The Relationship Between Age, Cost, and Patient Reported Outcomes in Primary ACLR: A Single Center Retrospective Study

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Objectives: To evaluate how surgical trends, costs, and outcomes for anterior cruciate ligament reconstruction (ACLR) vary with patient age.

Design: Retrospective Cohort Study

Setting: Outpatient Ambulatory Surgery Center

Patients: 587 primary ACLR patients from 2009-2016. Inclusion criteria consisted of primary ACLR, complete preoperative, and two-year post-operative patient-reported outcome (PRO) data.

Intervention: ACLR

Main Outcome Measurements: ACLR failure/re-rupture, reoperation, cost of care, Knee Injury & Osteoarthritis Outcome Score (KOOS), and Single Assessment Numeric Evaluation (SANE).

Results: Younger patients were prevalently female compared to older patients ($p<0.0001$). Graft use varied according to age, with older patients more commonly being treated with allograft ($p<0.0001$). There were equivalent rates of meniscal injuries ($p=0.0855$), but meniscal treatment differed for patients older than age 25. Older patients on average received more meniscectomies versus repairs ($p=0.0009$). Operative time was found to be lowest in patients 40 and older. Total implant, day-of-surgery, and the two-year episode of care costs were significantly higher for older patients (respectively $r=0.48$, $r=0.43$, $r=0.37$; $p<0.001$). Re-rupture rates were similar among age groups, however, younger patients underwent more reoperations ($p=0.0349$). While baseline and two-year KOOS and SANE differed across ages ($p<0.032$), two-year changes did not ($p\geq0.384$).

Conclusions: Patient characteristics, treatment techniques, costs, and PROs were found to vary according to patient age but change in PROs did not. These results provide information on how patient age and can influence value in the setting of ACLR.

Keywords: Anterior Cruciate Ligament Reconstruction, KOOS, SANE, Cost, TDABC, Value-Based Care

Level of Evidence: Level IV

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INTRODUCTION

Anterior cruciate ligament (ACL) rupture is a common injury affecting an estimated 200,000 patients a year in the United States alone.[1] Treatment with ACL reconstruction (ACLR) has been shown to be effective, with high rates of return to sport and patient satisfaction.[2] Reconstruction techniques, including graft type used, depend on multiple factors such as patient age and activity level, concomitant ligament injury, donor site morbidity, and surgeon preference. Graft options for ACLR principally include autograft and allograft. Some of the benefits of autograft include decreased cost, no risk of disease transmission, and quicker graft incorporation, while allograft use has no donor site morbidity and generally decreased operative time. These patient and surgical factors can lead to substantial effects on cost and outcomes.

The annual cost of surgical treatment of ACL rupture is estimated to be two billion dollars[3] and will likely continue to increase as incidence rates of ACLR increase, particularly among adolescents and those aged 40 and over.[1, 4] In addition to the overall cost, it is important to determine the value of these procedures. Value can be defined by outcomes achieved per dollar spent, with high-value interventions obtaining excellent outcomes with fewer dollars spent.[5] There are multiple clinical outcome measures for ACLR including both subjective and objective measures. In addition, several patient-reported outcome measures (PROMs) have been created and validated for patients with an ACL injury including the International Knee Documentation Committee (IKDC) and

Knee Injury and Osteoarthritis Outcome Score (KOOS) scores. Several studies have analyzed the economic impact of ACLR. One large systematic review concluded that early, single (endoscopic)-incision outpatient ACLR using either bone patella tendon bone (BPTB) or hamstring autograft provides relatively lower-cost treatment options with similar outcomes.[5] Another large systematic review of the cost-effectiveness of ACL treatment concluded that early ACLR is likely more cost-effective in athletes and young populations with high-activity levels; however, they acknowledge there appears to be a gap in the literature regarding procedures in children and older individuals.[6] Despite these studies, there are no reports according to the authors' knowledge that directly compare age groups regarding baseline and surgical characteristics in the context of value, cost, and PROMs.

As the incidence of ACL injuries continues to rise in tandem with a population that continues to maintain its active and athletic involvements, more age-specific ACLR information can be beneficial to physicians and patients. Additionally, with age being one of the factors used to determine the method of treatment, characterization of ACLR outcomes and cost stratified by age is important. With this in mind, the objective of this study was to characterize and compare surgical trends, costs, and outcomes for ACLR within four distinct age groups: ages 16 and under, ages 17-25, ages 26-39, and ages 40 and over. It was hypothesized that value would vary amongst cohorts as a product of cost variance generated by graft selection despite equivocal changes in PROMs over time.

METHODS

This study was granted institutional review board approval in 2022. A retrospective cohort study in design, all patients having undergone a primary ACLR were eligible for inclusion and review. Patients who had undergone ACLR between the years of 2009-2016 were enrolled in the study and analyzed. A list of patients that underwent ACL surgical intervention was compiled with the use of a Current Procedural Terminology (CPT) code denoting primary ACLR (29888). All patients were treated within a single ambulatory surgical center. Board-certified orthopaedic surgeons performed all procedures. Graft selection for ACLR was at the discretion of the operating surgeon. With all procedures conducted under a single healthcare system umbrella, consistent institutional mandated anesthesia protocols including spinal blockades and postoperative pain medication regimens were implemented.

Patients included in this analysis had magnetic resonance imaging (MRI) confirming ACL rupture. Each patient's electronic medical record was investigated for the following demographic information: age, sex, and BMI. Operative reports were audited for surgical technique implemented in repair, graft choice selection, graft fixation method, and any reporting of concomitant procedures performed during this single anesthesia event. Reporting of meniscal injury and any surgical intervention was of particular importance. The length of operative time per procedure was also extracted from the medical record of each patient. Inclusion criteria required all patients to have undergone primary reconstruction and completed a preoperative and two-year post-operative PROM. Patients undergoing non-operative management, requiring multi-ligamentous repair, and poly-trauma patients were excluded. The composite list of patients that had undergone ACLR was then divided into separate cohorts by age. There were a total of four age groups created (group 1: 16 years old and younger, group 2: ages 17 to 25 years old, group 3: ages 26 to 39 years old and group 4: age 40 and older). A patient's age was designated at the time of surgery. All variables of interest were then evaluated by age distribution.

Outcome metrics of interest included the following: ACLR failures/re-ruptures, ipsilateral knee reoperations, delta change in PROMs, and incurred cost of surgical treatment. Knee Injury & Osteoarthritis Outcome Score (KOOS) and Single Assessment Numeric Evaluation (SANE) data were the PROMs utilized to assess patient perceptions of recovery. Both metrics are validated instruments frequently employed in ACL-centric literature and had been routinely prospectively collected by this institution. Associated ACLR cost was a tabulated evaluation of institutional charge master database documentation and time-driven activity-based costing (TDABC) accounting methodology. TDABC has been verified as an approved technique to quantify the associated cost of care in several other high-volume procedures in the orthopaedic literature.[7-9] TDABC computes cost over an entire episode of care, equating to direct and indirect costs at the patient level.[7-9] This was accomplished by determining the number of individuals involved in care administration, the time spent providing care, and the cost per unit time for the delivery of care utilizing practical capacity assumption principles.[10] The same accounting strategies were executed in this study. Process mapping was instrumental in the identification of all cost-generating components of care, including providers involved and the duration of time allocated towards care.[7-9] Direct costs variables included all healthcare personnel and equipment/supplies integral to providing care while indirect cost variables constituted services indirectly vital to care delivery (department of human resources, information technology, employee benefits, hospital administration, hospital legal representation, etc).[8, 11, 12] Adopting the same practices reported in the literature,[8, 11-13] indirect cost was calculated as an estimate of 29.5% of the total direct cost of care. A practical work capacity of 80% was implemented for all involved healthcare personnel, excluding surgeons in the accounting of indirect cost at the healthcare personnel level.[8, 10, 11]

All statistical analysis was conducted with the use of Intellectus Statistics (Clearwater, FL, USA). One-way analysis of variance, chi-square, and Spearman correlation tests were conducted, evaluating based on age distribution to calculate significance. Factors influencing cost were examined with multivariable regression analysis and further scrutinized with general linear modeling to evaluate the emphasis patient age and surgical decision makings impart on the episode of cost in ACLR. Categorical data was reported with frequencies and percentages, and continuous data was reported in means and accompanying standard deviations.

Table 1: Characteristics of ACLR[a] according to age group (N=587).

Variable	16 and younger (n=128)	17-25 (n=159)	26-39 (n=158)	40 and older (n=142)	p-value
Age	14.8 ± 1.4	20.2 ± 2.5	32.2 ± 4.0	47.4 ± 5.9	-
Sex					< 0.0001
Male	26 (20.3%)	68 (42.8%)	87 (55.1%)	61 (43.0%)	-
Female	102 (79.7%)	91 (57.2%)	71 (44.9%)	81 (57.0%)	-
BMI[b]	22.9 ± 3.7	25.3 ± 4.5	27.0 ± 4.5	26.5 ± 4.0	< 0.0001
Injury Acuity					<0.0001
Acute	126 (98.4%)	158 (99.4%)	136 (86.1%)	128 (90.1%)	-
Chronic	2 (1.6%)	1 (0.6%)	22 (13.9%)	14 (9.9%)	-
Graft Type					< 0.0001
Allograft	1 (0.8%)	13 (8.2%)	53 (33.5%)	95 (66.9%)	-
Autograft	127 (99.2%)	146 (91.8%)	105 (66.5%)	47 (33.1%)	-
Patella BTB[c]	85 (66.4%)	108 (67.9%)	52 (33.0%)	22 (15.5%)	-
Hamstring	42 (32.8%)	38 (23.9%)	53 (33.5%)	25 (17.6%)	-
Meniscal Injury	62 (48.4%)	87 (54.7%)	71 (44.9%)	83 (58.5%)	0.0855
Meniscal Operation	45 (46.4%)	80 (58.4%)	59 (52.2%)	74 (62.7%)	0.0009
Meniscectomy	26 (27.7%)	53 (38.7%)	43 (37.7%)	66 (56.4%)	-
Repair	22 (23.2%)	36 (26.3%	19 (16.7%)	8 (6.8%)	-
Operative Time (min)	108.2 ± 25.0	114.7 ± 34.4	106.7 ± 31.4	95.8 ± 28.7	< 0.0001
Re-rupture	11 (8.6%)	8 (5.0%)	5 (3.2%)	7 (4.9%)	0.2330
Re-operation	22 (17.2%)	17 (10.7%)	12 (7.6%)	11 (7.7%)	0.0349

Continuous data reported as mean ± standard deviation. Categorical data reported as N/n (%). [a]ACLR = Anterior Cruciate Ligament Reconstruction, [b]BMI = Body Mass Index, [c]BTB = Bone-Tendon-Bone

Table 2. Patient reported outcomes for primary ACLR[a] patients by age group (N = 587)

Variable	16 and younger (n=128)	17-25 (n=159)	26-39 (n=158)	40 and older (n=142)	p-value
Baseline KOOS[b]	69.6 ± 13.1	67.4 ± 14.0	64.6 ± 16.6	59.6 ± 18.6	0.0010
Two-year KOOS[b]	87.9 ± 11.0	83.5 ± 13.0	82.5 ± 12.1	80.1 ± 15.9	0.0020
Two-year change in value	18.3 ± 14.6	16.2 ± 16.6	17.9 ± 15.3	20.6 ± 20.2	0.3840
Baseline SANE[c]	68.0 ± 23.7	67.1 ± 21.5	59.2 ± 23.9	61.3 ± 24.0	0.0040
Two-year SANE[c]	89.9 ± 21.5	88.5 ± 19.6	82.5 ± 24.4	85.4 ± 22.0	0.0320
Two-year change in value	21.9 ± 29.0	21.5 ± 28.7	23.3 ± 30.6	24.1 ± 30.2	0.8790

Continuous data is reported as mean ± standard deviation. [a]ACLR = Anterior Cruciate Ligament Reconstruction, [b]KOOS = Knee Injury & Osteoarthritis Outcome Score, [c]SANE = Single Assessment Numeric Evalaution

Table 3. Costs of ACLR[a] by age group (N = 587)

Variable	16 and younger (n=128)	17-25 (n=159)	26-39 (n=158)	40 and older (n=142)	p-value
Total Cost of Care	$4184.35 ± 786.84	$4258.71 ± 1079.38	$4806.99 ± 1341.88	$5606.56 ± 1306.88	< 0.0010
Day-of Surgery Cost	$2528.24 ± 427.42	$2683.98 ± 701.27	$3222.13 ± 1045.29	$3777.37 ± 995.23	< 0.0010
Implant Cost	$501.89 ± 362.10	$607.11 ± 590.48	$1207.95 ± 1016.33	$1848.08 ± 1027.55	< 0.0010
Follow-up Cost	$717.31 ± 384.35	$546.58 ± 251.81	$605.81 ± 262.06	$596.30 ± 257.90	< 0.0010

Continuous data reported as mean ± standard deviation. [a]ACLR = Anterior Cruciate Ligament Reconstruction

RESULTS

After applying inclusion and exclusion criteria, a total of 587 patients were analyzed. Table 1 illustrates the distribution of patients by the four established age cohorts. The mean age across the entire study was 28.8 ± 12.9. Men accounted for 242 of the patient population. There was significant variance between age groupings regarding sex and BMI distribution. Females had an approximately four to one higher rate of ACLR in the 16 years old and younger group. BPTB autograft was the most frequently utilized tissue graft for ligament reconstruction. A total of 31 patients sustained an ACLR failure/re-rupture. 62 patients underwent a reoperation during the duration of the study period. 63% of these patients were within the younger than 26 years of age group.

Approximately 13.6% of injuries in patients aged 26 and older were chronic injuries (p<0.0001). Graft use differed according to age, with older patients exhibiting a higher rate of allograft use (p<0.0001). Re-rupture rates were equivalent among age groups. Re-operations were significantly higher in patients aged 16 and under (p=0.0349). Despite equivalent rates of meniscal injuries (p=0.0855), meniscal treatment differed with patients older than age 25, particularly those aged 40 and older. Patients older than 40 underwent a higher rate of meniscectomies compared to meniscal repair procedures (p=0.0009). Patients aged 40 and over exhibited the lowest operative time.

Pre-operative and postoperative KOOS values by age group from oldest to youngest were group 1: 69.6 ± 13.1 vs. 87.9 ± 11.0, group 2: 67.4 ± 14.0 vs. 83.5 ± 13.0, group 3: 64.6 ± 16.6 vs. 82.5 ± 12.1, group 4: 59.6 ± 18.6 vs. 80.1 ± 15.9 (Table 2). The variance in PRO value amongst each group was statistically significant (p<0.032). Pre-operative and postoperative SANE values by age group were group 1: 68.0 ± 23.7 vs. 89.9 ± 21.5, group 2: 67.1 ± 21.5 vs. 88.5 ± 19.6, group 3: 59.2 ± 23.9 vs. 82.5 ± 24.4, group 4: 61.3 ± 24.0 vs. 85.4 ± 22.0. The change from baseline to the two-year postoperative measurement did not achieve significance across age groups (p=0.0349).

The total cost of the two-year episode of care by age group from youngest to oldest was $4184.35 ± 786.84, $4258.71 ± 1079.38, $4806.99 ± 1341.88, $5606.56 ± 1306.88, respectively (Table 3). Total cost, day of surgery cost, implant cost, and follow-up cost were all found to significantly vary by age group (p<0.0010) (Figure 1). Graft choice was shown to influence the total cost of care (Figure 2). Patients 40 and older were found to exhibit the highest total cost of care, day of surgery cost, and implant cost compared to the other groups while the youngest age group had the highest follow-up care costs (p<0.0010).

DISCUSSION

ACLR is one of the most performed orthopaedic surgeries in the country and a broad demographic of patients are requesting these elective procedures with goals of returning to preinjury activities. Although KOOS and SANE baseline and two-year follow-up outcomes varied statistically amongst age groups (P-values: 0.0010, 0.0020; 0.0040, 0.0320 respectively), there was no significant variance regarding

Figure 1: ACLR costs stratified by age group and cost type. Currency is in US dollars.

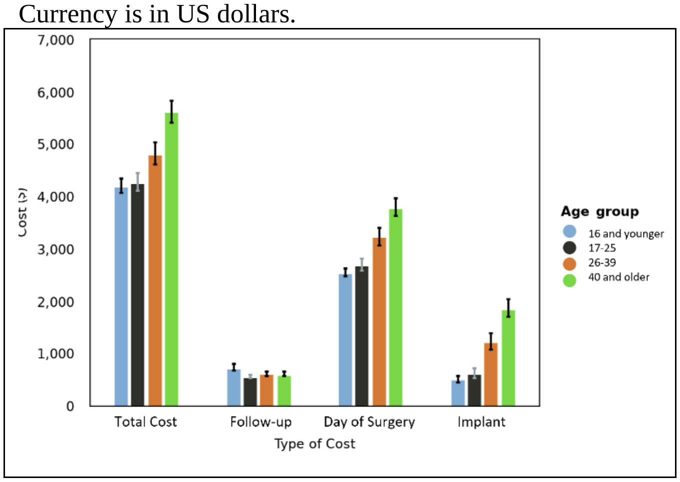
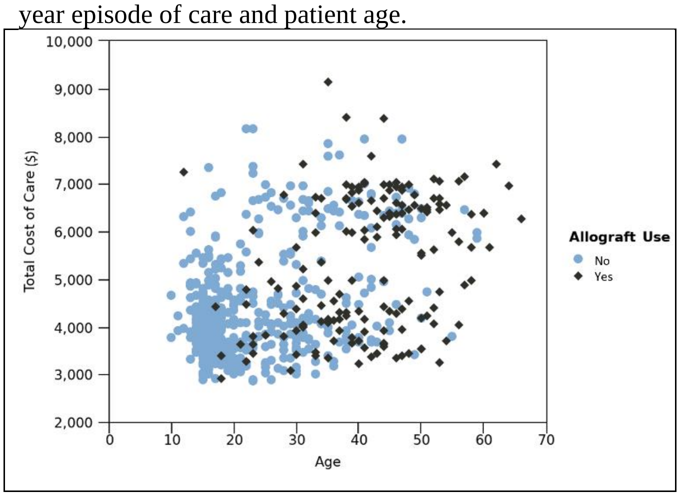


Figure 2: The relationship between the total cost of the 2-year episode of care and patient age.



the two-year change in both PROMs across groups (P-value: 0.3840; 0.8790). Trends in surgical decisions were apparent across age divides, with a higher incidence of allograft and meniscectomy utilization in the management strategies for patients older than 40 years old. This corresponded to an overall higher total episode of cost (P-value: <0.0010) in this age group compared to the other age cohorts despite all having similar PROMs results and no increased risk of re-rupture and/or reoperation.

ACL ruptures are debilitating injuries that result in knee instability and limitations to one's ability to engage in certain athletic activities. Graft selection for ACLR has been a much debated and scrutinized topic throughout the orthopaedic community.[1-3, 14] Autograft is generally recommended for younger patients as the odds of an ipsilateral retear have been reported to be 5 times greater for reconstructions utilizing allograft rather than BPTB.[15] Several studies have examined the impact graft selection potentiates outcomes following ACLR in an older population.[16-21] Barber et al. reported the absence of a correlation between re-rupture rates and graft choice in their study.[14] Similar findings have been reaffirmed in other studies examining the relationship between graft choice, patient age, and re-rupture/failure rates.[16, 19] In patients aged 40 and over, the absolute risk of retear was found to be 2% higher for allograft versus autograft.[4] The incidence of ACL re-rupture did not statistically vary in this analysis (P-value= 0.233). Comparable PROMs between younger and older cohorts of patients undergoing ACLR has been documented in the literature.[16] Cinque et al. founds similar Tegner activity scale, Lysholm, IKDC, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Short Form–12 (SF-12) mental health component summary (MCS), and SF-12 physical component summary (PCS) between their two age cohorts.[16] No statistical significance was noted amongst age groups based on two-year change in PROMs in our study; an indication that irrelevant of age, patients undergoing ACLR perceive a positive outcome in reflection of their recovery.

Value in healthcare continues to be a critical topic of discussion in how best to optimize care, dictate reimbursement, and the allocation of healthcare funding.

Multiple orthopaedic studies have investigated value, by examining the ratio of change in patient perception of recovery over an interval of time to the total incurred cost of care.[5, 7, 9, 22] Autograft harvesting for ACLR has established itself as the gold standard option for the reduction of cost and the achievement of improvements in PROMs at follow up intervals in an active patient population.[5-7, 22] This value principle has been generally accepted at a macroscopic level while seemingly ignored or overlooked on a microscopic level. As previously documented, a clear distinction in treatment strategies was found to exist in the operative management of ACL injuries based on age alone within this study. In our analysis, patients over the age of 40 predominately received allograft ACLRs. This directly facilitates an increase in the cost of care without a correlating increase in value as reflected by an improvement in PROMs or reduction in post-operative complications (re-rupture/failure/reoperation).

Advancements in medical innovation will continue to alter our perceptions of optimal care. The genesis of new treatments, accompanied by the refined deployment of established care principles, will facilitate the acquisition of better outcomes. ACLR and other high-volume procedures provide a platform for surgical efficacy and resource utilization evaluation. Surgeons weld immense power within the operating room. Each decision impacts patient outcomes and the allocation of funds. Orthopaedic surgeons generate a significant portion of hospital revenue, while simultaneously contributing to considerable healthcare costs. These costs are often the direct result of clinical/surgical decision-making. Older patients disproportionately received allograft ACLRs without an associated elevation in outcomes nor a reduction in complications to offset the drastic increase in cost in our study. The current dogmatic approach to ACLR accounting for patient age appears void of value assessment and an opportunity exists for correction.

This study contained several strengths and limitations. Patients were all treated within a single ambulatory surgery center in a large metropolitan area. Representing a diverse demographic, the outcomes of this study can be considered applicable to the general population. Meniscal injuries and associated treatment data were collected in addition to ACLR management for each patient. This study protocol further illuminated the apparent variations in clinical decision-making that exist in the management of similar injuries across patient age ranges. The two-year follow-up window was a strength and a weakness. At two years post-surgical intervention, most patients are expected to no longer be limited by restrictions and have resumed most desired activities. Evaluation of PROMs at a time point where most patients have achieved recovery, facilitating return to sport and activities, provides a valued patient-centric assessment of postoperative recovery. On the contrary, at two years of follow-up, it is possible that patients are self-imposing activity restrictions out of fear of re-injury. The retrospective study design did not allow for the incorporation of patient survey information pertaining to current activity at two-year follow-up. Reinjury and reoperating data thus may be underrepresented in this study.

CONCLUSION

An active and aging population is contributing to an already increasing number of ACLR performed annually. The restoration of knee stability and the ability to re-engage in athletic activities is valued across age divides as evident based on changes in PROMs. Graft selection patterns, while found to promote a higher cost of care for older patients undergoing ACLR, did not generate a reciprocal increase in patient-perceived value. Opportunity exists for providers to modify operative decision-making, resulting in cost savings while maintaining patient-centric value in the management of ACLR injuries in an older patient population.

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