746/QALY	Dominant

the probable minimum and maximum proportions of patients who will have symptomatic instability after rehabilitation. We assumed the minimum value of 37% in order to be conservative, but a rigorous sensitivity analysis was performed on this assumption. In the MOON cohort, 3% of patients had experienced a retear two years after reconstruction. We assumed an annual retear rate of 1.5% for the first six years after injury and an annual rate of 0% after that time in order to be conservative.

Meniscal Status: Long-term outcomes, specifically the development of osteoarthritis, appear to be dependent on meniscal status, primarily determined in the short to intermediate term[3,10,11]. Assumptions regarding meniscal injury rates were based on values reported in the KANON study for (1) injury to the meniscus with the initial ACL tear, (2) future surgical procedures for meniscal tears, and (3) the development of meniscal symptoms. Meniscal tear rates were similar in the MOON database and KANON study, and the values from the KANON study were used as they represent a direct comparison of ACL reconstruction and rehabilitation. In the KANON study, 8% of patients in the ACL reconstruction arm and 32% of patients in the rehabilitation arm were reported to have required knee arthroscopy for meniscal treatment at two years of follow-up. In the MOON cohort, a meniscal tear rate of 30% was reported after delayed ACL reconstruction. Lastly, 22% of the patients in the rehabilitation arm of the KANON study were reported to be living with meniscal symptoms at two years, whereas <1% of the patients in the ACL reconstruction arm had meniscal symptoms at that time. These rates were applied to determine meniscal status in the short to intermediate-term model and were used to determine osteoarthritis development in the long-term model.

Other: As the specific number of physical therapy visits used for postoperative rehabilitation or for nonoperative rehabilitation in the KANON study was not available, the best practices of the authors were assumed in the model: three visits per week for sixteen weeks for both nonoperative and postoperative rehabilitation after an ACL tear or ACL reconstruction. Three visits for six weeks were assumed for rehabilitation following subsequent knee surgical procedures.

Costs

As recommended by the Panel on Cost-Effectiveness in Health and Medicine, the model included costs that accrue to society rather than to only an individual hospital or practice. The costs for rehabilitation, ACL reconstruction, knee arthroscopy, and revision procedures were estimated starting with the national mean Medicare reimbursements for the procedures in 2012 U.S. dollars. To reflect all-payer costs, estimates of direct medical costs were adjusted with use of payment rates of other insurers (as a percentage of the Medicare rate) and then weighted by the national distribution of payers for the treatment of ACL reconstruction (see Appendix)[12,13].

Long-Term Model Parameters (Table I)

The long-term phase of the model examined the link between ACL tears and osteoarthritis. We used meniscal status (tear or symptoms compared with no tear or symptoms) to determine the risk for the development of osteoarthritis. As previously noted, a recent systematic review by Øiestad et al. supports the assumption of an association, with the reported prevalence of radiographic osteoarthritis being 0% to 13% in knees with no meniscal injury and 21% to 48% in knees with such an injury at a minimum of ten years of follow-up[2]. That review included seven prospective and twenty-four retrospective studies with a minimum follow-up of ten years. The mean modified Coleman methodology score of the included studies was 52 of 90. Meniscal status was the most frequently reported risk factor for the development of osteoarthritis. We used the specific rates from Øiestad et al. in our model. Details on the costs, utilities, and transition from radiographic osteoarthritis to total knee arthroplasty can be found in the Appendix[14,15].

Indirect Cost Estimates

We generated estimates of indirect costs in the short to intermediate term and over a patient's lifetime (see Appendix). For the short to intermediate-term phase of the model, we estimated the effects of functional limitations due to the ACL tear on work status, earnings, and disability payments. For the long-term phase of the model, we incorporated indirect costs (involving the same economic outcomes) associated with knee osteoarthritis and total knee arthroplasty. Our basic approach was to first estimate the relationship between functional status and economic outcomes, utilizing data from the National Health Interview Survey (NHIS), and then to use patient-reported outcomes involving functional status to estimate outcomes with and without surgery.

Patient-reported data on pre-surgery and post-surgery functional status were obtained from the MOON database (patients with an ACL tear undergoing reconstruction) and from a survey by a large physician group practice (patients undergoing total knee arthroplasty). We assumed that rehabilitation-only patients with symptomatic instability would have functional limitations similar to the pre-surgery limitations of patients with an ACL tear as reported in the MOON database.

Patients who had developed osteoarthritis after an ACL tear but who had not yet developed end-stage osteoarthritis requiring treatment with total knee arthroplasty were assumed to have indirect costs equal to 0.60 times the costs for patients with end-stage osteoarthritis. This assumption is consistent with results reported by Dibonaventura et al.[16] on the effect of osteoarthritis severity on costs. They reported annual costs of $9801 for mild osteoarthritis, $14,761 for moderate osteoarthritis, and $22,111 for severe osteoarthritis. The ratio of the mean cost for moderate osteoarthritis to the cost for severe osteoarthritis in that study was therefore approximately 0.67. We believe that a value of 0.60 accounts for the range of severity of osteoarthritis, and the assumption was subject to rigorous sensitivity analysis.

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Results

The model was internally validated against the results of the KANON study, but external validation was not possible

TABLE III Results of Threshold Analyses for the Short to Intermediate-Term Perspective

Parameter*	Base Value†	Threshold for Cost	Threshold for Cost-Effectiveness
Instability after rehab.	37%	27%	18%
Proportion of PT visits, rehab/ACLR‡	1	0.29	Robust
Utility of unstable knee**	0.71	Robust	Robust
Cost of ACLR	$12,713	$23,289	$42,846

*PT = physical therapy, and ACLR = ACL reconstruction. †Derived from the KANON study or MOON database. ‡If rehabilitation for ACL tears can be accomplished with a more efficient program compared with postop. rehab. after ACLR, rehab. becomes the preferred cost-effective strategy.

because of the lack of availability of similar studies. Results for the base case are shown in Table II. For short to intermediate-term outcomes (six years) in a cohort representative of the patients in the MOON cohort, ACL reconstruction resulted in a mean incremental cost that was $4503 less than that for rehabilitation, while providing an incremental QALY gain of 0.18 compared with rehabilitation. In cost-effectiveness analyses, a strategy is termed dominant when it is both less costly and more effective than an alternative. Therefore, ACL reconstruction was shown to be a dominant treatment strategy, and no incremental cost-effectiveness calculation was necessary for comparing the two strategies.

Adding the long-term perspective did not change the preferred strategy but expanded the economic impact. The mean lifetime cost to society for a typical patient undergoing ACL reconstruction was $38,121 compared with $88,538 for rehabilitation. ACL reconstruction thus resulted in mean incremental cost savings of $50,417 compared with rehabilitation, while providing an incremental QALY gain of 0.72 compared with rehabilitation. The lifetime burden of ACL tears in the U.S. was estimated to be $7.6 billion annually (expressed as the net present value) when treated with ACL reconstruction and $17.7 billion annually when treated with rehabilitation. If all of these individuals were treated with ACL reconstruction, 118,000 patients would develop radiographic osteoarthritis over their lifetime, 31,600 of these would become symptomatic, and 25,800 would need a total knee arthroplasty. In comparison, if all were treated with the rehabilitation strategy, 140,000 patients would develop radiographic osteoarthritis, 38,000 of these would become symptomatic, and 30,800 would need a total knee arthroplasty.

Sensitivity Analyses

Probabilistic Sensitivity Analysis for Short to Intermediate-Term Findings

Probabilistic sensitivity analysis indicated that the mean total cost (and standard deviation) for the ACL reconstruction

TABLE IV Results of the Sensitivity Analyses for the Long-Term Perspective*

	Rate of Meniscal Symptoms for Rehab. Arm	Rate of Development of Radiographic OA	Progression to Symptomatic OA from Radiographic OA	Progression to TKA	Ratio of Costs of Entire Symptomatic OA Group to End-Stage OA Costs
Base value of parameter	11%	6.5%/34%†	21%/1.3%‡	2.5%	0.60
Cost *($)*					
ACLR	44,000-44,125	38,488-49,000	40,045-47,740	42,830-45,967	39,925-48,214
Rehab.	83,444-85,912	85,109-88,742	81,836-91,693	84,719-88,669	82,081-91,497
QALYs					
ACLR	19.74-19.88	19.5-20	19.69-20.02	19.62-19.99	—
Rehab.	19.97-19.19	18.9-19.27	18.97-19.39	19.01-19.34	—
Rate of symptomatic knee OA					
ACLR	0.155-0.16	0.10-0.20	0.125-0.18	—	—
Rehab.	0.197-0.21	0.13-0.23	0.15-0.21	—	—
Rate of TKA					
ACLR	0.13-0.13	0.08-0.165	0.095-0.16	0.10-0.15	—
Rehab.	0.16-0.17	0.11-0.19	0.11-0.19	0.12-0.17	—

*OA = osteoarthritis, and TKA = total knee arthroplasty. †The range tested for this variable was based on the ranges in Øiestad et al.[2]: 0%-13% for no meniscal tear and 21%-48% for meniscal tears. ‡21% is the initial rate and 1.3% is the annual incidence thereafter. Sensitivity analysis was performed across a range 25% higher and lower than the base case.

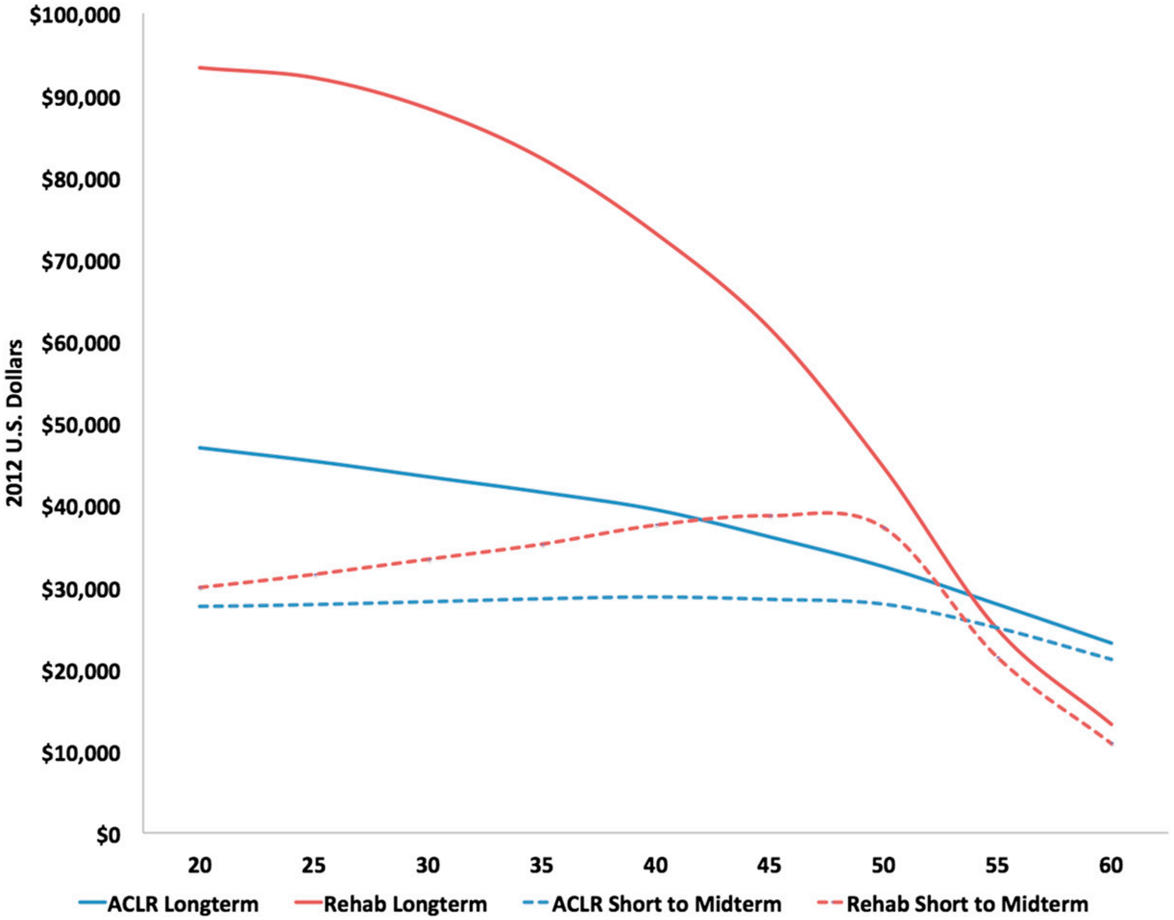

Fig. 2
Sensitivity of total cost to age at the time of the initial ACL tear. ACLR = ACL reconstruction.

strategy was $27,452 ± $492, with a median cost of $27,433. The mean cost for the rehabilitation strategy was $32,276 ± $3418, with a median cost of $31,905. The mean utility for ACL reconstruction was 5.06 ± 0.43 QALYs, with a median of 5.06 QALYs, and the mean utility for rehabilitation was 4.89 ± 0.37 QALYs, with a median of 4.90 QALYs. ACL reconstruction was the preferred cost-effective strategy for 93% of trials when the willingness-to-pay threshold was set at $50,000/QALY. With the willingness-to-pay threshold set at $25,000/QALY, ACL reconstruction was preferred in 96% of trials.

Microsimulation for Long-Term Findings

Microsimulation for the long-term phase of the model indicated the mean cost for the ACL reconstruction strategy to be $38,411 ± $37,662, with a median of $24,210. The mean cost for the rehabilitation strategy was $92,786 ± $123,738, with a median of $22,224. The mean utility for reconstruction was 20.50 ± 3.91 QALYs, with a median of 21.80 QALYs, and the mean for rehabilitation was 19.72 ± 4.02 QALYs, with a median of 20.67 QALYs. ACL reconstruction was the preferred cost-effective strategy for 59% of patients and rehabilitation was preferred for 41% with the willingness-to-pay threshold set at either $25,000 or $50,000/QALY.

One-Way Sensitivity Analysis

With cost-effectiveness as the outcome measure, one-way sensitivity analyses of the base case identified only one "sensitive" variable: the rate of instability after initial rehabilitation. The rehabilitation-only strategy became the preferred cost-effective strategy when the rate of instability was <18%. With total cost as the outcome, age also becomes a sensitive variable. The break-even point for the rate of instability after initial rehabilitation was 27.5% in the short to intermediate-term phase of the model, but the model was robust with respect to the instability rate in the long term. The break-even age was fifty-four years in both the short to intermediate term and the long term. As mentioned previously, the rate of instability after rehabilitation may actually be as high as 71%[3]. At this rate of instability, ACL reconstruction would cost $21,248 less than rehabilitation in the short to intermediate term and $95,766 less in the long term. The results of the sensitivity analyses are given in Tables III and IV and Figures 2 and 3. Further details regarding the sensitivity analyses can be found in the Appendix.

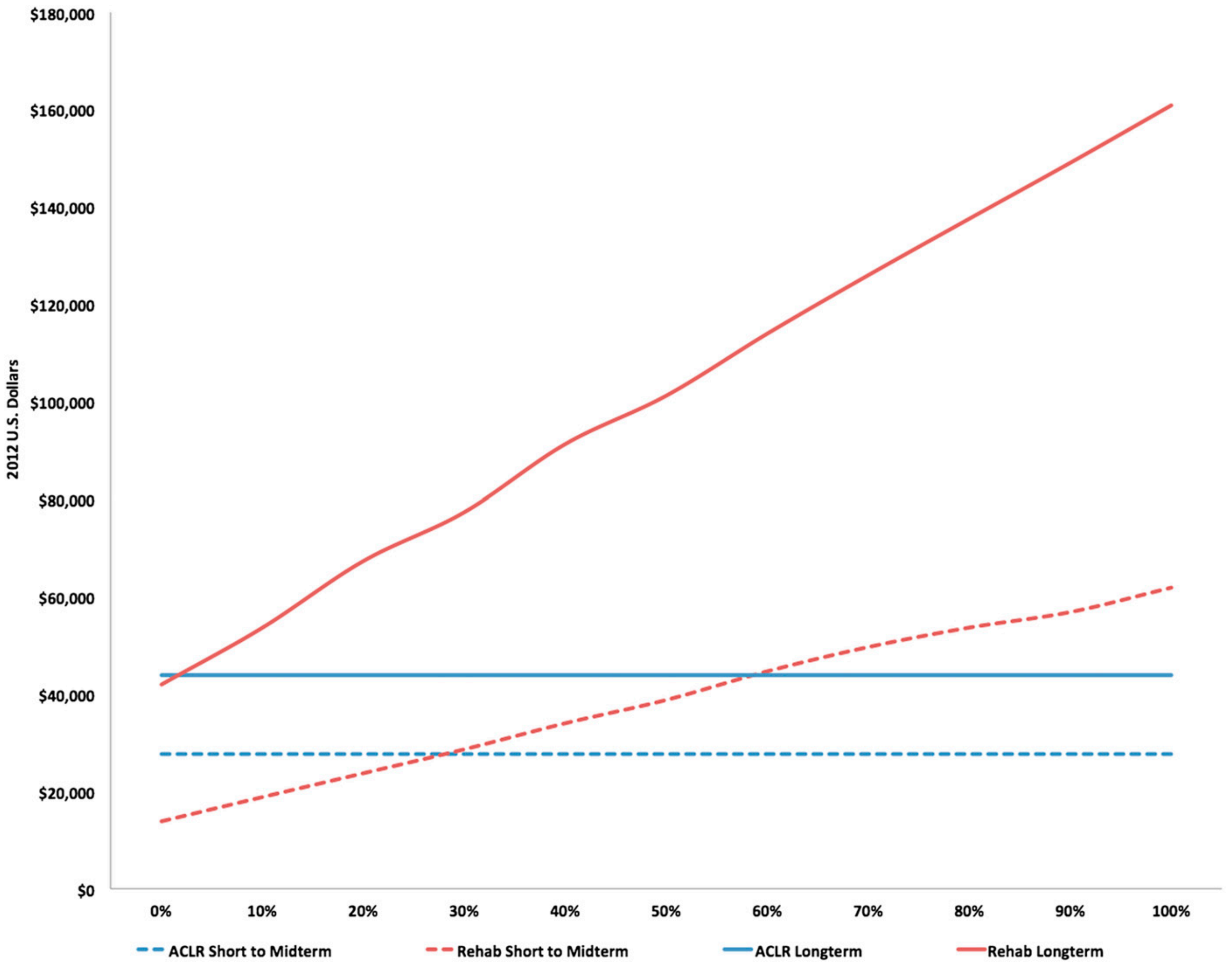

Fig. 3
Sensitivity of total cost to the rate of instability after rehabilitation. ACLR = ACL reconstruction.

Effect of Innovations in ACL Tear Treatment

The potential effect of innovations in ACL tear treatment was examined by applying a relative risk factor for the development of radiographic knee osteoarthritis in the ACL reconstruction arm. The cost savings to society would be $1.1 billion annually ($5500/patient) if the risk were halved (a relative risk factor of 0.5). A reduction of the risk by one-fourth (a relative risk factor of 0.75) would save society $460 million annually ($2300/patient). These risk reductions may be attainable, as the rate of knee osteoarthritis in patients sustaining an ACL tear with concomitant meniscal tearing is more than fourfold higher than the rate in patients with an ACL tear alone.

Discussion

Two primary conclusions can be drawn from this analysis. First, the indirect costs (as defined by lost wages, productivity, and disability) associated with a symptomatic unstable knee after an ACL tear are substantial. The large majority of societal costs are due to the indirect costs associated with an unstable knee, rather than with the development of knee osteoarthritis. However, the impact of ACL tears on the burden of degenerative joint disease is substantial, contributing an increment of 30,000 to 38,000 patients with symptomatic knee osteoarthritis and 25,000 to 30,000 total knee arthroplasties per year. Second, limiting access to ACL reconstruction may be harmful to patients and costly to society. In both the short to intermediate term and the long term, ACL reconstruction produced greater QALY improvements at a lower cost compared with rehabilitation only.

This long-term impact, although based on several assumptions not supported by extensive data from studies with a high level of evidence, cannot be ignored. For ACL reconstruction, 27% of the total cost was accrued beyond six years, and for rehabilitation, 63% was accrued beyond that time. Some of this reflects long-term disability resulting from an unstable knee, but much is due to knee osteoarthritis. Based on an annual incidence of 200,000 ACL reconstructions in the U.S., the annual cost attributable to the long-term development of osteoarthritis would be $4.24 billion for the rehabilitation strategy and $2.78 billion for the ACL reconstruction strategy. Posttraumatic osteoarthritis after an ACL tear is a substantial economic problem, and research resources should be focused on altering this long-term trajectory.

The conclusions from the sensitivity analyses provide important insights into treatment decisions for ACL tears. Probabilistic sensitivity analysis, which evaluates the impact of parameter uncertainty on outcome, demonstrated that ACL reconstruction was preferred in >90% of trials. On the other hand, microsimulation, which evaluates the impact of individual patient variability with respect to the input parameters, demonstrated that the distribution of costs is skewed to the left, especially in the rehabilitation treatment strategy. In other words, the cost of an ACL tear is low for most patients but the high cost of an unstable knee in a fraction of the patients drives the total economic burden to substantially higher levels. Efforts to improve the recognition and treatment of these "high-risk" ACL patients will yield the greatest cost reductions.

Both ACL reconstruction and rehabilitation treatment strategies are likely to yield high-quality, low-cost care when performed for the appropriate patient. In the short to intermediate term, opportunities for improving treatment for ACL tears reside in better understanding patient preferences and in patient-centered care. For example, a patient who is at risk of low knee-related quality of life due to an unstable knee might be better treated with early ACL reconstruction, whereas a low-demand patient who has a lower-than-average risk of symptomatic instability could undergo rehabilitation as an initial treatment. This study demonstrated the potential effects of minimizing meniscal injury on the rates of symptomatic osteoarthritis and total knee arthroplasty. However, research is needed to document progression from meniscal injury to radiographic osteoarthritis and to symptomatic osteoarthritis. As these are long-term outcomes, proxy measures for osteoarthritis (such as biomarkers) will be an important component of such future studies as well.

There are several limitations to the present study. First, we use meniscal symptoms to represent the risk of meniscal tears. This assumption partially drove the long-term difference in osteoarthritis development between the two strategies. Although the KANON study did not use arthroscopy or magnetic resonance imaging to confirm the presence of meniscal tears in these patients with meniscal symptoms, the literature suggests that the history combined with physical examination are highly specific for meniscal tears[17]. Second, although the assumptions for the short to intermediate-term phase of the model are based on Level-I evidence, the assumptions for the long-term perspective are based on lower levels of evidence. This prevents us from making strong recommendations regarding treatments that may improve long-term outcomes. Rather, the long-term findings suggest that ACL tears may result in substantial later effects with either strategy under any set of reasonable assumptions. Third, we inferred the effects of an ACL tear and the effects of osteoarthritis on indirect costs by linking the effects of having an unstable knee or having osteoarthritis, respectively, to functional limitations and then to economic outcomes. We were not able to directly observe the impact of having an unstable knee or having osteoarthritis on employment and other economic outcomes. Lastly, direct medical costs were estimated with use of reimbursements rather than actual costs. More accurate cost measurement, utilizing techniques such as time-driven activity-based costing, may yield more accurate outcomes[18].

In conclusion, ACL reconstruction was shown to be cost-saving and more effective in both the short to intermediate term and the long term. Long-term outcomes, although less certain, appeared to only increase the cost savings of the ACL reconstruction strategy. Substantial downstream effects of ACL tears exist. These findings support greater attention on preventative injury strategies or early intervention to prevent osteoarthritis. Greater study involving patient-centered care is necessary to determine the optimal treatment strategy for individual patients and providers, but the present study demonstrated that access to ACL reconstruction is critical to optimal societal health-care delivery.

Appendix

eA Further details regarding the methodology and sensitivity analyses, including the indirect cost model, are available with the online version of this article as a data supplement at jbjs.org. ■

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