The Cost-Effectiveness of Anterior Cruciate Ligament Reconstruction in Competitive Athletes

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Investigation performed at the Houston Methodist Hospital, Houston, Texas, USA

Background: Competitive athletes value the ability to return to competitive play after the treatment of anterior cruciate ligament (ACL) injuries. ACL reconstruction has high success rates for return to play, but some studies indicate that patients may do well with nonoperative physical therapy treatment.

Purpose: To evaluate the cost-effectiveness of the treatment of acute ACL tears with either initial surgical reconstruction or physical therapy in competitive athletes.

Study Design: Economic and decision analysis; Level of evidence, 2.

Methods: The incremental cost, incremental effectiveness, and incremental cost-effectiveness ratio (ICER) of ACL reconstruction compared with physical therapy were calculated from a cost-effectiveness analysis of ACL reconstruction compared with physical therapy for the initial management of acute ACL injuries in competitive athletes. The ACL reconstruction strategy and the physical therapy strategy were represented as Markov models. Costs and quality-adjusted life-years (QALYs) were evaluated over a 6-year time horizon and were analyzed from a societal perspective. Quality of life and probabilities of clinical outcomes were obtained from the peer-reviewed literature, and costs were compiled from a large academic hospital in the United States. One-way, 2-way, and probabilistic sensitivity analyses were used to assess the effect of uncertainty in variables on the ICER of ACL reconstruction.

Results: The ICER of ACL reconstruction compared with physical therapy was $22,702 per QALY gained. The ICER was most sensitive to the quality of life of returning to play or not returning to play, costs, and duration of follow-up but relatively insensitive to the rates and costs of complications, probabilities of return to play for both operative and nonoperative treatments, and discount rate.

Conclusion: ACL reconstruction is a cost-effective strategy for competitive athletes with an ACL injury.

Keywords: knee; ligaments; economic and decision analysis; epidemiology; physical therapy/rehabilitation

Treatment options for athletes with anterior cruciate ligament (ACL) tears include reconstruction of the ligament or nonoperative management with physical therapy. ACL reconstruction is one of the most commonly performed orthopaedic procedures in the United States (US), with approximately 250,000 reconstructions annually.[16] Success rates of ACL reconstruction are often measured by the athlete's ability to return to play. The return-to-play rates vary significantly but generally range from 50% to 80%.[12,20,29,34] Most studies of nonoperative management with physical therapy report much lower return-to-play rates of between 10% and 30%.[18,35,38] Recent studies have questioned the initial use of ACL reconstruction, concluding that there is insufficient literature to support clinical decision making.[10,27,43] A randomized study by Frobell et al[10] argued that rehabilitation plus early ACL reconstruction is not superior to rehabilitation plus optional delayed ACL reconstruction.

To further understand the utility of these different treatments, a cost-effectiveness analysis can be helpful. Although previous studies have investigated the economic aspects of ACL reconstruction, few have focused on the cost-effectiveness of ACL reconstruction. The purpose of this study was to evaluate the cost-effectiveness of the treatment of acute ACL tears with initial surgical reconstruction versus physical therapy in competitive athletes.

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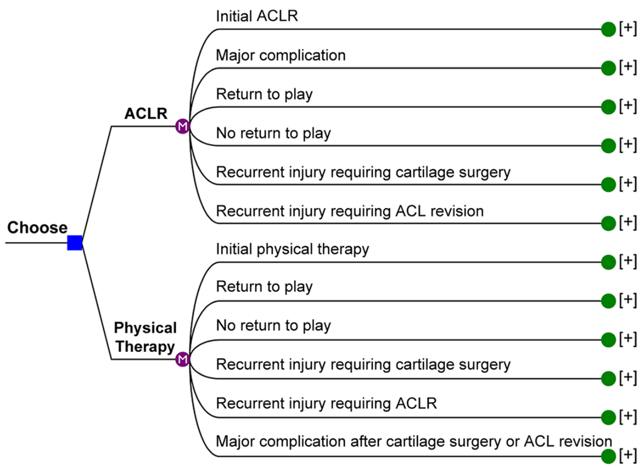

Figure 1. Decision tree of anterior cruciate ligament (ACL) reconstruction (ACLR) compared with physical therapy. The decision tree begins with a decision to choose ACLR or physical therapy for the initial management. Each strategy is represented as a Markov model with 6 mutually exclusive states. For this study, a major complication required additional surgery or hospitalization. The probability of return to play after a major complication is different than the probability of return to play with no complication or a minor complication and is modeled as a separate state. The [+] symbol at the end of each line indicates that the given branch is collapsed for simplicity and can be expanded to show further detail.

METHODS

Design

This study was a cost-effectiveness analysis of ACL reconstruction compared with physical therapy for competitive athletes with an ACL injury. We compared the expected incremental effectiveness, as measured by quality-adjusted life-years (QALYs), expected incremental cost, and incremental cost per incremental life-year gained for ACL reconstruction compared with physical therapy alone over a 6-year time horizon. The study used a societal perspective, which accounts for costs and outcomes that are important for society as a whole rather than only for the patient, payer, physician, or any other single entity. Such costs may include direct medical costs, direct nonmedical costs, indirect costs, and intangible variables such as pain or discomfort experienced by the patient. For example, indirect costs such as time lost from work would not be accounted for from the perspective of the insurer. The design and parameters used in this study were based on the guidelines of the Panel on Cost-Effectiveness in Health and Medicine.[14,41,45]

Decision Model

The model begins with a decision to choose either surgical reconstruction or a program of physical therapy for a competitive athlete with a new ACL tear and is represented in a decision tree (Figures 1-4). Each alternative is represented as a Markov model with mutually exclusive states; patients transition between disease states over time at 3-month intervals. Patients' quality of life and health care costs over each 3-month interval were used to estimate the cumulative QALYs and costs for each alternative. One of the key tenets of a Markov model is that future states depend only on the current state and not on any preceding states. Furthermore, all states in this model are mutually exclusive; that is, a patient may be in only 1 health state at any time point in the model.

The following assumptions were made in the construction of the model: (1) athletes who return to play at the same level will have the same quality of life regardless of the initial treatment (reconstruction or physical therapy); (2) once the athlete has a late knee injury requiring knee surgery, regardless of the type of injury, he/she will no longer return to play at the same level; and (3) athletes who fail initial nonoperative treatment (physical therapy group) and require late ACL reconstruction are considered to be failures of the physical therapy group and do not return to play at the same level. These assumptions were then tested in a sensitivity analysis to confirm that the conclusions of the study were not altered.

Probabilities

The probabilities of the clinical outcomes of ACL reconstruction, ACL revision, and physical therapy; surgical complications; and recurrent injuries were derived from a literature search in PubMed. Specific search terms, inclusion and exclusion criteria, and referenced articles for operative and nonoperative treatment strategies are listed in Tables 1 and 2. The references of all the studies that met our criteria were examined to find additional studies that could be included. The mean and range of the probabilities were used in the analysis. The probabilities of surgical complications were derived from the 22 studies that were used to determine the probability of return to play after ACL reconstruction and supplemented by a literature search to include complications that may not have been seen in the previously included studies. Patients in either the initial operative group or initial therapy group could sustain a late knee injury or instability that required secondary surgery, and the probabilities of these injuries were derived from the previously referenced studies. All reinjury data were abstracted as surgical procedures per person-years. The rates were abstracted, and the mean of the rates was calculated. The mean and range were converted to 3-month probabilities for use in the analysis.

Health Utilities and Quality of Life

Health utilities are paramount in allowing health economists to evaluate the cost-effectiveness of medical treatments for patients. Health utility values represent a patient's preference for a certain health state, also known as quality of life. These values are expressed on a scale from 0.0 for death to 1.0 for perfect health. These health utility values can be measured via different methods. Direct approaches

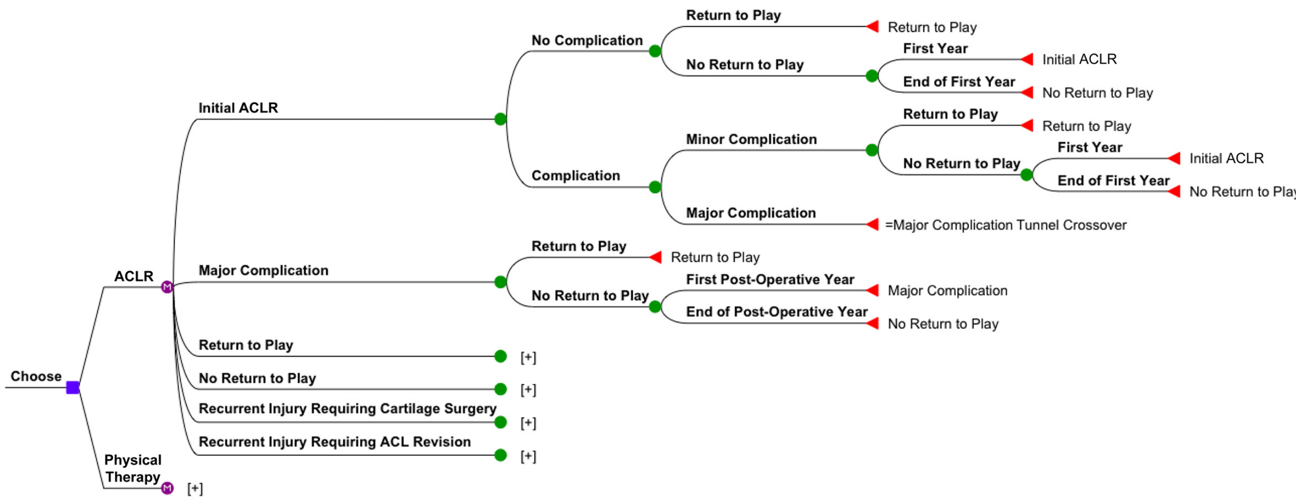

Figure 2. Decision tree showing the anterior cruciate ligament (ACL) reconstruction (ACLR) strategy with the Markov states for initial ACLR and major complication states expanded. The probability of a return to the previous level of play varies by a 3-month interval after initial ACLR. Minor and major complications increase costs and reduce quality of life. Major complications, but not minor complications, influence the probability of a return to the previous level of play. The [+] symbol at the end of each line indicates that the given branch is collapsed for simplicity and can be expanded to show further detail.

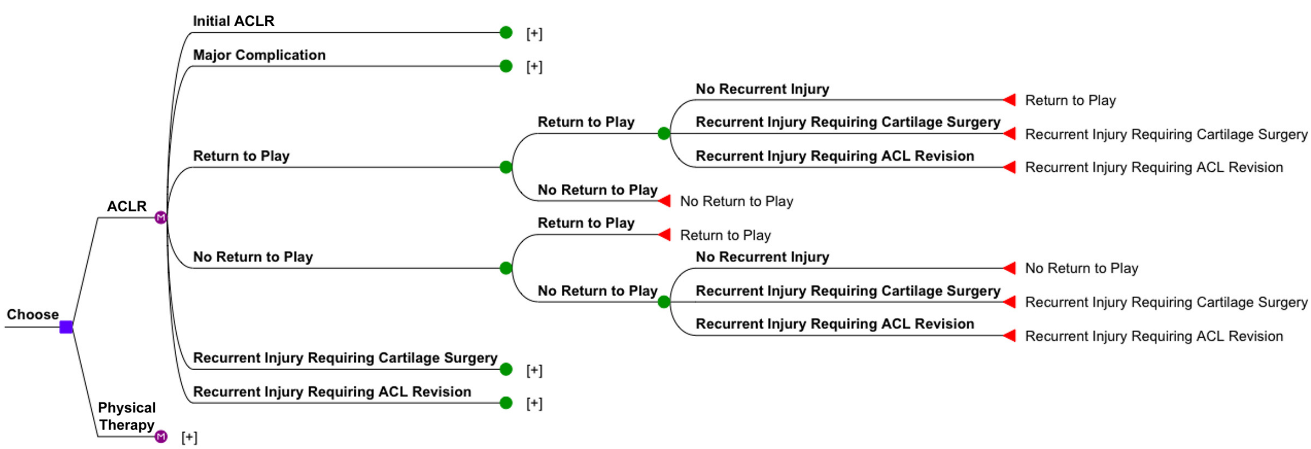

Figure 3. Decision tree showing the anterior cruciate ligament (ACL) reconstruction (ACLR) strategy with the Markov states for return to play and no return to play after ACLR expanded. Athletes who return to play at their preinjury level either stay at this level or they may transition to the ''no return to play'' state after a repeat injury and can transition to the recurrent surgery states (either ACL revision or cartilage surgery). Athletes who do not return to play at their previous level can also transition to the same recurrent surgery states. The [+] symbol at the end of each line indicates that the given branch is collapsed for simplicity and can be expanded to show further detail.

to evaluate heath utilities include the time trade-off method, standard gamble method, and visual analog method. An indirect method to measure a health utility value is the EuroQol 5 dimension (EQ-5D) survey. Created by the EuroQol Group Association, the EQ-5D survey measures health outcomes in 5 categories: mobility, self-care, usual activities, pain/discomfort, and anxiety/depression.

In the current study, the generic health status was measured using the Short Form–36 Health Survey (SF-36) from published studies of National Collegiate Athletic Association (NCAA) athletes.[19,32] The SF-36 score was then converted to an EQ-5D value using a published algorithm that has been tested and found to be reliable and accurate.[2,36] For athletes who returned to their prior level of play, the range of EQ-5D values for our sensitivity analysis extended from 0.89 (mild knee injury but still able to play) to 1.00 (perfect health). The range of EQ-5D values for those not returning to their prior level of play extended from 0.62 (less than perfect health but still able to play moderately stressful sports) to 0.89. The QALY was then calculated by multiplying quality of life by time, expressed in years. Thus, if one were to maintain perfect health

Figure 4. Decision tree for physical therapy as the initial management strategy for anterior cruciate ligament (ACL) injuries is shown with each of the Markov states expanded to show the details. The late ACL reconstruction (ACLR) states are analogous to the initial ACLR states in the initial ACLR strategy shown in Figure 2.

throughout the 6-year time horizon, the QALYs would be 6.0.

To account for the expected temporary disability in the immediate postoperative period, quality of life for the 3-month interval with surgery was further adjusted by subtracting 0.5 from the baseline value for the first 2 weeks postoperatively and for an additional 8 weeks after a major complication. Quality of life was also further adjusted for minor complications in a similar manner by subtracting 0.2 from the baseline value for a period of 2 weeks. This yielded reductions in the QALYs of 0.02 for surgery, 0.04 for a major complication, and 0.008 for a minor complication.

Costs

Costs were determined from a societal perspective. Hospital costs (not "charges") for ACL reconstruction, treatment of complications, subsequent knee surgery, physical therapy, and outpatient visits were obtained for a large academic medical center in the US from an activity-based cost accounting system (EPSi-Eclipsys). The average days missed from work/school for both treatment groups was based on the clinical experience of the senior author (D.L.). Time lost in transportation and waiting time for appointments were found in the literature.[37] Time costs were then calculated by multiplying the total time away from work/school (hours missed because of treatment plus transportation/wait times) by the average hourly wage for the base group. The average hourly wage from the base group was calculated from the US Census for the age group of 15 to 24 years.[1] All costs were adjusted to 2015 US dollars using the appropriate medical price component categories (Hospital Outpatient Services, Physician Services, Services by Other Medical Professionals, and Medical Equipment and Supplies) from the Consumer Price Index detailed report for December 2015.[6]

Analysis

The incremental cost was calculated as the difference in costs between the ACL reconstruction and nonoperative physical therapy treatments. The incremental effectiveness was calculated as the difference in QALYs between the ACL reconstruction and physical therapy treatments. The incremental cost-effectiveness ratio (ICER) was calculated by dividing the difference in incremental costs (expressed in dollars) by the difference in incremental effectiveness (expressed in QALYs) to yield a value expressed in dollars per QALY. A medical treatment strategy that is below a willingness-to-pay (WTP) threshold is considered cost-effective. In this study, we considered an ICER of <$50,000 per QALY gained to be cost-effective.[17] The probabilities, costs, quality-of-life values, and other data used in the analysis are summarized in Table 3. Both future costs and future utilities (QALYs) were discounted at 3% annually to be consistent with current practices in cost-effectiveness analyses.

TABLE 1
Rates of Return to Preinjury Level of Play After ACL Reconstruction[a]

Study[b]	No. of Patients	Length of Follow-up, y	Patients Who Returned to Play at Preinjury Level, n (%)
Ibrahim et al[20]	85	6.75	66 (77.6)
Mastrokalos et al[30]	100	3.25	30 (30.0)
Gobbi et al[13]	80	3	52 (65.0)
Shaieb et al[39]	70	2.75	40 (57.1)
Fithian et al[9]	63	6.6	33 (52.4)
Gobbi et al[12]	80	3	48 (60.0)
Smith et al[42]	77	3.58	32 (41.6)
Gobbi and Francisco[11]	100	2	65 (65.0)
Lee et al[26]	64	5	28 (43.8)
Kvist et al[23]	62	3.5	33 (53.2)
Frobell et al[10]	61	2	27 (44.3)
Mascarenhas et al[28]	38	9.7	23 (60.5)
Osti et al[34]	50	6	44 (88.0)
Laboute et al[25]	298	3.5	186 (62.4)
Devgan et al[7]	48	5	22 (45.8)
Ardern et al[3]	314	3.3	140 (44.6)
Widuchowski et al[46]	52	15	39 (75.0)
Mascarenhas et al[29]	46	4.5	23 (50.0)
Bourke et al[5]	673	16	493 (73.3)
McCullough et al[33]	147	2	63 (42.9)
Jang et al[21]	67	2.9	51 (76.1)
Kyung et al[24]	144	2.2	120 (83.3)
Mean return-to-play rate, %			61.0

[a]ACL, anterior cruciate ligament.
[b]A total of 691 studies were retrieved from a PubMed search through January 2016 using the search terms "return to sports, anterior cruciate ligament"; 2 were added after reviewing the references from the initial 19 qualifying studies for other studies that met the inclusion/exclusion criteria. A total of 22 studies met the following inclusion criteria: minimum 2-year follow-up (studies with ranges below 2 years of follow-up were excluded), explicit statement that patients returned to their preinjury level of sport activity, minimum of 25 patients, English language, patients who underwent a modern postoperative rehabilitation program with early active motion, patients with a complete ACL tear (no partial tear), no delay seeking treatment, skeletally mature patients, patients with no other torn ligaments, and no extra-articular or synthetic graft reconstruction.

TABLE 2
Rates of Return to Preinjury Level of Play After Nonoperative ACL Treatment[a]

Study[b]	No. of Patients	Length of Follow-up, y	Patients Who Returned to Play at Preinjury Level, n (%)
Scavenius et al[38]	58	7.1	4 (6.9)
Pattee et al[35]	49	5.6	18 (36.7)
Hawkins et al[18]	40	3.8	4 (10.0)
Mean return-to-play rate, %			17.7

[a]ACL, anterior cruciate ligament.
[b]A total of 540 studies were retrieved from a PubMed search through January 2016 using the search terms "return to sports, anterior cruciate ligament, therapy"; 143 studies were retrieved using the search terms "nonoperative, anterior cruciate ligament" for a second search. A review of references of the qualifying studies yielded no additional studies that met the inclusion criteria. Three studies met the following inclusion criteria: minimum 2-year follow-up, explicit statement that patients returned to their preinjury level of sport activity, minimum of 25 patients, English language, patients who underwent a formal therapy program, patients with a complete ACL tear (no partial tear), no delay seeking treatment, skeletally mature patients, and patients with no other torn ligaments.

Sensitivity Analyses

Sensitivity analyses evaluated the effect of the uncertainty in the variables used in the analysis on the incremental cost, incremental effectiveness, and ICER. One-way sensitivity analyses were performed for each independent variable in Table 3. In these analyses, each variable was individually varied over the ranges shown in Table 3, and the incremental costs, incremental QALYs, and ICERs were calculated. Thresholds for independent variables in which ACL reconstruction would be considered cost-effective based on an ICER of <$50,000 per QALY gained were identified. Selective 2-way sensitivity analyses were performed for variables identified in the 1-way sensitivity analyses as having a large effect on the incremental cost, incremental effectiveness, or ICER. In the 2-way sensitivity analyses, 2 independent variables were varied over their ranges to identify the ranges of these

TABLE 3
Variables in Markov Model[a]

Variable	Base Case Value	Low Value	High Value
Probability			
Return to play after ACL reconstruction[b]	0.610	0.300	0.880
Return to play after nonoperative treatment[b]	0.177	0.069	0.367
Minor surgical complication	0.0080	0.0000	0.0210
Major surgical complication	0.0066	0.0000	0.0800
Rate[c]			
Reinjury requiring cartilage knee surgery with initial ACL reconstruction and:			
Return to play at preinjury level	0.018	0.000	0.029
No return to play at preinjury level	0.005	0.000	0.016
Reinjury requiring cartilage knee surgery with initial nonoperative treatment and:			
Return to play at preinjury level	0.043	0.025	0.055
No return to play at preinjury level	0.022	0.007	0.055
Reinjury requiring ACL revision surgery with initial ACL reconstruction and:			
Return to play at preinjury level	0.010	0.005	0.016
No return to play at preinjury level	0.005	0.007	0.016
Reinjury requiring late ACL reconstruction surgery with initial nonoperative treatment and:			
Return to play at preinjury level	0.038	0.033	0.080
No return to play at preinjury level	0.034	0.033	0.080
Utility (quality of life)[d]			
Return to play at preinjury level	0.95	0.89	1.00
No return to play at preinjury level	0.76	0.62	0.89
Cost of surgical procedures and complications,[e] $			
ACL reconstruction surgery[f]	9974	4987	14,961
ACL revision surgery[f]	13,176	6588	19,764
Late cartilage surgery[f]	6487	3244	9731
Minor surgical complication, additional costs	706	353	1059
Major surgical complication, additional costs	49,085	24,543	73,628
Cost used in ACL reconstruction strategy, $			
Surgical cost of ACL reconstruction[f]	9974	4987	14,961
Patient time cost with ACL reconstruction (lost wages)	665	333	998
Physical therapy after ACL reconstruction	6737	3369	10,106
Follow-up appointments after ACL reconstruction	583	292	875
Brace	785	393	1178
Total societal cost for ACL reconstruction[g]	18,744	9372	28,116
Cost used in nonoperative treatment strategy, $			
Physical therapy for nonoperative treatment	6400	3200	9600
Patient time cost with nonoperative treatment	200	100	300
Follow-up appointments after nonoperative treatment	703	352	1055
Brace	785	393	1178
Total societal cost for nonoperative treatment[h]	8088	4044	12,132
Model variable			
Discount rate, %	3	0	5
Follow-up, y	6	3	10

[a]ACL, anterior cruciate ligament.
[b]Base case value is the weighted average from referenced studies. The low and high values for probabilities, rates, health utilities, and costs are 50% and 150% of the base case value, respectively.
[c]Rate per person-year.
[d]Converted from the Short Form–36 Health Survey score to the EuroQol 5 dimension survey value.
[e]Base case and high values are derived from data from an activity-based cost accounting system of a major hospital in the southern United States (US). All costs are adjusted to 2015 US dollars using the relevant medical price component category of the Consumer Price Index.[6]
[f]Includes facility, surgeon, and anesthesia costs.
[g]Includes surgery, physical therapy, patient time, follow-up visit, and durable medical equipment costs.
[h]Includes physical therapy, patient time, follow-up visit, and durable medical equipment costs.

variables in which the ACL reconstruction strategy or the physical therapy strategy resulted in a greater net monetary benefit using a WTP threshold of $50,000 per QALY gained.

We conducted a probabilistic sensitivity analysis (Monte Carlo sensitivity analysis) by representing 20 key variables identified in the 1- and 2-way sensitivity analyses as distributions (Table 4), sampling each variable from its

TABLE 4
Variables and Distributions for Monte Carlo Sensitivity Analysis[a]

Variable	Base Case Value	Low Value	High Value	Distribution	Mean ± SD
Cost of nonoperative treatment, $	8088	4044	12,132	Gamma	8088 ± 1622
Cost of operative treatment, $	18,174	9372	28,116	Gamma	18,174 ± 3024
Cost of operative treatment for revision ACL reconstruction, $	21,946	10,973	32,919	Gamma	21,946 ± 3711
Probability of minor complication	0.0080	0	0.0210	Beta	0.008 ± 0.00525
Probability of major complication	0.0066	0	0.0800	Beta	0.0066 ± 0.02000
Probability of late ACL repair after initial physical therapy and no return to play	0.0085	0.0080	0.0200	Beta	0.0085 ± 0.0031
Probability of late ACL repair after initial physical therapy and return to play	0.0095	0.0080	0.0200	Beta	0.0095 ± 0.0031
Probability of ACL revision for reinjury after initial ACL repair and no return to play	0.0012	0.0017	0.0040	Beta	0.0012 ± 0.0006
Probability of ACL revision for reinjury after initial ACL repair and return to play	0.0025	0.0013	0.0040	Beta	0.0025 ± 0.0007
Probability of cartilage surgery for reinjury after initial physical therapy and no return to play	0.0055	0.0018	0.0137	Beta	0.0055 ± 0.003
Probability of cartilage surgery for reinjury after initial physical therapy and return to play	0.0107	0.0062	0.0137	Beta	0.0107 ± 0.0019
Probability of cartilage surgery for reinjury after ACL repair and no return to play	0.0012	0	0.0040	Beta	0.0012 ± 0.001
Probability of cartilage surgery for reinjury after ACL repair and return to play	0.0045	0	0.0072	Beta	0.0045 ± 0.0018
Multiplier for probability of return to play for ACL reconstruction	1.0	0.5	1.5	Gamma	1.0 ± 0.2551
Multiplier for probability of return to play for nonoperative treatment	1.0	0.5	1.5	Gamma	1.0 ± 0.2551
QoL, reduction for major complication	0.04	0	0.08	Beta	0.04 ± 0.0204
QoL, reduction for minor complication	0.008	0	0.016	Beta	0.008 ± 0.0041
QoL, no return to play	0.76	0.62	0.89	Beta	0.76 ± 0.0689
QoL, return to play	0.95	0.89	1.00	Beta	0.95 ± 0.0281
QoL, reduction for surgery	0.02	0	0.04	Beta	0.02 ± 0.0102

[a]ACL, anterior cruciate ligament; QoL, quality of life.

distribution, and calculating the incremental cost, incremental effectiveness, and ICER. The Monte Carlo sensitivity analysis used 10,000 samples.

The analysis allowed the calculation of 95% CIs around the incremental cost and incremental effectiveness and a scatterplot of the ICERs with the 95% CI ellipse around the ICERs in a 2-dimensional graph in the cost-effectiveness space (Figure 5). An acceptability curve was created by calculating the proportion of samples that were cost-effective with an ICER less than the WTP threshold as the WTP threshold was varied from $1000 to $100,000 (Figure 6).

RESULTS

For competitive athletes with a new ACL injury, with over 6 years of follow-up, the ACL reconstruction strategy would be expected to result in 4.675 QALYs at an expected cost of $20,298. The ICER of ACL reconstruction was $22,702 per QALY, which is well below the WTP threshold of $50,000 per QALY gained (Table 5).

The ICER was most sensitive to the quality of life of returning to play or not returning to play, costs, and duration of follow-up. In contrast, the ICER was relatively insensitive to the rates and costs of complications, probabilities of return to play for both operative and nonoperative treatments, and discount rate.

Competitive athletes who highly value returning to play at their previous level but are unable to do so and rate their quality of life as low (below the base case value of 0.76) had a low ICER. However, for athletes who have their quality of life less negatively affected by the inability to return to their preinjury level of play, the ICER of ACL reconstruction increased from $22,702 per QALY, with a utility score of 0.76 (base case), to $50,000 per QALY gained, with a utility score of 0.83 for not returning to play. The ICER further increased to $100,000 per QALY gained, with a utility score of 0.86. Thus, the less important that return to sport is for the athlete, the less cost-effective ACL surgery becomes. Conversely, the more value placed on returning to sport by the athlete, the more cost-effective the procedure becomes. A 1-way sensitivity analysis demonstrated how the quality of life of not returning to play affected the ICER (Figure 7). A 2-way sensitivity analysis showed the ranges of each of these quality-of-life values in which ACL reconstruction was the optimal strategy with an ICER less than $50,000 per QALY (Figure 8). ACL reconstruction is preferred when the quality of life of returning to play is high and the quality of life of not

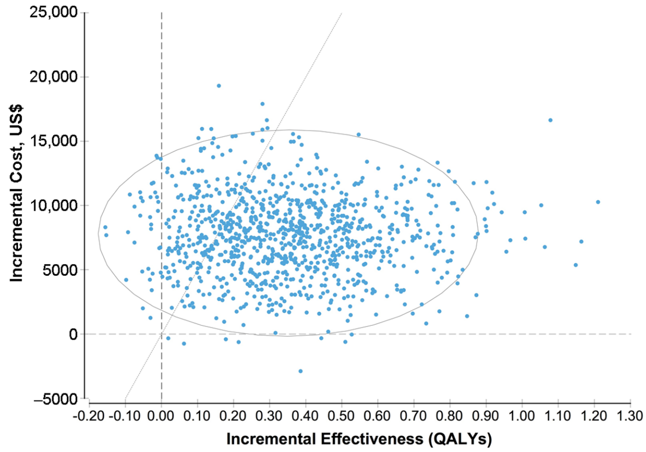

Figure 5. Monte Carlo sensitivity analysis of anterior cruciate ligament reconstruction compared with physical therapy. The scatterplot depicts the incremental cost-effectiveness ratios derived from the Monte Carlo (probabilistic) sensitivity analysis for the first 1000 samples of the total 10,000 random samples. In a graph in the cost-effectiveness space, the incremental effectiveness is plotted on the x-axis, and the incremental cost is plotted on the y-axis. Values in the upper right quadrant represent a strategy that is more costly but also more effective than the comparator, while in the lower right, it is more effective and less costly than the comparator. Values in the upper left are more costly and less effective, and values in the lower left are less costly and less effective than the comparator. QALY, quality-adjusted life-year.

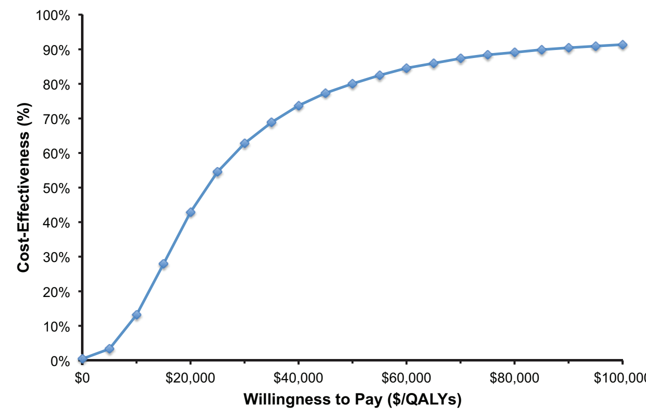

Figure 6. Acceptability curve of the incremental cost-effectiveness ratio (ICER) of anterior cruciate ligament reconstruction compared with physical therapy as the willingness-to-pay (WTP) threshold on the x-axis is varied. The y-axis shows the proportion of simulation samples in which the ICER is less than the WTP threshold. QALY, quality-adjusted life-year.

returning to play is low. The figure illustrates the threshold for the quality-of-life values in which ACL reconstruction is the preferred strategy.

The ICER was relatively insensitive to the range of probabilities of return to play for both the ACL reconstruction and physical therapy treatment strategies. When the probability of return to play after ACL reconstruction was varied from 50% to 150% of the base case value, the ICER fell from $52,968 to $15,747 (Figure 9). Similarly, the ICER only increased from $19,695 to $26,962 as the probability of return to play with physical therapy varied from 50% to 150% of the base case probability. In contrast, the ICER was sensitive to the duration of analysis. As the duration increased from 2 to 10 years, the ICER fell from $96,581 to $11,340, with the steepest decline occurring over the first 3 years. The model was relatively insensitive to the discount rate. As the rate was varied from 0% to 5%, the ICER only increased from $19,973 to $24,590.

The ICER scatterplot shows the wide variation in the ICERs from the 10,000 samples of the Monte Carlo sensitivity analysis (Figure 5) plotted in a 2-dimensional cost-effectiveness space. The distribution of potential incremental costs (mean, $7850; 95% CI, $1792 to $14,611) and associated incremental effectiveness (mean, 0.352 QALYs; 95% CI, –0.002 to 0.832 QALYs) within the 95% CI ellipse provides a visual depiction of the magnitude of uncertainty in the estimates of the incremental costs and associated incremental effectiveness from 1000 to 10,000 random samples of the simulation. The acceptability curve (Figure 6) shows the proportion of samples in which ACL reconstruction was preferred over physical therapy with an ICER less than the WTP threshold.

DISCUSSION

Our analysis indicates that ACL reconstruction for competitive athletes with an ACL injury is preferable to a nonoperative strategy with a cost of $22,702 per QALY gained. The ICER was most sensitive to the competitive athletes' valuation of their quality of life if they were unable to return to their previous level of play. The ICER was also sensitive to costs of ACL reconstruction and physical therapy and the duration of follow-up. The ICER was relatively insensitive to the rates and costs of complications, probabilities of return to play for both operative and nonoperative treatments, and discount rate. The Monte Carlo (probabilistic) sensitivity analysis that accounted for simultaneous uncertainty in 20 of the model's important parameters for clinical probabilities, patients' quality of life, and costs found considerable variation in the ICER but indicated 80% confidence that the ICER is less than $50,000 per QALY gained and 91% confidence that the ICER is less than $100,000 per QALY gained.

Few previous studies have used a Monte Carlo sensitivity analysis to study the cost-effectiveness of ACL reconstruction. The Monte Carlo sensitivity analysis allowed us to use several probability distributions in the model. One criticism of this type of study is that the results are only as good as the assumptions or numbers used. Furthermore, certain variables such as days missed from work using either treatment strategy were estimated by the senior author. However, the 1-way, 2-way, and Monte Carlo sensitivity analyses allowed us to see the relative

TABLE 5
Cost-Effectiveness of ACL Reconstruction Compared With Physical Therapy[a]

Strategy	Cost, $	Incremental Cost, $	Effectiveness, QALYs	Incremental Effectiveness, QALYs	Incremental Cost-Effectiveness Ratio, $/QALY
Physical therapy	11,853		4.303		
ACL reconstruction	20,298	8445	4.675	0.372	22,702

[a]ACL, anterior cruciate ligament; QALY, quality-adjusted life-year.

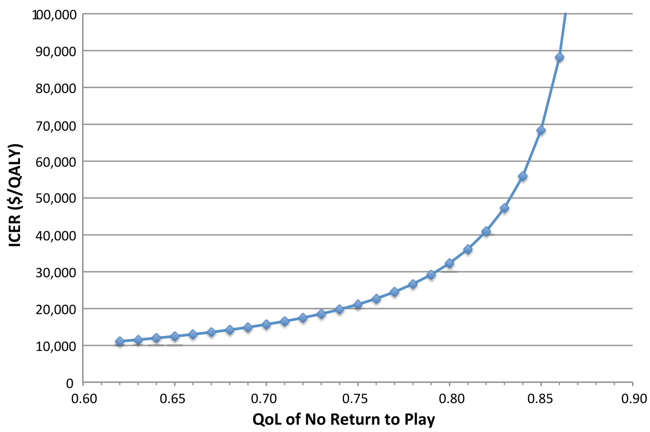

Figure 7. One-way sensitivity analysis showing how the quality of life (QoL) of not returning to play affects the incremental cost-effectiveness ratio (ICER). QALY, quality-adjusted life-year.

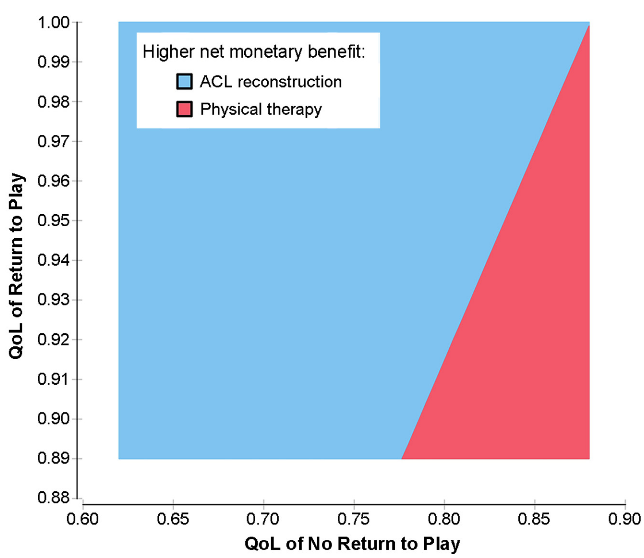

Figure 8. Two-way sensitivity analysis showing ranges for the quality of life (QoL) of ''return to play'' and ''no return to play'' in which anterior cruciate ligament (ACL) reconstruction or physical therapy is the optimal treatment strategy. The ACL reconstruction strategy is optimal (higher net monetary benefit) for combinations of QoL values shown to the left of the graph, and the physical therapy strategy is optimal for combinations of QoL values shown to the right.

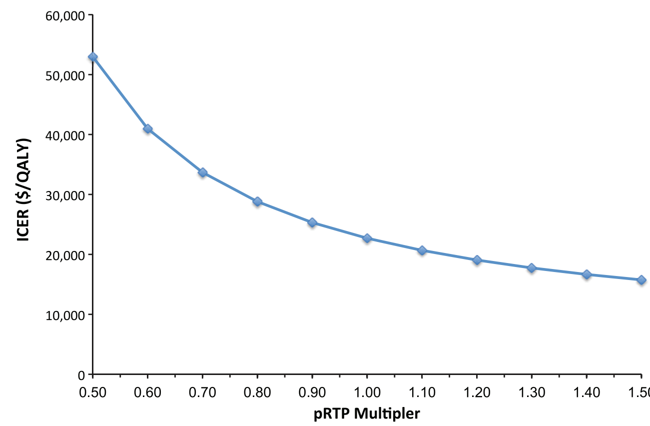

Figure 9. One-way sensitivity analysis demonstrating how changes in the probability of returning to play at the same level (pRTP) affect the incremental cost-effectiveness ratio (ICER). QALY, quality-adjusted life-year.

importance of different variables and then showed what happens to the results as these variables change. The results of these analyses showed that even if the variables are changed substantially, the main finding that ACL reconstruction is cost-effective still holds true.

A limitation in all cost-effectiveness studies is that the validity of the results is limited by the quality of the data used in the analysis. We used strict inclusion and exclusion criteria in selecting peer-reviewed publications for our study, but nonetheless, the data are derived from different studies. Additionally, while there is extensive work published on the outcomes of surgical reconstruction of the ACL, far fewer studies have examined the treatment of ACL tears with nonoperative physical therapy. Nevertheless, by using strict criteria in reviewing multiple peer-reviewed studies and conducting a thorough sensitivity analysis, we demonstrated how uncertainty in the data influenced the ICER, and we identified the variables that have the largest effect on the ICER. Another limitation of this study reflects the cost data. The costs were derived from a large academic hospital in the US. The costs for the same procedure in smaller hospitals or similar hospitals in other regions of the country may not be comparable. In addition, we used $50,000 per QALY as our threshold for what is deemed cost-effective. Ultimately, this is an arbitrary number but one that is often quoted as the benchmark in health economic analyses. Finally, although this study shows that ACL reconstruction is a cost-effective strategy from a societal perspective, these results cannot be extrapolated individually to the hospital's, payer's, or surgeon's perspectives.

In the present study, our findings support the conclusion that ACL reconstruction is cost-effective. However, our cost per QALY ($22,702) was substantially higher than the cost reported by Gottlob et al[15] ($5857) and Farshad et al[8] ($4890). Gottlob et al[15] used utility values of 1.0 for athletes who were able to return to their previous level of activity and 0.43 to 0.62 for athletes who were not able to return to their previous level of play based on a survey of local university students. The value of 0.62 that Gottlob et al[15] reported for an athlete who is able to only return to moderately stressful sports such as baseball, skiing, and racket sports instead of very stressful sports such as soccer, basketball, and football was much lower than that for most major diseases. For example, blindness (0.78), heart failure (0.71), emphysema (0.71), renal failure (0.71), osteoarthritis (0.78), and diabetes (0.80) all have substantially higher published utility scores.[44] A decrease in the level of athletic participation from very stressful (ie, soccer) to moderately stressful (ie, baseball) would be unlikely to have a substantially worse utility score than the abovementioned conditions. The lower utility scores for failure to return to the previous level of play used by Gottlob et al[15] would make ACL reconstruction more attractive with a lower ICER. Furthermore, we did not take into account the potential long-term risks from meniscal tears and articular cartilage damage that are more likely to occur with nonoperative treatment. Such variables may further decrease the cost per QALY.

Our study results are in line with those of a recent study by Mather et al[31] that used a Markov decision model to evaluate the cost-effectiveness of ACL reconstruction using data from the MOON (Multicenter Orthopaedic Outcomes Network) database and the KANON (Knee Anterior cruciate ligament, NON-surgical versus surgical treatment) database. It was shown that ACL reconstruction was dominant over rehabilitation in all age groups over the long term.

In this study, we used predetermined search terms with strict inclusion and exclusion criteria to determine the probabilities of return to play with both operative and nonoperative treatments. Many studies failed to meet our criteria. Some of the articles had results that were quite different than the ones that we used in this study. For example, a recent meta-analysis of ACL reconstruction[4] found a 71% rate of return to the preinjury level of activity, which is 10 percentage points higher than the proportion in our study. However, probabilities of 1.5 and 0.5 times the base case values were tested as part of the sensitivity analysis, which showed that the ICER is relatively insensitive to this range of probabilities. Higher rates of return to the preinjury level further lower the ICER, making ACL reconstruction even more cost-effective.

The progressive increase in US health care costs and health care reform proposals to control health care costs has led to an increased interest in comparative effectiveness studies, which may be used by policy makers and payers to make payment decisions based on the effectiveness and costs of treatments. Our study found that ACL reconstruction has a cost of $22,702 per QALY gained compared with physical therapy and is cost-effective using the common WTP threshold of $50,000 per QALY.

Strengths of this study include the use of a Markov model, extensive sensitivity analyses, a Monte Carlo sensitivity analysis, utility assessments based on NCAA assessments that appear consistent with published population norms, and a societal perspective for the analysis. Another strength of our study is the use of QALYs based on a widely used health status measure, the SF-36, which has been shown to be accurately and reliably mapped to the EQ-5D for use in cost-utility studies. The SF-36 score is not knee or ACL specific, but it has been recommended for use in the evaluation of ACL injuries and has been found to show important and significant changes with treatment over time.[22,40] While we consider the utility values in our study to be accurate and a strength of our approach, prospectively collected utility scores for both the surgical treatment and physical therapy of ACL tears are needed and should be included in future studies.

This study supports previous work showing that ACL reconstruction is cost-effective in competitive athletes and provides a reference for payers and decision makers. It also serves as a model for future ACL cost-effectiveness studies that can focus on other populations and treatment alternatives.

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