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Societal and Economic Impact of Anterior Cruciate Ligament Tears

This technical appendix describes our approach to estimating the effects of ACL reconstruction on the indirect costs associated with ACL tears in the short to intermediate term and over a patient's lifetime. A brief description of this approach as well as our approach to converting Medicare reimbursement rates to all-payer reimbursement levels are presented below.

Framework for Estimating Indirect Costs

For the short to intermediate-term phase of the model, we estimated the effects of functional limitations due to an ACL tear on work status, earnings, and disability payments. Data from the NHIS were used to generate regression coefficients that described the statistical relationship between physical functional status and economic outcomes. We applied these coefficients to surgical and nonsurgical outcomes data from the MOON cohort to estimate the effect of surgery on income, missed workdays, and the probability of receiving disability payments. These findings were entered into a Markov decision model to estimate total societal savings resulting from repair of ACL tears.

The NHIS, which is used to monitor the health of the U.S. population, is one of the major data collection programs of the National Center for Health Statistics (NCHS), which is part of the Centers for Disease Control and Prevention (CDC). The NHIS covers the civilian noninstitutionalized population residing in the U.S. and has an expected sample size (completed interviews) of approximately 35,000 households each year.

In later time periods, it was assumed that some patients would develop osteoarthritis of the knee, which would sometimes progress to end-stage osteoarthritis. For these patients, additional indirect costs were assessed utilizing the results from Ruiz et al.[19], a study on the societal costs of end-stage osteoarthritis of the knee.

Cost-Effectiveness Analysis

We used a Markov cohort model to conduct a cost-effectiveness analysis of the present-day value of the expected costs and QALY gains over the first six years and over the lifetime of a hypothetical patient cohort for each treatment strategy. Outcome measures included mean costs and effectiveness (in QALYs) as well as the cost-effectiveness ratio for each strategy. The incremental costs and effectiveness were also calculated and represent the relative difference between the two alternative strategies, ACL reconstruction and rehabilitation alone. The principal outcome measure calculated was the incremental cost-effectiveness ratio (ICER), which is the ratio of the cost difference between the strategies and the QALY difference between the strategies. In terms of this model, the ICER is expressed as: $\text{ICER} = (\text{Cost}_{\text{Reconst}} - \text{Cost}_{\text{Rehab}})/(\text{QALY}_{\text{Reconst}} - \text{QALY}_{\text{Rehab}})$.

An ICER of <\$50,000 per QALY gained was considered to be cost-effective on the basis of a \$50,000 threshold for the willingness of the health-care system to pay (WTP). In this cost-effectiveness analysis, the preferred treatment strategy is the more effective strategy if ICER < WTP.

One, two, and three-way sensitivity analyses were performed on all variables in the model. Variables deemed "sensitive" were those that, when changed across a reasonable range, also changed the preferred strategy. If the preferred strategy did not change, then the variable was termed "robust." When available, data from the MOON cohort were used to determine parameter distributions; for the remaining variables, probabilistic sensitivity analyses were performed by calculating beta or uniform distributions.

Monte Carlo analysis using microsimulation and a probabilistic sensitivity analysis were used to generate 95% confidence intervals (CIs) for the outcomes and to estimate the incidence of radiographic and symptomatic osteoarthritis and total knee arthroplasty over a lifetime in the U.S.

Functional Limitation Index (FLI) Score from the MOON Data

Patient-level outcomes data from the MOON database were used to calculate FLI scores based on select questions from the SF-36 and KOOS (Knee injury and Osteoarthritis Outcome Score) instruments that correspond to those in the NHIS. Baseline and postoperative index scores were obtained and summarized according to five age categories (eighteen to twenty-nine, thirty to thirty-nine, forty to forty-nine, fifty to fifty-nine, and sixty to sixty-nine years).

The FLI score incorporated responses from the following questions:

- Does your health limit you in walking several blocks? (SF-36)
- Does your health limit you in climbing one flight of stairs? (SF-36)
- Does your health limit you in bending, kneeling, or stooping? (SF-36)
- Does your health limit you in lifting or carrying groceries? (SF-36)
- Does your health limit you in moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf? (SF-36)
- In the last week, what degree of difficulty have you experienced with sitting due to your knee? (KOOS)

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In the last week, what degree of difficulty have you experienced with standing due to your knee? (KOOS)

An algorithm was used to encode each response as a point value of 1 (severely affected), 2 (moderately affected), or 3 (not affected). The responses were mapped in accordance with Tables E-1 and E-2. The sum of the values corresponding to the responses by an individual was divided by the maximum possible score of 21 points to calculate that individual's FLI score.

Mean FLI scores according to age group are presented in Table E-3 at baseline (after the ACL tear but prior to surgery) and after two years; these values were used to estimate indirect costs. Baseline scores were adjusted to account for improvement in physical function that can occur over time prior to surgery. Specifically, we estimated a regression model, with use of ordinary least squares, in which the baseline FLI score was the dependent variable and age, sex, and time between injury and surgery (captured as zero to six months, six to twelve months, one to three years, and more than three years) were the explanatory variables. The results revealed progressively better baseline function as the period between injury and surgery increased. As a result, we used the parameter estimates from the regression model to adjust all baseline FLI scores to baseline scores for a time since injury of between six and twelve months.

Estimating the Relationship Between Functional Limitations and Indirect Costs

The NHIS collects information from a stratified random sample of the U.S. population regarding physical function, economic factors such as employment status and income, and other patient characteristics. Our analysis combined the 2003 through 2009 NHIS files to increase the sample size. For functional limitations, the NHIS asks respondents:

By yourself, and without using any special equipment, how difficult is it for you to:

Walk a quarter of a mile—about 3 city blocks?
Walk up 10 steps without resting?
Sit for about two hours?
Reach up over your head?
Stand or be on your feet for about two hours?
Stoop, bend, or kneel?
Lift or carry something as heavy as 10 pounds such as a full bag of groceries?
Push or pull large objects like a living room chair?

Responses to each question include: (1) not at all difficult, (2) only a little difficult, (3) somewhat difficult, (4) very difficult, and (5) can't do at all. Our analysis focused only on functional limitations in which the person indicates that back pain contributed to his or her limitations.

The responses from the NHIS sample were mapped in accordance with Table E-4 and were used to calculate an FLI score. Since the NHIS question related to the ability to reach is not included in the FLI, we included that variable separately in the model.

Regression Analysis of FLI Scores Based on NHIS Responses of Patients with a Knee Injury

Regression analysis was used to compare economic outcomes for adults with greater functional limitations to economic outcomes for adults with fewer functional limitations—controlling for age group (eighteen to thirty-nine, forty to forty-four, forty-five to forty-nine, fifty to fifty-four, and fifty-five to fifty-nine years), sex, highest education attainment (high school diploma, baccalaureate degree, post-baccalaureate degree), and occupation (for analysis of the employed population). Our analysis was restricted to patients less than sixty years of age who reported some level of pain in the knee because of a joint injury.

Ordinary least-squares regression was used to quantify the impact of functional limitations on household income for the employed population and missed workdays. Logistic regression was used to quantify the impact of functional limitations on the employment rate and the probability of being disabled. The results of the regression modeling are reported in Table E-5.

Estimating Indirect Costs for Patients Undergoing Total Knee Arthroplasty

In the long-term phase of the model, some members of the cohort will progress to end-stage osteoarthritis of the knee and undergo total knee arthroplasty. We estimated the effects of end-stage osteoarthritis and total knee arthroplasty on patients' indirect costs (involving employment, earnings, disability pay, and missed workdays) with use of results from Ruiz et al.[19], in which patient-reported outcomes and NHIS regression results were combined to estimate the effects of total knee arthroplasty on economic outcomes. Outcomes data reported by total knee arthroplasty patients were collected by a physician group practice with multiple locations in the northeastern U.S. Electronic questionnaires were sent to 310 patients who received a total knee arthroplasty from September 2010 to April 2011. A total of seventy-three responses were received and were used in the analyses. The survey contained questions regarding an individual's socioeconomic status and functional ability (using the same questions on functional status used in the NHIS) prior to undergoing surgery and after undergoing surgery. Functional questions included the following possible answers: "no difficulty," "only a little difficult," "somewhat difficult," "very difficult," and "cannot do." Numerical values of

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1 through 5 were assigned to the responses, with "no difficulty" assigned a value of 1 and "cannot do" assigned a value of 5. Patients were categorized as receiving full benefit from the total knee arthroplasty if their mean post-surgery response for all functional questions was 3 (somewhat difficult) or less and as limited benefit otherwise (Table E-6).

Ruiz et al.[19] used regression analysis to compare economic outcomes between adults with and without activity limitations, controlling for age group (eighteen to thirty-nine, forty to forty-four, forty-five to forty-nine, fifty to fifty-four, fifty-five to fifty-nine, sixty to sixty-four, sixty-five to sixty-nine, and seventy years or more), sex, highest education attainment (high school diploma, baccalaureate degree, post-baccalaureate degree), and occupation (for analysis of the employed population). Responses to physical function questions were made independent of the questions by creating a binary variable (1 = yes, 0 = no) for each of the possible responses (e.g., "not at all difficult," "only a little difficult," "somewhat difficult," "very difficult," and "can't do at all") to each question. Respondents claiming that the physical function task was "not at all difficult" were used as the comparison group.

Ordinary least-squares regression was used to quantify the impact of activity limitations on household income and missed work days in the employed population and on disability payments. Regression results for the functional outcome variables were generated on the basis of the methodology described in Dall et al.[21].

Estimating Indirect Cost Components

The relationships between functional limitations and indirect costs were estimated by least-squares and logistic regression analyses as described above. The results from the models allowed us to determine an individual's probability of being employed, number of missed workdays, household income, and disability payments conditional on the probability of being employed, as well as a person's disability payments conditional on his or her level of functional ability in a given year.

The expected income in a given year was calculated as: Expected Income = Estimated Income Conditional on Being Employed × Probability of Being Employed. The cost associated with missed workdays in a given year was calculated as: Value of Missed Workdays = Estimated Income Conditional on Being Employed × Probability of Being Employed × (Missed Workdays/240). Additionally, we assumed that workers lost an average of twenty-eight workdays recovering from ACL surgery and forty days recovering from total knee arthroplasty surgery[20]. The expected disability payment in a given year was calculated by multiplying the probability of being disabled by the mean SSI (Supplemental Security Income) payment according to sex and age. Disability payments as function of age were taken from the 2011 Current Population Survey (Table E-7).

The results of ACL reconstruction are shown in Table E-8. Baseline and two-year outcomes were estimated with use of the FLI scores in Table E-3 and the regression results in Table E-5. Negative values in Table E-8 reflect increased costs of remaining at a baseline functional level after nonsurgical treatment (rehabilitation only) compared with ACL reconstruction. For example, patients eighteen to thirty-nine years of age who would have remained at a baseline level of functional limitation without surgery would lose $8871 in income without a reconstruction. Our base assumption in the Markov decision model was that 37% of individuals in the rehabilitation arm would exhibit the same functional level (as measured by the FLI) at two years as in the baseline period, and the remaining 63% would exhibit a level equivalent to that achieved by patients in the ACL reconstruction arm.

Long-Term Model Methodology

Progression of Radiographic Osteoarthritis to Total Knee Arthroplasty

Radiographic osteoarthritis imposes additional costs or decreased quality of life only if it is symptomatic. In a study by Kellgren and Lawrence, 24% of patients with radiographic changes had symptoms[14]. Recently, a fourteen-year longitudinal study utilizing the Kellgren and Lawrence grading system indicated a 3% annual rate of progression of radiographic to symptomatic osteoarthritis. Osteoarthritis of greater severity progressed faster compared with lower grades in that study. In a longitudinal study of radiographic knee osteoarthritis in 2262 patients, Muraki et al. reported a 21.1% prevalence of knee pain in patients with radiographic osteoarthritis at time zero and a 4% increase over the next three years of the study. Using the findings from Muraki et al., we assumed a 21% baseline rate of symptoms associated with radiographic knee osteoarthritis and a 1.3% annual increase in the rate of knee pain thereafter[15].

Symptomatic osteoarthritis progresses to end-stage osteoarthritis requiring total knee arthroplasty, although little published evidence exists to quantify the progression. The United Healthcare Database suggests an annual conversion rate of approximately 2.3% on the basis of 2009 data showing that 12,806 patients underwent total knee arthroplasty with a coded diagnosis of osteoarthritis while a total of 566,027 patients received a coded diagnosis of knee osteoarthritis. The effect of innovations that might decrease the risk of development of osteoarthritis was tested with a sensitivity analysis in which a relative risk factor was applied to the rate of development of radiographic knee osteoarthritis.

Utilities

A utility value of 0.69 was assumed for symptomatic osteoarthritis and a value of 0.781 was assumed for total knee arthroplasty on the basis of the work of Losina et al.[5].

Cost Estimates for Total Knee Arthroplasty and End-Stage Osteoarthritis of the Knee

Direct medical costs for osteoarthritis of the knee were obtained from Losina et al.[5]. For total knee arthroplasty, we used Medicare claims data to calculate the costs of surgery as well as post-acute care. We used 2009 Medicare inpatient claims for a 5% sample of beneficiaries to calculate the direct medical costs of total knee arthroplasty. The ICD-9 (International Classification of Diseases, Ninth Revision) diagnosis code "715.x6" was used to identify patients admitted to a hospital with a primary diagnosis of osteoarthritis of the knee. The ICD-9 procedure code "81.54" was used to identify total knee arthroplasty procedures, and codes "81.55" and "00.80" through "00.84" were used to identify revision knee arthroplasty. The direct costs in the model included Medicare payments for inpatient care, physician services, and care provided in a post-acute-care setting, such as a skilled nursing facility, hospice, home health, inpatient rehabilitation facility, or long-term-care hospital. These costs were tracked for six months after surgery, as our clinical expert panel estimated the expenses that accrued in this time period to be potentially linked to the total knee arthroplasty surgery. Additionally, the mean cost of physical therapy visits over this time period, $2016, was included as part of the rehabilitation costs associated with primary or revision total knee arthroplasty. We obtained the costs of perioperative complications and end-stage osteoarthritis for the Medicare population from Losina et al.[5] and then adjusted the costs for an all-payer population, resulting in estimates of $17,514 and $5282 per year, respectively.

Converting Medicare Costs to All-Payer Costs

Cost estimates based on Medicare payment rates may underestimate payments made by private insurers and overestimate payments made by Medicaid and self-insured and uninsured patients. To reconcile these differences, we adjusted our estimates of direct medical costs by determining payment rates for other insurers (expressed as a percentage of the Medicare rate) and then weighting the results by the national distribution of payers for treatment of anterior cruciate ligament tears. We set the payment rates for Medicaid and self-pay patients at 80% and 50% of the Medicare rate, respectively. For private insurers, we used the payment rates reported in the literature. Ginsburg estimated that, on average, private insurers paid 139% of Medicare payment rates for inpatient care nationally in 2008[12]. The same study also indicated private insurer payments as a percentage of Medicare rates for outpatient services in selected areas; these ranged from 193% in Cleveland to 368% in San Francisco. We used the median of the reported range, which is 280%, to adjust the costs of outpatient services. The Medicare Payment Advisory Committee (MedPAC) estimated that the private rate for physician services averaged 123% of the Medicare rate across all services and areas in 2003[13]. For all other patients, including those paid by Workers' Compensation, we assumed the rate to be equal to the mean of the rates of Medicare and private insurers.

Sensitivity Analyses

Duration that Knee Instability Is Symptomatic

The duration of time that knee instability is symptomatic was very influential on the preferred strategy, with either cost or cost-effectiveness as the outcome, because of its effects on both the utility values and indirect costs. In patients who experience instability after structured rehabilitation, ACL reconstruction was less costly if those symptoms lasted for 3.71 years or more. This was also the threshold at which reconstruction became a dominant treatment strategy. If the symptoms lasted for 2.05 years or more, reconstruction was the preferred cost-effective strategy.

Indirect Costs Associated with Symptomatic Instability

The sensitivity of the model to the indirect costs associated with symptomatic instability was also tested by varying the indirect costs relative to the value in the base case. In the short to intermediate term, when indirect costs were ≥65% of the value in the base case, ACL reconstruction was cost-saving to society, and when they were >22%, ACL reconstruction was cost-effective. In the long term, when indirect costs were ≥17% of the base case value, reconstruction was cost-saving. Even if indirect costs were $0, reconstruction was cost-effective in the long-term scenario.

Utility of Knee Osteoarthritis

We assumed a value of 0.69 for the utility of symptomatic knee osteoarthritis. We assumed symptomatic knee instability to have a utility of 0.71 (based on the MOON data). In the sensitivity analysis, if a utility of 0.71 rather than 0.69 was assumed for the utility of knee osteoarthritis in the long-term model, ACL reconstruction yielded 0.67 QALY more than structured rehabilitation compared with 0.72 QALY in the base case.

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TABLE E-1 Conversion Between SF-36 and FLI

FLI Point Value	SF-36 Response(s)
1, severely affected	1, limited a lot
2, moderately affected	2, limited a little
3, not affected	3, not limited at all

TABLE E-2 Conversion Between KOOS and FLI

FLI Point Value	KOOS Response(s)
1, severely affected	3, severe; or 4, extreme
2, moderately affected	1, mild; or 2, moderate
3, not affected	0, none

TABLE E-3 FLI Scores According to Age*

		Baseline		At 2 Years	
Age *(yr)*	No. of Patients	Mean†	Std. Error	Mean	Std. Error
18-39	755	0.832	0.008	0.936	0.016
40-44	115	0.777	0.008	0.916	0.016
45-49	73	0.782	0.008	0.934	0.017
50-54	44	0.738	0.008	0.894	0.017
55-59	44	0.738	0.008	0.894	0.017

*Calculated with use of the MOON database. †FLI scores were obtained during the week prior to surgery and adjusted to reflect baseline scores 6 to 12 months after injury.

TABLE E-4 Conversion Between NHIS and FLI

FLI Point Value	NHIS Response(s)
1, severely affected	Unable or very difficult
2, moderately affected	Somewhat difficult or little difficulty
3, not affected	Not difficult

TABLE E-5 Regression Models for the Effect of Knee Pain Due to Joint Injury on Economic Outcomes

Variable	Employed, N = 22,459*	Receives SSI, N = 21,867*	Income, N = 10,147†	Missed Workdays, N = 11,550†
Intercept	−4.93‡	0.61§	17,593‡	2.21
Male sex	0.53‡	−0.29‡	3721‡	−1.83‡
Age group in yr, relative to <40 yr				
40-44	0.17‡	−0.01	8330‡	1.41#
45-49	0.01	0.09	7977‡	−0.57
50-54	0.06#	0.08	8729‡	0.4
55-59	−0.27‡	0.01	8404‡	−0.77
FLI score	4.53‡	−1.93‡	23,678‡	−55.56‡
Difficulty reaching, relative to group with no difficulty				
Only a little difficult	0.43‡	0.04	716	1.21
Somewhat difficult	0.04	0	344	5.14‡
Very difficult	−0.24§	0.2#	−2520	−5.73§
Can't do at all	−0.94‡	0.01	5498	43.61‡
Has mobility difficulty due to				
Back pain	0.66‡	−0.43‡	−22,784‡	53.14‡
Joint injury	−0.1#	0.02	−276	2.32
Musculoskeletal condition	−0.21‡	0.14#	−741	2.15‡
Arthritis	−0.3‡	0.44‡	920	−8.26‡
Highest educational attainment, relative to less than high school				
High school degree	0.45‡	−1.03‡	19,873‡	−0.14
College (baccalaureate) degree	0.78‡	−2.1‡	38,713‡	−0.64
Post-baccalaureate degree	0.91‡	−2.67‡	49,668‡	−1.36

*Logistic regression. Models also included the year. †Ordinary least-squares regression. Models also included year and occupation indicators. ‡P < 0.01. §P < 0.05. #P < 0.10.

TABLE E-6 Total Knee Arthroplasty Patient Responses from an Orthopaedic Practice (N = 73)*

Questions	Pre-Surgery Responses *(%)*		Post-Surgery Responses *(%)*	
	Full Benefit	Limited Benefit	Full Benefit	Limited Benefit
Walk a quarter of a mile	48	52	90	10
Walk up 10 steps	64	36	92	8
Sit for about 2 hr	85	14	100	0
Reach up over your head	96	4	99	1
Stand or be on your feet for about 2 hr	49	51	81	19
Stoop, bend, or kneel	33	67	75	25
Lift or carry 10 lb	74	26	93	7
Push or pull large objects (e.g., chair)	63	37	89	11

*All differences between mean pre-surgery and post-surgery scores were significant at the p < 0.001 level. Some response percentages may not add up to 100% because of rounding.

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TABLE E-7 Annual SSI Disability Payments

Age *(yr)*	Mean SSI Payment
18-39	$8928
40-44	$11,558
45-49	$15,135
50-54	$15,583
55-59	$14,291
60-64	$17,044
65-69	$12,129
≥70	$12,833

TABLE E-8 Costs of Remaining at Baseline Functional Level Compared with Undergoing ACL Reconstruction*

	Age Group *(yr)*				
Indirect Cost Category	18-39	40-44	45-49	50-54	55-59
Income	−$8871	−$12,896	−$14,363	−$14,835	−$14,636
Missed work days	−$2565	−$3549	−$4021	−$3839	−$3661
Disability payments	$0	−$175	−$269	−$302	−$261
Total savings	−$11,436	−$16,620	−$18,654	−$18,976	−$18,558
Lost income recovering from surgery	$4374	$4622	$4305	$3963	$3273

*Remaining at baseline functional level assumes that patients received nonsurgical treatment (rehabilitation only).