Effect of Operative Time on Short-Term Adverse Events After Isolated Anterior Cruciate Ligament Reconstruction

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Background: A longer operative time has been previously recognized as a risk factor for short-term complications after various orthopaedic procedures; however, it has yet to be investigated as an independent risk factor for postoperative complications after anterior cruciate ligament (ACL) reconstruction.

Purpose: To identify whether a longer operative time in ACL reconstruction is an independent risk factor for the development of postoperative complications, hospital readmissions, or an extended length of stay within 30 days of the index procedure.

Study Design: Descriptive epidemiology study.

Methods: Patients undergoing ACL reconstruction between 2005 and 2016 were identified using the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) database. Cases with concomitant procedures were excluded from the analysis. We evaluated the association between operative time and preoperative variables such as patient age, sex, body mass index, comorbidities, and procedure. Correlations between adverse events and operative time, while controlling for the above preoperative variables, were calculated using multivariate Poisson regression with robust error variance.

Results: A total of 14,159 procedures were included in this investigation. The mean patient age was 32.6 ± 10.8 years, the mean body mass index was 27.7 ± 6.5 kg/m^2, and the mean operative time was 89.7 ± 28.6 minutes. Patients who were between the ages of 18 and 30 years (mean operative time, 95.1 ± 27.8 minutes; relative risk [RR], 17.7; $P < .001$), male (mean operative time, 91.9 ± 28.3 minutes; RR, 4.7; $P < .001$), and nondiabetic (mean operative time, 89.8 ± 28.6 minutes; RR, 7.1; $P = .011$) were associated with a longer operative duration. The overall complication rate was 1.1%. After adjusting for demographic characteristics and procedures, 15-minute incremental increases in operative duration were associated with an increased risk of deep vein thrombosis (RR, 1.12; $P = .042$), surgical site infections (RR, 1.21; $P = .001$), and sepsis (RR, 1.66; $P < .001$) as well as increased readmission rates (RR, 1.23; $P = .001$) and an extended length of stay (RR, 1.18; $P = .008$).

Conclusion: While the overall adverse risk rate after ACL reconstruction remains low, marginal increases in operative time are associated with an increased risk of adverse events such as deep vein thrombosis, surgical site infections, sepsis, an extended length of stay, and readmissions. Thus, the operating physician and surgical staff should make all efforts to coordinate and prepare for each case to maximize surgical efficiency.

Keywords: anterior cruciate ligament; operative time; complications; deep vein thrombosis; surgical site infection

Anterior cruciate ligament (ACL) ruptures are among the most common traumatic knee injuries experienced by athletes.[47] Their management typically includes operative reconstruction to restore knee stability and function with the intention of enabling athletes to return to their preinjury functionality.[49] Because of improvements in anesthesia techniques[8] and postoperative rehabilitation protocols,[7] ACL reconstruction is commonly performed in outpatient ambulatory surgical centers.[38] Outpatient ACL reconstruction is more efficient and results in lesser economic costs to providers while yielding equivalent or improved patient satisfaction, strength, and knee function.[21,43] The 2013 changes to health care regulations in the United States mandated that providers receive decreased compensation or reimbursement in cases where patients were readmitted within 30 days of initial discharge.[12,19,33] As such, it is important to identify risk factors that may contribute to adverse events in the immediate postoperative period.

ACL reconstruction is a common procedure that yields good functional outcomes regardless of the technique or

The Orthopaedic Journal of Sports Medicine, 7(2), 2325967118825453
DOI: 10.1177/2325967118825453

graft used.[4,13,25,54] However, risk factors such as ethnicity, history of bleeding disorders, or use of epidural anesthesia have been associated with an increased risk of hospital readmissions in the short-term postoperative period.[10] A longer operative time has been previously recognized as a risk factor for short-term complications after various orthopaedic procedures[8,9]; however, it has yet to be investigated as an independent risk factor for postoperative complications after ACL reconstruction. In ACL reconstruction, tourniquet use is associated with an increased incidence of hemarthrosis and pain in the immediate postoperative period.[46] The relationship between tourniquet time and the development of postoperative complications is not fully understood and may simply be a result of complications due to the intricacy of lengthier procedures.

Although ACL reconstruction is a common procedure, it is imperative to minimize adverse events to maximize patient safety and outcomes by manipulating modifiable risk factors. Diabetes has been associated with an increased risk of postoperative infections after ACL reconstruction.[11] While obesity is related to poorer outcomes and an increased risk of osteoarthritis after ACL reconstruction, it has not been identified as a modifiable risk factor for postoperative complications.[16] Identifying operative time as an independent modifiable risk factor for postoperative complications would emphasize the need for efficiency and surgical planning in ACL reconstruction.

The purpose of this investigation was to determine whether operative time is an independent risk factor for complications within 30 days after ACL reconstruction. We hypothesized that a positive linear correlation exists between operative time and the risk of developing surgical site infections and adverse events after this procedure.

METHODS

This investigation analyzed data from the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP). This registry contains demographics, comorbidities, laboratory values, and concomitant procedures with corresponding readmission and complication rates within 30 days of the index procedure. Patients are identified through Current Procedural Terminology (CPT) and International Classification of Diseases, 9th and 10th Revisions (ICD-9 and ICD-10, respectively) codes.[32] This database is composed of a network of participating hospitals, which are required to employ clinical reviewers with a background in health care to collect over 274 variables from surgical procedures. The ACS-NSQIP has several quality assurance programs in place, such as random internal audits performed biweekly, to ensure the accuracy and quality of the collected data.[15,52]

The ACS-NSQIP was queried for all isolated ACL reconstructions (CPT 29888) between 2005 and 2016. This CPT code for ACL reconstruction includes diagnostic knee arthroscopic surgery, synovial resection for visualization, notchplasty, ACL stump removal, partial synovectomy and fat pad resection, intra-articular ligament reconstruction, harvesting and insertion of a graft, internal fixation of a graft, lysis of adhesions, and manipulation of the knee. Secondary CPT codes were queried for "NULL" to eliminate bias created from concomitant procedures such as concomitant meniscal repair or multiligamentous reconstruction. It was not discernable whether the procedure was primary or revision reconstruction.

Patient demographics, including age, smoking status, comorbidities, sex, and American Society of Anesthesiologists (ASA) physical status classification class, were collected. An ASA class greater than 3 corresponded to severe systemic disease (new classification of physical status). A history of diabetes was reported as either insulin dependent, oral medication only, or no diabetes. Procedures were excluded if any of the following variables were missing: ASA class, sex, body mass index (BMI), operative time, and type of anesthetic. Patients younger than 18 years were excluded from the analysis because of additional factors that must be considered in these patients, such as physis status, variations in reconstruction techniques (eg, extraphyseal, transphyseal, physeal-sparing, or hybrid techniques), and graft usage.[39] Although there are variations in technique and graft choice in the adult population, consideration of the physis and subsequent growth abnormalities can affect intraoperative decision making and technique, which may have skewed the results of this investigation.

Complications were reported within 30 days of the index procedure. These included anemia requiring transfusion, cardiac arrest requiring cardiopulmonary resuscitation, death, cerebrovascular accidents, wound dehiscence, deep vein thrombosis (DVT), pneumonia, myocardial infarction, renal insufficiency, pulmonary embolism, surgical site infections, sepsis, urinary tract infections, unplanned

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One or more of the authors has declared the following potential conflict of interest or source of funding: G.H.G. has received educational support from Smith & Nephew. D.D.B. receives research support from OPED and has received educational support from Medwest Associates. N.N.V. has received research support from Arthrex, Arthrosurface, Athletico, ConMed Linvatec, DJO, Miomed, Mitek, Ossur, and Smith & Nephew; is a consultant for Arthrex, Medacta, Minivasive, and Orthospace; is a paid speaker/presenter for Pacira Pharmaceuticals; has received educational support from Medwest Associates; has stock/stock options in CyMedica, Minivasive, and Omeros; and receives royalties from Smith & Nephew, *Arthroscopy*, and Vindico Medical (Orthopedics Hyperguide). B.F. receives research support from Arthrex and Stryker, receives fellowship support from Smith & Nephew and Ossur, has received educational support from Medwest Associates, is a consultant for Sonoma Orthopedics and Stryker, has received an honorarium from Arthrosurface, receives royalties from Elsevier, and has stock/stock options in Jace Medical. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval was not sought for the present study.

intubation, hospital readmissions, and extended length of stay in the hospital (≥2 days). This last category was included to prevent patients who were kept on a 23-hour observation period from being considered as a complication. Operative time was defined as the duration, in minutes, from skin incision to wound closure. This was collected as a continuous variable. During the analysis, operative time was segmented into 15-minute increments to determine marginal increases in the complication risk after a 15-minute extension in operative duration. Cases were also excluded if the operative time was longer than 150 minutes (>2 SDs from the mean). These cases (n = 2094 [12.9%]) were excluded to eliminate outlier effects on the linear model employed in this investigation. It is possible that these cases represented complicated revisions that may result in a significantly longer operative time.

Statistical Analysis

Stata 13.1 (StataCorp) was used to perform the statistical analysis in this investigation. The association of demographic and comorbidity variables with operative duration was analyzed using bivariate linear regression. Subsequently, multivariate Poisson regression with robust error variance was performed to determine which of these variables were correlated with operative time. Poisson regression with robust error variance was implemented into the analysis, as it has been previously shown to be most efficacious in epidemiological analyses of binary variables, allowing for relative risk (RR) calculations.[56] A bivariate analysis was then performed on operative duration and the risk of developing short-term complications. Multivariate Poisson regression with robust error variance was again utilized to determine the RR of developing each complication while accounting for correlated demographic variables. Fifteen-minute increments were used in this investigation to allow for clinical interpretation of the impact of marginal increases in operative time on postoperative complications.

RESULTS

A total of 14,159 ACL reconstruction procedures were included in the analysis. The mean age of patients included in the analysis was 32.6 ± 10.8 years, the mean BMI was 27.7 ± 6.5 kg/m^2, and the mean operative time was 89.7 ± 28.6 minutes (Figure 1). Patients in the youngest cohort (18-30 years) had the longest operative duration (95.1 ± 27.8 minutes; RR, 17.7; $P < .001$). Additionally, male patients had a longer operative duration (91.9 ± 28.3 minutes; RR, 4.7; $P < .001$), and patients who were not diabetic had longer operative times than patients who were diabetic (89.8 ± 28.6 minutes; RR, 7.1; $P = .011$). Last, patients who underwent ACL reconstruction under general anesthesia had a shorter procedure than patients who underwent reconstruction with regional anesthesia (91.8 ± 28.3 minutes; RR, –3.3; $P = .002$) (Table 1).

The overall rate of all adverse events was 1.1% (Table 2). DVT was observed in 0.52% of cases, and a surgical site infection was diagnosed in 0.44% of patients. Readmission

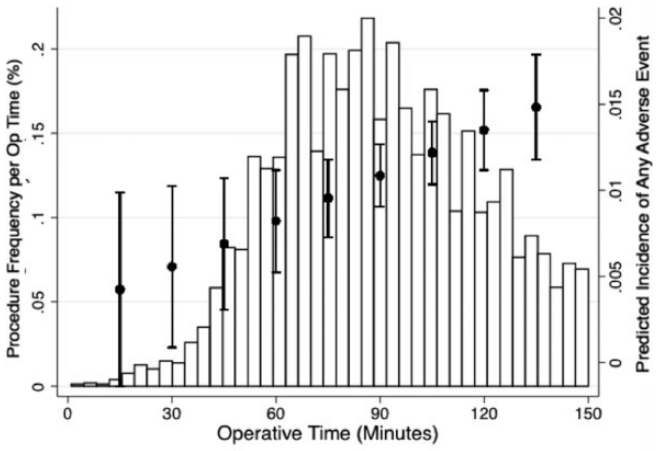

Figure 1. Predicted linear correlation between operative time and frequency of adverse events in comparison with the distribution of operative time. Error bars represent 95% confidence intervals.

to the hospital within 30 days occurred in 0.65% of cases, and an extended length of stay (≥2 days) was seen in 0.58% of patients. After accounting for confounding demographics and comorbidities, the multivariate analysis demonstrated that a 15-minute increase in operative duration was associated with an increased risk of DVT (RR, 1.12; $P = .042$), surgical site infections (RR, 1.21; $P = .001$), and sepsis (RR, 1.66; $P < .001$). The same 15-minute incremental increase in operative time resulted in significantly greater readmission rates (RR, 1.23; $P = .001$) and an extended length of stay (RR, 1.18; $P = .008$) (Table 2).

DISCUSSION

After adjusting for other correlated risk factors, we established that 15-minute incremental increases in operative time were found to be an independent risk factor for developing postoperative DVT, surgical site infections, sepsis, an extended length of hospital stay, hospital readmissions, and subsequent irrigation and drainage after ACL reconstruction. While some risk factors for postoperative complications are nonmodifiable, physicians should be cognizant in identifying and minimizing causes of increased operative time, as this may contribute to postoperative complications.

Surgical duration has previously been shown to be an independent risk factor for postoperative complications, an extended length of hospital stay, and hospital readmissions after total hip arthroplasty, total knee arthroplasty, and shoulder arthroscopic surgery.[5,6,8,9] However, previous investigations treated time as a binary variable to ascertain its relationship with developing postoperative complications.[5,6,8] While a relationship between operative time and adverse events was identified, quantifying the impact of surgical duration on adverse events could not be identified. Similarly, operative length greater than 1 hour increased the risk of surgical site infections and thromboembolism after ACL reconstruction.[41,53] Bohl et al[9] identified that

TABLE 1
Operative Time by Demographic, Comorbidity, and Procedure Characteristics[a]

	n	Operative Time, Mean ± SD, min	Bivariate	Multivariate[b]		
			P Value	RR	95% CI	*P* Value
Overall	14,159					
Age, y			<.001			**<.001**
18-30	6487	95.1 ± 27.8		17.7	15.8 to 19.6	
31-50	6563	86.6 ± 28.2		9.2	7.4 to 11.1	
51-70	1084	76.6 ± 28.4		Reference	—	
>70	25	68.8 ± 35.6		–7.1	–18.2 to 4.1	
Sex			<.001			**<.001**
Female	5217	85.9 ± 28.7		Reference	—	
Male	8942	91.9 ± 28.3		4.7	3.7 to 5.7	
BMI, kg/m^2			.377			
<25	4669	89.3 ± 27.9		–2.3	–4.4 to –0.2	
25-30	5575	90.3 ± 28.6		–1.0	–3.1 to 1.0	
31-35	2458	89.5 ± 29.0		–0.5	–2.7 to 1.6	
36-40	903	89.1 ± 29.4		Reference	—	
>40	554	89.2 ± 31.4		0.1	–2.9 to 3.1	
ASA class			<.001			.338
1	7650	91.2 ± 28.1		0.2	–2.6 to 2.9	
2	5919	88.2 ± 28.9		–0.4	–2.9 to 3.1	
3	586	85.5 ± 30.5		Reference	—	
4	4	65.3 ± 36.6		–20.7	–48.4 to 6.9	
Current smoker			.190			.143
No	11,591	89.6 ± 28.5		Reference	—	
Yes	2568	90.4 ± 29.2		0.9	–0.3 to 2.2	
Diabetes mellitus			<.001			**.011**
No	13,955	89.8 ± 28.6		7.1	2.4 to 11.8	
Non–insulin-dependent	149	78.1 ± 30.6		Reference	—	
Insulin-dependent	55	84.7 ± 26.3		4.9	–3.7 to 13.6	
Chronic obstructive pulmonary disease			.178			.862
No	14,127	89.7 ± 28.6		Reference	—	
Yes	32	82.9 ± 30.4		–0.9	–10.9 to 9.1	
Hypertension			<.001			.739
No	13,226	90.1 ± 28.4		Reference	—	
Yes	933	84.6 ± 30.4		0.3	–1.7 to 2.4	
Dyspnea on exertion			.920			.259
No	14,086	89.7 ± 28.6		Reference	—	
Yes	73	89.4 ± 30.7		3.8	–2.8 to 10.4	
Anemia			.671			.064
No	13,912	89.7 ± 28.6		Reference	—	
Yes	247	88.9 ± 29.8		3.4	–0.2 to 6.9	
Functionally dependent			.549			.371
No	14,129	89.7 ± 28.6		Reference	—	
Yes	30	92.8 ± 33.9		4.6	–5.4 to 14.6	
Anesthesia			.040			**.002**
Regional only	752	91.8 ± 28.3		Reference	—	
General	13,407	89.6 ± 28.6		–3.3	–4.3 to –1.2	

[a]Bolded *P* values indicate statistically significant association with operative time. ASA, American Society of Anesthesiologists; BMI, body mass index; RR, relative risk.
[b]Adjusted for all characteristics listed in this table.

incremental 15-minute increases in operative time during lower extremity total joint arthroplasty resulted in 9% and 13% increases in surgical site infections and wound dehiscence, respectively. The multivariate analysis implemented in the present investigation adjusts for confounding variables, which enables a more practical application of the influence of operative time toward adverse events.

DVT occurred at a rate of 0.52%, which is similar to what has previously been reported in this cohort.[20,23] Despite DVT being a significant complication after lower extremity orthopaedic procedures, only 50% of sports medicine fellowship–trained surgeons routinely utilize thrombus prophylaxis in ACL reconstruction.[31] Because of the lack of a standardized protocol for thrombus prophylaxis,

TABLE 2
Association of a 15-Minute Increase in Operative Time With the Rate of Each Adverse Event or Hospital Metric[a]

		Unadjusted (Bivariate) Analysis		Adjusted (Multivariate) Analysis[b]	
	Rate, %	RR (95% CI)	*P* Value	RR (95% CI)	*P* Value
Adverse event	1.1				
Anemia requiring transfusion	0.01	0.90 (0.59-1.37)	.619	0.94 (0.68-1.30)	.729
Deep vein thrombosis	**0.52**	**1.09 (0.97-1.22)**	**.165**	**1.12 (1.00-1.26)**	**.042**
Dehiscence	0.05	1.30 (0.88-1.92)	.183	1.24 (0.81-1.91)	.325
Pneumonia	0.03	0.71 (0.36-1.38)	.310	0.69 (0.33-1.44)	.326
Pulmonary embolism	0.11	1.10 (0.87-1.38)	.420	1.13 (0.90-1.42)	.289
Sepsis	**0.01**	**1.64 (1.62-1.66)**	**<.001**	**1.66 (1.45-1.91)**	**<.001**
Surgical site infection	**0.44**	**1.19 (1.07-1.33)**	**.002**	**1.21 (1.08-1.35)**	**.001**
Urinary tract infection	0.07	1.25 (0.95-1.65)	.109	1.25 (0.92-1.69)	.159
Adverse hospital metric					
Hospital readmission	**0.65**	**1.23 (1.09-1.38)**	**.001**	**1.23 (1.09-1.39)**	**.001**
Extended length of stay[c]	**0.58**	**1.16 (1.03-1.31)**	**.012**	**1.18 (1.04-1.33)**	**.008**
Irrigation and debridement	**0.1**	**1.41 (1.16-1.72)**	**.001**	**1.33 (1.09-1.62)**	**.005**

[a]Bolded rows indicate statistically significant association with operative time. RR, relative risk.
[b]Adjusted for all demographic, comorbidity, and procedure characteristics listed in Table 1.
[c]Extended length of stay is a hospital visit that is ≥2 days.

clinical experience and personal opinion are the primary factors for determining usage and dosage protocols. Age older than 35 years, nicotine use, tourniquet time longer than 2 hours, surgery at higher elevations, and concomitant high tibial osteotomy or posterior cruciate ligament reconstruction have been associated with an increased risk of thrombus formation after ACL reconstruction.[17,23,28] Because of the compressive nature of tourniquets, its use may cause damage to vascular endothelial walls and the deformation of red blood cells, and blood stasis may result in thrombus formation.[26,37] Additionally, pain from the procedure and tourniquet may lead to a hypercoagulable state due to the release of catecholamines, which favor platelet aggregation.[17] While patient demographics or concomitant procedures may affect the risk of DVT, operative time also influences the risk of DVT by fostering an environment that favors thrombus formation.

Surgical site infections after ACL reconstruction were observed at an incidence of 0.44%, which is similar to previously reported rates of infections after ACL reconstruction.[14] A prolonged operative duration leaves the surgical site exposed, which may enable pathological organisms to seed the wound. Additionally, sustained anesthesia can cause hypothermia, which may lead to immunodeficiency and subsequent infections.[18,22] The use of autografts, particularly hamstring autografts, is associated with an increased risk of surgical site infections[2,55]; however, presoaking a graft in vancomycin has been shown to reduce the risk of surgical site infections.[44]

This investigation also established preoperative patient characteristics that may contribute to increased operative times. Identifying factors that may contribute to an increased surgical duration is paramount to ambulatory surgical centers, as these sites prefer patients who have a reduced risk of postoperative complications. Results indicated that nondiabetic patients had longer operative times than diabetic patients. However, this finding is likely extraneous and clinically irrelevant. We also found that male patients had a longer operative time. However, it has previously been shown that female patients may require special surgical consideration because of anatomic variation in women such as smaller trochlear notch widths, smaller ACL cross-sectional areas, increased posterior tibial slopes, and increased quadriceps angles.[51]

In this investigation, younger age was associated with an increased operative time. Bone–patellar tendon–bone and hamstring autografts are more commonly used in younger patients, as they result in higher functional outcomes and a lower risk of reruptures in comparison with allografts.[29,30,36] However, the use of autografts increases operative time, as the surgeon must harvest and prepare the graft before implantation. Allografts may be more commonly used in older patients, which may have resulted in a shorter operative time in this cohort. Thus, operative technique and graft choice may have influenced the result that operative times were longer in younger patients. This phenomenon of longer operative times in younger patients has also been reported with shoulder arthroscopic surgery, knee arthroplasty, and cervical fusion.[8,9,42]

Patients younger than 18 years were not included in this study because of the belief that pediatric patients represent a separate population. Pediatric patients undergoing ACL reconstruction have additional considerations, such as protection of the physis, which may affect operative management and technique.[39] These considerations in pediatric patients may result in a longer operative time. Additionally, younger patients are also subject to early graft failure and revision after ACL reconstruction because of more frequent involvement in high-risk sports and ligamentous laxity.[3,35] Further investigation may be warranted to assess the impact of operative time on postoperative complications in pediatric patients.

Because of the safety of arthroscopic assisted procedures, there has been a shift toward performing ACL

reconstruction in outpatient ambulatory surgical centers, which are predominantly owned by practicing physicians.[38,40,50] As of the 2013 changes to United States health care regulations, physicians who operate in self-owned ambulatory surgical centers have become more accountable for patient outcomes, complications, reimbursements, and penalties.[40] To maximize patient outcomes and minimize complications, it is important that physicians and the surgical team work efficiently to minimize the operative duration. It is advantageous for physicians to have a skilled surgical assistant available to simultaneously prepare the graft while optimizing tunnel placement. The additional cost of having a skilled assistant is likely to be offset in several ways. By increasing operative efficiency, one can perform more cases and reduce the number of complications if operative time is significantly reduced. Proper preoperative assessments and planning on behalf of the physician and operative team can improve patient care.

Prior investigations have demonstrated the effect of resident involvement with various orthopaedic procedures[1,27,34,45]; however, no information currently exists that quantifies the effect of resident or fellow involvement with ACL reconstruction. Academic centers may have longer operative times because of the involvement of residents or fellows. Additionally, academic centers may have more complicated cases because of sicker patients or complicated revision procedures compared with ambulatory surgery centers. Furthermore, it is plausible that higher volume surgeons may operate faster and may have fewer complications. Because of differences in the implementation of prophylactic measures to prevent infections or DVT, the rate of adverse events may vary.

The overall rate of adverse events was 1.1%, which is much lower than the rate of graft failure after primary ACL reconstruction (9%) by 25 years postoperatively.[48] The results of this investigation demonstrate that shorter operative times decrease the risk of medical complications in the immediate postoperative period. Given the rates of medical complications and graft failure, it may be advantageous to take an additional 15 minutes to ensure a good technique to minimize the risk of graft failure instead of decreasing the rate of adverse events in the immediate postoperative period.

Because of the low incidence of complications after ACL reconstruction, the use of a national database is essential to assess risk factors that may contribute to complications. The ACS-NSQIP provides high-quality assured data on complications that is sufficiently powered to address the trends of infrequent adverse rates. Despite the power from this study, limitations exist because of the retrospective nature of this database. Various preoperative and intraoperative patient demographics are unknown, thus contributing to variability in baseline patient information. Risk factors for poorer outcomes after ACL reconstruction, such as cartilage lesions of the medial, lateral, or patellofemoral compartments or any subsequent ipsilateral knee surgery, were unable to be collected.[25] However, these factors are not associated with short-term complications after ACL reconstruction. It was unknown whether a case included in the analysis was primary or revision reconstruction. Revision ACL reconstruction remains technically challenging for surgeons and results in inferior clinical outcomes in comparison with primary reconstruction.[24] Because of the technical complexity of revision ACL reconstruction, it inherently results in a prolonged operative duration. However, the goal of the present investigation was to establish the impact of operative duration on complication rates, not clinical outcomes. Although there is no evidence to suggest that revision ACL reconstruction results in an increased risk of infections or DVT in the immediate postoperative period, it is possible that the risk of complications is higher in revision surgery because rehabilitation is a slower process in these patients.

In addition, the use of a tourniquet and time of the procedure performed under a tourniquet, which directly influence the risk of developing DVT, could not be accounted for. We were also unable to record whether an antibiotic or a DVT prophylaxis was used; physician-specific preference on the use of these agents may have influenced the results of this investigation. Reconstruction procedures longer than 150 minutes were excluded, as they were outliers that may have affected the linear model employed in this study. However, it should be noted that these cases may also be associated with a higher risk of complications in the early postoperative period. Last, the outcomes of this study are limited to complications within the immediate postoperative period, and long-term outcomes such as reoperations and other procedure-specific factors were not captured. It is important to note that the results of this investigation assess complication rates and do not consider the impact of operative time on clinical outcomes after ACL reconstruction. Further investigation may be warranted to assess the effect of operative time on clinical outcomes.

CONCLUSION

While the overall adverse risk rate after ACL reconstruction remains low, marginal increases in operative time are associated with an increased risk of adverse events such as DVT, surgical site infections, sepsis, an extended length of stay, and readmissions. The operating physician and surgical staff should make all efforts to coordinate and prepare for each case to maximize surgical efficiency.

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