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Epidemiology of Anterior Cruciate Ligament Reconstruction

Trends, Readmissions, and Subsequent Knee Surgery

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Background: Anterior cruciate ligament reconstruction is widely accepted as the treatment of choice for individuals with functional instability due to anterior cruciate deficiency. There remains little information on the epidemiology of anterior cruciate ligament reconstruction with regard to adverse outcomes such as hospital readmission and subsequent knee surgery. We sought to identify the frequency of anterior cruciate ligament reconstruction, the rates of subsequent operations and readmissions, and potential predictors of these outcomes.

Methods: The Statewide Planning and Research Cooperative System (SPARCS) database, a census of all hospital admissions and ambulatory surgery in New York State, was used to identify anterior cruciate ligament reconstructions performed between 1997 and 2006. Patients with concomitant pathological conditions of the knee were included. The patients were tracked for hospital readmission within ninety days after the surgery and for subsequent surgery on either knee within one year. The risks of these outcomes were modeled with use of age, sex, comorbidity, hospital and surgeon volume, and inpatient or outpatient surgery as potential risk factors.

Results: We identified 70,547 anterior cruciate ligament reconstructions, with an increase from 6178 in 1997 to 7507 in 2006. Readmission within ninety days after the surgery was infrequent (a 2.3% rate), but subsequent surgery on either knee within one year was much more common (a 6.5% rate). Patients were at increased risk for readmission within ninety days if they were over forty years of age, sicker (e.g., had a preexisting comorbidity), male, and operated on by a lower-volume surgeon. Predictors of subsequent knee surgery included being female, having concomitant knee surgery, and being operated on by a lower-volume surgeon. Predictors of a subsequent anterior cruciate ligament reconstruction included an age of less than forty years, concomitant meniscectomy or other knee surgery, and surgery in a lower-volume hospital.

Conclusions: The rate of anterior cruciate ligament reconstruction has increased in frequency. Also, while anterior cruciate ligament reconstruction appears to be a safe procedure, the risk of a subsequent operation on either knee is increased among younger patients and those treated by a lower-volume surgeon or at a lower-volume hospital.

Level of Evidence: Prognostic Level II. See Instructions to Authors for a complete description of levels of evidence.

Anterior cruciate ligament injury is a common athletic injury and one of the most commonly treated conditions of the knee¹. Estimated rates of anterior cruciate ligament reconstructions performed per year in the United States range widely from 60,000 to 175,000^{2,3}. The literature on anterior cruciate ligament reconstruction has focused primarily

on individual practice patterns, choice of graft type, surgical approach, and other technical aspects of the procedure. Studies of outcomes and safety have largely focused on smaller cohorts of patients treated by individual surgeons or surgical practice groups. The frequencies of anterior cruciate ligament reconstruction, hospital readmission after the surgery, and subse-

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quent knee surgery in a population-based setting have not been well established⁴⁻⁸. One notable exception was a study of soldiers in the U.S. Army by Dunn et al., who identified predictors of reoperations, particularly cartilage and meniscal surgery⁹.

The aim of the present investigation was to determine the frequency of anterior cruciate ligament reconstruction and to identify factors affecting the frequency of hospital readmission within ninety days, with a specific focus on surgeon and hospital volume. We were also interested in exploring risk factors for subsequent operations on either knee following anterior cruciate ligament reconstruction.

Materials and Methods

The Statewide Planning and Research Cooperative System (SPARCS) database from the New York State Department of Health, a census of all hospital admissions and ambulatory surgery procedures within the state, was used to identify primary anterior cruciate ligament reconstructions performed in both inpatients and outpatients in the state of New York. SPARCS has been operational since 1982 and provides more than twenty years of hospital discharge data for New York State. However, unique patient identifiers have not been available until recently. Therefore, this study was restricted to SPARCS records for the years 1997 to 2006.

The unique patient identifiers were used to track all patients who had undergone primary anterior cruciate ligament reconstruction in order to identify (1) hospital readmissions within ninety days after the surgery, (2) subsequent operations on either knee within one year, and (3) subsequent anterior cruciate ligament reconstructions on either knee within one year. Isolated anterior cruciate ligament reconstruction was identified by ICD-9-CM (International Classification of Diseases, Ninth Revision, Clinical Modification) code 81.45 for inpatients or CPT-4 (Current Procedural Terminology, Fourth Revision) code 27407 (open) or 29888 (arthroscopic) for outpatients. Combined anterior cruciate ligament and collateral ligament reconstruction was coded as ICD-9-CM 81.43 for inpatients or CPT-4 27409, 27427, 27428, or 27429 for outpatients.

The ICD-9-CM code 81.45 is defined as “cruciate ligament repair” and does not differentiate between anterior and posterior cruciate ligament reconstructions. Fortunately, the SPARCS outpatient file includes both ICD-9-CM and CPT-4 codes, and there are separate CPT-4 codes for anterior and posterior reconstructions. In this database, 99.3% of all outpatient “cruciate ligament repair” procedures were anterior cruciate ligament reconstructions, suggesting that misidentification of a posterior cruciate ligament reconstruction as an anterior cruciate ligament reconstruction was rare and applied only to inpatient cases, which over the course of the study became an increasingly smaller percentage of the total population (18% of all cases, but <5% by 2006).

Concomitant knee procedures were recorded separately. “Meniscus procedure” (e.g., meniscal excision or repair) was coded separately, whereas all other concomitant procedures were combined into the category of “other concomitant knee

TABLE I Patient Demographics

Variable	No.
Reconstructions	70,547
Hospitals	263
Surgeons	1513
Age* (yr)	31.5 ± 12.0
Sex	
Male	44,172 (62.6%)
Female	26,352 (37.4%)
Isolated anterior cruciate ligament reconstruction	26,342 (37.3%)
Anterior cruciate ligament reconstruction with concomitant procedure	
With meniscal procedure	22,477 (31.9%)
With meniscal procedure and another procedure	13,208 (18.7%)
Without meniscal procedure, but with another procedure	8520 (12.1%)
Comorbidities	
0	68,693 (97.4%)
1	1791 (2.5%)
2 to 7	63 (0.1%)
Inpatient surgery	13,110 (18.6%)
Outpatient surgery	57,437 (81.4%)
Primary reimbursement	
Private insurance	29,382 (41.6%)
HMO	22,381 (31.7%)
Workers' Compensation	8010 (11.4%)
All government	4321 (6.1%)
Self-pay	2277 (3.2%)
Other source	4176 (5.9%)
Surgical volume in previous 12 mo	
<6 (low)	15,315 (21.7%)
6 to 51 (mid)	42,438 (60.2%)
≥52 (high)	12,794 (18.1%)
Hospital volume in previous 12 mo	
<24 (low)	11,162 (15.8%)
24 to 124 (mid)	35,239 (50.0%)
≥125 (high)	24,146 (34.2%)

*The value is given as the mean and standard deviation.

surgery.” Knee arthroscopy was not included as a concomitant procedure because a code for diagnostic arthroscopy without differentiation for débridement or meniscal or cartilage procedures probably does not represent a procedure that was performed in addition to the anterior cruciate ligament reconstruction. Concomitant knee procedures at the time of the index surgery were considered to represent comorbid knee conditions and were evaluated as potential risk factors for readmission or subsequent knee surgery. Surgical codes were

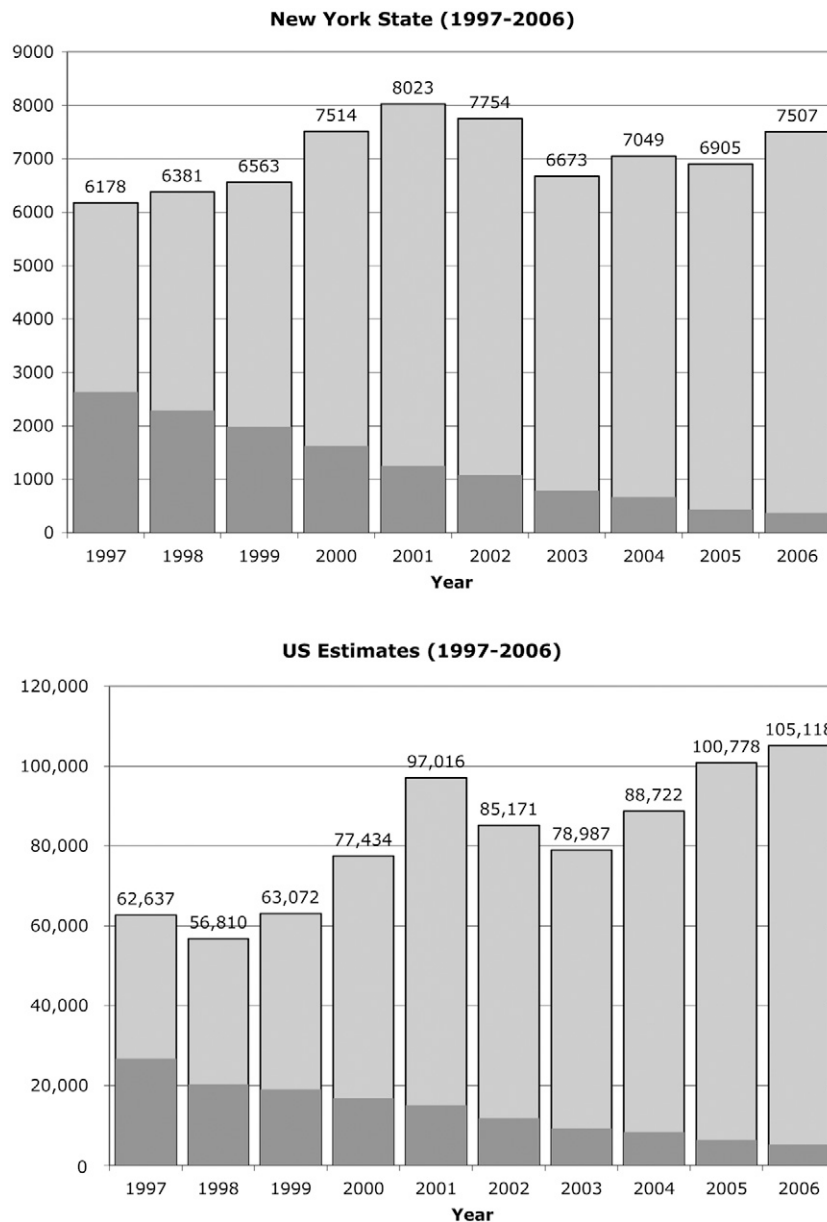


Fig. 1
Frequency of anterior cruciate ligament reconstruction in New York State and national estimates. The dark gray represents index anterior cruciate ligament reconstructions performed in an inpatient setting. The light gray represents index anterior cruciate ligament reconstructions performed in an outpatient setting.

used rather than diagnostic codes because reimbursement is driven more by procedures than by diagnoses so we believe that this coding is more likely to be accurate.

Of note, the codes for forty-five patients indicated that they had had a concomitant total knee arthroplasty (ICD-9-CM 81.54 or 81.55). Thirteen were identified as outpatients with a primary diagnosis code for either a cruciate ligament rupture or a meniscal tear and they were retained in the study. The other thirty-two were inpatients with a primary diagnosis of knee osteoarthritis, and they were excluded.

The same codes used to identify index anterior cruciate ligament reconstructions were used to identify subsequent anterior cruciate ligament reconstructions (with the surgery done in the same patient at a later date) because there was no code for revision anterior cruciate ligament surgery in either coding system. "Subsequent knee surgery" done on an inpatient basis was identified with use of all possible ICD-9-CM codes relating to knee surgery during a subsequent inpatient admission. "Subsequent knee surgery" done on an outpatient basis was identified with use of all possible CPT-4 codes

relating to knee surgery during a subsequent ambulatory surgery visit. These procedures are described as “subsequent knee surgery” rather than as “revision surgery” or “a reoperation” because the ICD-9-CM coding system lacks a laterality indicator and these indicators are used infrequently with the CPT-4 system; thus, we could not know which knee was operated on during either the first or the second procedure. Unlike “concomitant procedures,” “subsequent knee surgery” does include undifferentiated knee arthroscopy.

A modifier code identifying the laterality of procedures (left or right) is available in the CPT-4 system. Unfortunately, a laterality indicator was used for only 27.2% of the outpatient index anterior cruciate ligament reconstructions in the SPARCS database. Just 244 of these matched to a subsequent anterior cruciate ligament reconstruction, and 139 (57%) of these subsequent procedures were on the same side as the index procedure and 105 were on the contralateral side. This finding confirms previous research, which has demonstrated that half of all subsequent anterior cruciate ligament reconstructions done within two years involve the contralateral knee^{10,11}. For the purposes of this study, we used the category “subsequent anterior cruciate ligament reconstructions” of either knee rather than “revision anterior cruciate ligament reconstructions.”

Information about the mechanism of injury, the duration of symptoms, or the severity of cartilage or meniscal damage was not available as a result of the administrative nature of the database. However, data on patient age and sex, insurance status, year of surgery, and comorbid conditions (e.g., a history of myocardial infarction or liver disease) were available. The Deyo modification of the Charlson Comorbidity Index was used to identify comorbidities^{12,13}.

Hospital identification numbers and physician license numbers are available in the SPARCS database for each inpatient admission or ambulatory surgery case. The hospital identification number was used to calculate the hospital’s yearly volume of anterior cruciate ligament reconstructions in the twelve months prior to the index surgery. Surgeon volume was calculated for the twelve months prior to the month of the index surgery.

Hospital and surgeon volume were categorized as high, mid, or low. Low-volume hospitals were defined as those that handled fewer than twenty-four cases per year (i.e., fewer than two per month), while high-volume hospitals were defined as those that handled 125 or more cases annually (i.e., at least one every other day on a 250-day work-year calendar [52 weeks × 5 days – 10 federal holidays = 250 days]). Hospitals that handled between twenty-four and 125 cases per year were categorized as mid-volume hospitals. Low-volume surgeons were defined as those who performed fewer than six operations per year (i.e., fewer than one every two months), while high-volume surgeons were those who performed fifty-two or more operations per year (i.e., at least one per week). Surgeons who performed between six and fifty-one operations per year were categorized as “mid-volume” surgeons.

Of note, one orthopaedic surgeon performed more than twice as many anterior cruciate ligament reconstructions as any other surgeon in New York State during the time period eval-

Outcome	No.
Readmission within 90 days	1596 (2.3%)
Subsequent anterior cruciate ligament reconstruction within 1 yr	1318 (1.9%)
Subsequent knee surgery within 1 yr	4595 (6.5%)

uated; that surgeon performed >3% of the reconstructions done in the state. Because we were concerned about potential miscoding, we excluded these data from the inferential analyses.

Descriptive statistics consisted of means and standard deviations for continuous variables and frequency counts and percentages for discrete variables. Rates of readmission within ninety days and subsequent surgery within one year were calculated per 100 index cases.

National estimates of anterior cruciate ligament reconstruction rates were extrapolated with use of data from the Healthcare Cost and Utilization Project National Inpatient Sample (HCUP-NIS), which provides estimates of all hospitalizations in the United States¹⁴. The formula used for this calculation for each year was the NY-SPARCS inpatient-to-outpatient ratio divided by the estimate of inpatient anterior cruciate ligament reconstructions according to HCUP-NIS. For example, in 2006, inpatient admissions represented 4.9% of the anterior cruciate ligament reconstructions in the SPARCS database and there were 5167 anterior cruciate ligament reconstructions in the HCUP-NIS file. These numbers extrapolate to 105,118 anterior cruciate ligament reconstructions nationally in 2006.

Multivariate modeling was performed with use of a generalized estimating equation, accounting for clustering by surgeon with regard to case mix. The generalized estimating equation models were used to calculate odds ratios, 95% confidence intervals, and p values. These models were developed for readmission within ninety days after the index operation, subsequent knee surgery within one year, and subsequent anterior cruciate ligament reconstruction within one year. Models included age (categorized as less than twenty, twenty to twenty-nine, thirty to thirty-nine, or forty or more years), sex, comorbidity index, concomitant meniscectomy, other concomitant knee surgery, inpatient or outpatient surgery, hospital volume, and surgeon volume.

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Results

A total of 70,547 anterior cruciate ligament reconstructions were performed between 1997 and 2006 in New York State

TABLE III Predictors of Outcomes with Use of Generalized Estimating Equation Models

	Subsequent Anterior Cruciate Ligament Reconstruction within 1 Yr		Subsequent Knee Surgery within 1 Yr		Readmission within 90 Days	
	Odds Ratio (95% Confidence Interval)	P Value	Odds Ratio (95% Confidence Interval)	P Value	Odds Ratio (95% Confidence Interval)	P Value
Patient characteristics						
Age		<0.001		0.970		<0.001
<20 yr	1.82 (1.54, 2.15)		0.94 (0.74, 1.20)		0.46 (0.39, 0.54)	
20 to 29 yr	1.43 (1.20, 1.69)		0.90 (0.70, 1.14)		0.60 (0.52, 0.69)	
30 to 39 yr	1.19 (1.00, 1.41)		0.94 (0.77, 1.14)		0.82 (0.72, 0.93)	
≥40 yr	Reference		Reference		Reference	
Female	1.03 (0.92, 1.16)	0.603	1.18 (1.05, 1.33)	0.007	0.84 (0.75, 0.94)	0.002
Comorbidity index						
0	Reference		Reference		Reference	<0.001
1	1.31 (0.95, 1.80)	0.098	0.93 (0.63, 1.37)	0.916	2.05 (1.64, 2.57)	
2 to 7	0.94 (0.13, 6.89)	0.954	1.05 (0.42, 2.65)	0.714	3.74 (1.66, 8.45)	
Concomitant meniscectomy	1.23 (1.10, 1.38)	<0.001	1.05 (0.95, 1.16)	0.380	0.94 (0.85, 1.05)	0.262
Other concomitant knee surgery	1.26 (1.11, 1.42)	<0.001	1.34 (1.14, 1.58)	<0.001	1.17 (1.05, 1.31)	0.005
Hospital characteristics						
Inpatient at baseline	0.82 (0.70, 0.96)	0.012	1.41 (1.26, 1.59)	<0.001	1.91 (1.70, 2.14)	<0.001
Surgeon volume		0.175		0.006		<0.001
<6 (low)	1.12 (0.90, 1.39)		1.22 (1.01, 1.48)		1.44 (1.19, 1.75)	
6 to 51 (mid)	1.01 (0.83, 1.22)		1.19 (1.01, 1.41)		1.18 (0.99, 1.39)	
≥52 (high)	Reference		Reference		Reference	
Hospital volume		<0.001		0.551		<0.001
<24 (low)	1.53 (1.27, 1.85)		1.04 (0.92, 1.17)		1.32 (1.12, 1.55)	
24 to 124 (mid)	1.32 (1.14, 1.54)		1.02 (0.93, 1.12)		1.30 (1.14, 1.48)	
≥125 (high)	Reference		Reference		Reference	

(Table I). These were carried out at 263 distinct medical centers by 1513 surgeons. Just 37.3% of these procedures were isolated anterior cruciate ligament reconstructions, >50% involved a concomitant meniscal procedure, and >30% involved another concomitant knee procedure. There was a strong trend toward ambulatory surgery over the course of the study, with the rate of outpatient procedures increasing from 57.3% in 1997 to 95.1% in 2006. This coincided with a 21.5% increase in the frequency of anterior cruciate ligament reconstruction, from 6178 in 1997 to 7507 in 2006 (Fig. 1). We extrapolated these frequencies to represent between 56,810 (1998) and 105,118 (2006) anterior cruciate ligament reconstructions performed annually in the United States (Fig. 1).

The frequency of readmission within ninety days was 2.3% (n = 1596) (Table II). The frequency of subsequent surgery on either knee within one year was 6.5% (n = 4595), whereas the frequency of a subsequent anterior cruciate ligament reconstruction on either knee within one year was substantially lower (1.9%; n = 1318).

Of those readmitted within ninety days, 77.0% were readmitted because of a definite medical complication (e.g., infection) or surgical complication (e.g., stiffness of the knee

joint). Eight percent were readmitted for reasons possibly related to the index admission (e.g., acute myocardial infarction); 9.9%, for rehabilitation; and 5.0%, for medical or surgical reasons thought to be unrelated to the index anterior cruciate ligament reconstruction (e.g., acute appendicitis). Twenty-eight percent of these readmitted patients underwent subsequent knee surgery at the time, primarily for lysis of adhesions (28.6%) or another anterior cruciate ligament reconstruction (21.6%).

Of those who underwent a subsequent operation on either knee within one year, 28.7% underwent another anterior cruciate ligament reconstruction, 28.0% underwent lysis of adhesions, 24.5% underwent a meniscectomy, and 18.8% had another knee procedure. The reason for the subsequent knee surgery was infection in 11.8% of the cases; a pathological patellar condition in 1.6%; and a variety of indications, including knee pain and complications from previous surgery, in 5.4%.

Patient-based predictors of readmission within ninety days (Table III) were age (patients younger than forty had a substantially decreased risk of readmission; p < 0.001), male sex (odds ratio, 1.19 [inverted from the value in Table III

showing the odds ratio for “female”]; $p = 0.002$), a higher comorbidity index (odds ratio, 2.05 for a comorbidity index of 1 and 3.74 for an index of >1 ; $p < 0.001$), and other concomitant knee surgery (odds ratio, 1.17; $p = 0.005$). Hospital-based predictors of readmission were an index inpatient operation (odds ratio, 1.91; $p < 0.001$), a hospital volume of fewer than 125 cases per year, and a surgeon volume of fewer than six cases per year (odds ratio, 1.44; $p < 0.001$).

The only patient-based risk factors for subsequent surgery on either knee within one year (Table III) were female sex (odds ratio, 1.18; $p = 0.007$) and other concomitant knee surgery (odds ratio, 1.34; $p < 0.001$). An index inpatient operation (odds ratio, 1.41; $p < 0.001$) and a surgeon volume of fewer than fifty-two cases per year were significant hospital-based predictors. Hospital volume was not a significant predictor of this outcome.

Patient-based predictors of a subsequent anterior cruciate ligament reconstruction on either knee within one year (Table III) were an age younger than forty (patients in this age group, and particularly those younger than twenty, had a substantially increased likelihood of a subsequent anterior cruciate ligament procedure compared with patients forty years of age or older [odds ratio, 1.82 for those younger than twenty; $p < 0.001$]), concomitant meniscectomy (odds ratio, 1.23; $p < 0.001$), and other concomitant knee surgery (odds ratio, 1.26; $p < 0.001$). Other predictors were treatment on an outpatient basis (odds ratio, 1.22 [inverted from the value in Table III showing the odds ratio for “inpatient at baseline”]; $p = 0.012$) and treatment at a hospital with a yearly volume of fewer than 125 cases (these patients, and particularly those treated at a hospital with a yearly volume of fewer than twenty-four cases, had a higher likelihood of having a subsequent anterior cruciate ligament reconstruction within one year [odds ratio for those treated at a hospital with a yearly volume of fewer than twenty-four cases, 1.53; $p < 0.001$]).

Discussion

This research represents an attempt to describe and quantify the epidemiology of anterior cruciate ligament reconstruction and its outcomes. Our results showed that, from 1997 to 2006, the frequency of anterior cruciate ligament reconstructions increased by 21.5% in New York State and by as much as 67.8% nationally if the extrapolated frequency figures are accurate. While our estimation of the U.S. frequency of anterior cruciate ligament reconstruction (Fig. 1) is highly speculative and is based on several broad assumptions, we present it here because other estimates of the frequency of anterior cruciate ligament reconstruction have varied greatly^{2,3}.

This upward trend in the frequency of anterior cruciate ligament reconstruction may represent an increase in the frequency of anterior cruciate ligament injury or in the likelihood of anterior cruciate ligament reconstruction should an injury occur, or both. A similar trend toward more frequent operative management of a torn anterior cruciate ligament was observed by Dunn et al.⁹; however, variation in the management of these

injuries persists⁵. In the same time period as this study, the population of New York State has increased by $<3\%$, according to data from the U.S. Census Bureau intercensal estimates for 1997 and 2006, suggesting that this increase in the frequency of anterior cruciate ligament reconstruction does not represent an increase in the size of the population at risk. Apparently, this increase also does not reflect an increase in the number of surgeons performing anterior cruciate ligament reconstructions in New York State. In 1997, the first year of the study, 680 different surgeons performed anterior cruciate ligament reconstructions. In 2006, the final year of the study, 684 surgeons performed anterior cruciate ligament reconstructions, suggesting that there has not been an increase in demand due to an increased number of providers.

Of note, just over 37% of all anterior cruciate ligament reconstructions were isolated procedures (without concomitant surgery). More than half (50.6%) of all cases included a concomitant meniscal procedure and 30.9% included another concomitant knee procedure, findings that were similar to those in previous reports¹⁵. This has implications for studies that focus on outcomes after isolated anterior cruciate ligament reconstructions as a clear minority of all anterior cruciate ligament reconstructions are isolated procedures.

The rate of subsequent anterior cruciate ligament reconstructions on either knee within one year was found to be 1.9%, which is a third of the incidence found by Wright et al. in the Multicenter Orthopaedic Outcomes Network (MOON) study, although the MOON study was conducted over a two-year period¹¹. This discrepancy is likely explained by the fact that, while well over 90% of the patients in the MOON study were followed for two years, in the present study patients from contiguous states who had the anterior cruciate ligament reconstruction performed in New York State (4.1% of all patients in the cohort) may have had subsequent surgery outside of the state (the frequency of subsequent anterior cruciate ligament reconstruction at one year was 1.25% of admissions identifiable as non-New York State residents). Also, young people (e.g., those of college age and young professionals) tend to be more transient than older individuals, so even those who were New York State residents at the time of the index surgery may have moved elsewhere before undergoing subsequent surgery. Therefore, there was probably a systematic underestimation of the frequency of subsequent anterior cruciate ligament reconstruction and any subsequent surgery in our study.

In the current study, age was a strong predictor of readmission within ninety days, with patients forty years of age and older being readmitted more often than younger patients, independent of other factors. There was also a strong relationship between age and subsequent anterior cruciate ligament reconstruction of either knee within one year. Younger patients (those under forty years of age, but most apparently those under twenty) were more likely to undergo another anterior cruciate ligament reconstruction than were older patients (over forty years of age). We hypothesize that this may be due to younger patients having higher postoperative activity

levels, resulting in graft rupture, or perhaps to younger patients being less compliant with rehabilitation protocols and restrictions on activity. However, these factors could not be explored with use of this administrative database. In a previous study, there were no differences in the rates of either early or late complications between young patients and middle-aged patients¹⁶. In two other studies, the outcomes of older patients were similar to those of young patients¹⁷.

Several studies have shown female athletes to have a significantly higher prevalence of knee injuries, particularly anterior cruciate ligament ruptures, than male athletes^{18,19}. Our study demonstrated that females had a lower prevalence of readmission within ninety days but a higher prevalence of subsequent operations on either knee within one year. However, females did not have an increased risk of specifically needing a subsequent anterior cruciate ligament reconstruction within one year. To our knowledge, this is the first study showing the prevalence of subsequent surgery after anterior cruciate ligament reconstruction on either knee to be higher in women than in men. Further study is needed to clarify this issue.

It is known that there is substantial variation in outcomes among hospitals and individual surgeons with different case volumes^{20,21}. There have been several reports of an association between surgeon or hospital volume and the outcomes of total knee and total hip arthroplasties²²⁻²⁴. There is well-established evidence that patients treated with shoulder arthroplasty, coronary angioplasty, cardiac surgery, cancer resection, and liver transplantation by high-volume surgeons and hospitals have lower mortality rates and better outcomes than do those treated by low-volume surgeons and hospitals^{21,25-29}. Similar research for anterior cruciate ligament reconstruction has not previously been reported. We expected that patients treated by higher-volume surgeons would have lower risks of readmission and subsequent anterior cruciate ligament reconstruction because of the technical requirements of the procedure. However, while this was demonstrated for readmission and subsequent knee surgery on either knee, our study did not show the association specifically for subsequent anterior cruciate ligament reconstruction. The muted effect might be explained by surgeons with a higher operative volume being more likely to accept complicated cases for operative management and those with low volume choosing less complex cases, but this seems unlikely because our analysis included an adjustment for concomitant procedures. Another possibility is that the volume categories that were chosen were not ideal for this evaluation. However, these thresholds demonstrated a significant relationship with subsequent anterior cruciate reconstruction in our univariate evaluation (a relative risk of 1.41 for low-volume compared with high-volume categories; $p < 0.001$), although apparently much of the relationship was accounted for by the case mix (age, sex, comorbidities, and concomitant knee surgery).

Independent of the surgeon effect, hospital volume was associated with readmissions and with subsequent anterior cruciate ligament reconstruction. However, rather than a linear relationship, it appears that there is a threshold (125 or more

cases per year) above which hospitals perform anterior cruciate ligament reconstructions more safely (with a decreased rate of readmission). As was demonstrated, the effect of surgeon volume on the frequency of readmission was greater than the effect of hospital volume since anterior cruciate ligament reconstruction is a technically demanding procedure with a relatively low rate of postoperative hospitalization (82% of the patients in this study went home on the day of surgery). This effect was also demonstrated for subsequent surgery on either knee, but surprisingly it was not found specifically for subsequent anterior cruciate ligament reconstruction, which had a significant linear relationship with hospital volume but not with surgeon volume.

The rates of readmission within ninety days and of a subsequent knee operation within one year were significantly higher among patients who had undergone an index inpatient anterior cruciate ligament reconstruction than they were for patients who had undergone an index outpatient anterior cruciate ligament reconstruction. This is not surprising since patients undergoing inpatient anterior cruciate ligament reconstruction had a higher frequency of comorbidities (3.8%) compared with patients undergoing ambulatory anterior cruciate ligament reconstruction (2.3%). Previous studies have demonstrated that comorbidity is a significant predictor of an adverse outcome after total joint replacement and shoulder surgery^{30,31}.

There is no laterality indicator in the ICD-9-CM coding system, and the laterality indicator in the CPT-4 coding system was rarely recorded in this database (27% of the time in the time period of interest), so it is unknown if the subsequent operations were performed on the same knee or on the contralateral knee. Our evaluation of the subset of 244 patients who had a laterality indicator for both the index anterior cruciate ligament reconstruction and a subsequent anterior cruciate ligament reconstruction confirms previous findings that approximately half of subsequent anterior cruciate ligament reconstructions are on the contralateral knee^{10,11}. Therefore, in the current analysis of risk factors, no attempt was made to guess which procedures were ipsilateral and which were contralateral. This limitation speaks to the need for a laterality indicator in the ICD coding system and more diligent reporting of the CPT-4 modifying code by institutions in which surgery is performed on the appendicular skeleton.

As with any health outcome study based on administrative data, our study had limitations with regard to the very nature of the data. We lacked clinical information such as the mechanism of injury, operative details, complexity of the procedure, and rehabilitation protocol. More importantly, it is unknown whether the subsequent operations represented reinjury, were associated with technical failures, or represented contralateral injury. Only objective outcome measures (e.g., readmission and a subsequent operation) were investigated since patient-based outcome measures were not available. In addition, patient, surgeon, and hospital-related factors unique to New York State may not reflect the entire U.S. population, as

a result of variation among geographic regions. Ultimately, this kind of analysis of administrative data is best used to identify trends and draw broad conclusions about procedures, which can be used to generate hypotheses that are best tested in a clinical setting.

Despite these limitations, this study demonstrated, for what we believe to be the first time, that the frequency of anterior cruciate ligament surgery is increasing in the United States, that younger patients are at higher risk for a subsequent anterior cruciate ligament reconstruction on either knee within one year, and that selected outcomes are better when the procedures are performed at higher-volume hospitals and by higher-volume surgeons. Nevertheless, the primary value of these results is that they may be used to inform hypotheses that

can be evaluated in clinical research projects, which do not have the limitations of administrative data analyses. ■

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