Original Research

Relationship Between Revision Rate, Osteoarthritis, and Obesity for ACL Reconstruction

A Nationwide Retrospective Cohort Study

Junwoo Byun,* MD, Han-Kook Yoon,* MD, Hyun-Cheol Oh,* MD, Taemi Youk,† PhD, Joong-Won Ha,* MD, Seungyeon Kang,* MD, and Sang-Hoon Park,*‡ MD
Investigation performed at National Health Insurance Service Ilsan Hospital, Goyang, Republic of Korea

Background: The long-term goal of anterior cruciate ligament (ACL) reconstruction is to prevent secondary osteoarthritis due to instability. Obesity itself is also a risk factor for osteoarthritis and shows an increase in its incidence, but little is known about the relationship between obesity and the outcome of ACL reconstruction.

Purpose/Hypothesis: This study aimed to determine the relationship between the outcome of ACL reconstruction and obesity. It was hypothesized that obesity would be associated with the revision rate of ACL reconstruction and additional surgical treatment for osteoarthritis in patients who undergo ACL reconstruction.

Study design: Cohort study; Level of evidence, 3.

Methods: Claims and health screening data of the National Health Insurance Service were used to analyze patients who underwent ACL reconstruction between January 1, 2003, and December 31, 2021. The association between obesity and risk of revision ACL reconstruction and additional surgical treatment for osteoarthritis or meniscal lesion was analyzed. Body mass index (BMI) was used to classify patients as underweight (BMI, <18.5), normal weight (BMI, 18.5-24.9), overweight (BMI, 25.0-29.9), obese (BMI, 30.0-39.9), or morbidly obese (BMI, ≥ 40.0). Multivariable Cox proportional hazards model analysis was conducted.

Results: A total of 56,734 patients were included. Of them, 311 (0.5%) patients were underweight, 26,613 (46.9%) were normal weight, 24,372 (43.0%) were overweight, 5324 (9.4%) were obese, and 114 (0.2%) patients were morbidly obese. The underweight group showed a significantly lower risk of revision ACL reconstruction than the normal weight group (hazard ratio [HR], 0.54; 95% CI, 0.31-0.93; P = .0273). However, the overweight, obese, and morbidly obese groups had no significant difference from the normal weight group. The risk of high tibial osteotomy (HTO) or total knee arthroplasty (TKA) was significantly high for the overweight (HR, 1.93; 95% CI, 1.70-2.19; $P < .0001$) and obese (HR, 2.71; 95% CI, 2.23-3.30; $P < .0001$) groups. Subgroup analysis performed in patients ≥ 40 years of age for the risk of HTO showed a significant increased risk in the overweight group (HR, 1.889; 95% CI, 1.56-2.29; $P < .0001$) and obese group (HR, 2.78; 95% CI, 2.10-3.69; $P < .0001$). Subgroup analysis performed in patients ≥ 50 years of age for the risk of TKA also showed a significant increased risk in the overweight group (HR, 2.03; 95% CI, 1.67-2.47; $P < .0001$) and obese group (HR, 2.53; 95% CI, 1.83-3.50; $P < .0001$). After adjusting for meniscal injury at index surgery by multivariate regression analysis, 1.87- and 2.75-fold increased risks of HTO were identified for the overweight and obese groups, respectively, for patients aged >40 years. For patients aged >50 years, 2.02-fold and 2.52-fold increased risks of TKA were observed for the overweight and obese groups, respectively. The risk of additional surgery due to the meniscal lesion was high for the overweight (HR, 1.09; 95% CI, 1.03-1.15; P = .002) and obese (HR, 1.10; 95% CI, 1.01-1.21; P = .0351) groups, while no significant difference was found for the underweight and morbidly obese groups.

The Orthopaedic Journal of Sports Medicine, 12(8), 23259671241266597
DOI: 10.1177/23259671241266597
© The Author(s) 2024

This open-access article is published and distributed under the Creative Commons Attribution - NonCommercial - No Derivatives License (https://creativecommons.org/licenses/by-nc-nd/4.0/), which permits the noncommercial use, distribution, and reproduction of the article in any medium, provided the original author and source are credited. You may not alter, transform, or build upon this article without the permission of the Author(s). For article reuse guidelines, please visit SAGE's website at http://www.sagepub.com/journals-permissions.

Conclusion: This study highlights that obesity does not increase the revision rate of ACL reconstruction. However, the risk of additional surgical treatment for osteoarthritis and meniscal lesions increased as BMI increased. Further investigation is needed to determine the efficacy of ACL reconstruction for preventing osteoarthritis in obese patients.

Keywords: knee; ligaments; ACL; ACL reconstruction; obesity; revision ACL reconstruction; osteoarthritis

Instability due to anterior cruciate ligament (ACL) injury could cause cartilage and meniscal damage, resulting in the progression of osteoarthritis.[5,8,10] Considering the natural history and poor results of ACL repair, ACL reconstruction is considered the gold standard for ACL injury with instability. Among the various risk factors for ACL injury, obesity is known to be a contributing factor for ACL injury.

Obesity is a multifactorial disease with continuously increasing incidence, causing higher annual medical costs due to various comorbidities.[9,23] It is a risk factor for various diseases, including diabetes mellitus, cardiovascular disease, hypertension, dyslipidemia, gall bladder diseases, and certain types of cancer.[22] Of those various comorbidities, a higher prevalence of knee osteoarthritis and a higher risk of ACL injury are known effects of obesity in the knee joint.[7] Furthermore, obesity is also associated with poor outcomes for various surgical procedures such as spinal fusion[14] and total knee arthroplasty (TKA).[20]

Few studies have explored the relationship between obesity and the risk of ACL injury and outcomes of ACL reconstruction. Current studies on obesity and ACL injury have shown that an increase in body mass index (BMI) is associated with a higher incidence of noncontact ACL injury[6,11,24] as well as a higher incidence of ultra-low-velocity knee dislocations, which could cause multiligament injuries including ACL injury.[26] Maletis et al[18,19] reported that a BMI >25 was associated with a lower revision rate, while Inderhaug et al[13] reported no effect of BMI on the risk of revision ACL reconstruction, indicating conflicting results. Almeida et al[1,2] and Ballal et al[3] reported no significant association between Lysholm score, Knee injury and Osteoarthritis Outcome Score, and return to sports in obese patients, while Kowalchuk et al[15] reported inferior International Knee Documentation Committee scores in obese patients. To our knowledge, no large-scale study has been conducted regarding symptomatic osteoarthritis progression leading to an additional surgical procedure as the outcome of ACL reconstruction in accordance with obesity. Considering the increasing prevalence of obesity and the effect of obesity on ACL injury and osteoarthritis, our study was conducted to analyze the relationship between obesity and the outcome of ACL reconstruction. Besides the risk of revision ACL reconstruction, the risk of additional surgery for a secondary meniscal injury and the risk of osteoarthritis progression leading to high tibial osteotomy (HTO) or TKA were also analyzed as an outcome of ACL reconstruction since one of the purposes of ACL reconstruction is to prevent additional damage caused by instability. We hypothesized that obesity would be associated with the revision rate of ACL reconstruction and additional surgical treatment for osteoarthritis in patients who undergo ACL reconstruction.

METHODS

Patient Selection and Criteria

This study is a retrospective observational cohort study that used data from a large nationwide database, the National Health Insurance Service–Health Screening (NHIS-HealS). It was approved by the institutional review committee of the ethics committee of our hospital (NHIS-2023-1-256). The Republic of Korea has an obligatory NHIS system with universal coverage, which could reduce selection bias. The NHIS-HealS database has reimbursement records from all medical institutions in the Republic of Korea, and raw data cannot be taken out, following NHIS policy.

We used the claims data in the NHIS to identify patients who underwent ACL reconstruction between January 1, 2003, and December 31, 2021, for a nationwide study. Of the patients, those who had available NHIS-HealS data within 1 year before or after ACL reconstruction were included. The listed diagnostic codes were used for acute or chronic ACL rupture (S83.50, S83.52, M23.53, M23.63, M23.83, M23.93, M23.01, M23.11, M23.21, M23.31, M23.41, and S83.7). Patients with a diagnostic code of ligament injuries other than ACL were excluded. Because individualized evaluation of growth plate closure was impossible, patients aged <20 years were excluded to analyze mature patients. Of these patients, those with a surgical procedure code of cruciate ligament reconstruction (N0880 and N0881) were included. Surgical codes for other concomitant surgeries, such as meniscectomy and meniscal repair, were also

‡Address correspondence to Sang-Hoon Park, MD, Department of Orthopaedic Surgery, National Health Insurance Service Ilsan Hospital, 100 Ilsan-ro, Ilsandong-gu, Goyang, 10444, Republic of Korea (email: almania@nhimc.or.kr).

*Department of Orthopaedic Surgery, National Health Insurance Service Ilsan Hospital, Goyang, Republic of Korea.

†Research Institute, National Health Insurance Service Ilsan Hospital, Goyang, Republic of Korea.

Final revision submitted December 24, 2023; accepted February 2, 2024.

The authors declared that they have no conflicts of interest in the authorship and publication of this contribution. 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 for this study was obtained from the National Health Insurance Service Ilsan Hospital (ref No. 2023-03-027).

TABLE 1
Definition of Obesity by BMI[a]

	Underweight	Normal Weight	Overweight	Obese (classes 1 and 2)	Morbidly Obese (class 3)
BMI	<18.5	18.5-24.9	25.0-29.9	30.0-39.9	≥40

[a]BMI, body mass index.

TABLE 2
Age Distribution for BMI Group[a]

	Underweight	Normal Weight	Overweight	Obese	Morbidly Obese
Total No. of patients	311	26,613	24,372	5324	114
Age, y					
20-29	77 (24.8)	4320 (16.2)	3316 (13.6)	1029 (19.3)	34 (29.8)
30-39	88 (28.3)	6655 (25.0)	7155 (29.4)	1961 (36.8)	40 (35.1)
40-49	88 (28.3)	8607 (32.3)	7717 (31.7)	1526 (28.7)	29 (25.4)
50-59	40 (12.9)	5491 (20.6)	4860 (19.9)	671 (12.6)	10 (8.8)
≥60	18 (5.8)	1540 (5.8)	1324 (5.4)	137 (2.6)	1 (0.9)

[a]Data are presented as n (%) unless otherwise indicated. BMI, body mass index.

included. Because procedures besides ACL reconstruction as the index surgery on the ipsilateral side are considered additional surgical procedures, while they are claimed as the main procedure when performed on the contralateral knee, laterality was confirmed by whether an additional surgical procedure was claimed or not.

Obesity

NHIS-HealS data were used to collect weight and height within 1 year before or after primary ACL reconstruction. BMI was used to define obesity. The definition of obesity by the World Health Organization was used to group patients as underweight, normal weight, overweight, obese, or morbidly obese.[27] The definition of each group is as follows: a BMI <18.5 is underweight, 18.5 to 24.9 is normal weight, 25.0 to 29.9 is overweight, 30 to 39.9 is obese, and ≥40 is morbidly obese (Table 1).

Risk of Subsequent Surgical Procedures

Besides revision ACL reconstruction, the risk of meniscectomy, HTO, and TKA was also considered. Using surgical procedure codes, we analyzed the risk of meniscectomy (N0821, N0822, N0826, and N0827), HTO (N0304), and TKA (N2072 and N2077) in each of the BMI groups. To identify whether the subsequent surgical procedure was done for the ipsilateral knee, claims data for postoperative radiographs were compared with the laterality of the radiograph obtained after the index surgery, which is side specific. Considering the age distribution of candidates for HTO or TKA, subgroup analyses of patients aged ≥40 for HTO and ≥50 for TKA were done. Multivariate regression analysis was performed to adjust for the effect of meniscal injury on osteoarthritis progression.

Statistical Analysis

SAS Enterprise Guide, which runs on SAS Version 9.4 (SAS Institute), was used for analysis in this study. Multivariable Cox proportional hazards model analysis was used to analyze the independent risk of revision ACL reconstruction, meniscectomy, HTO, TKA, and HTO or TKA. A *P* value of <.05 was considered significant. The hazard ratio (HR) and 95% confidence interval were analyzed.

To adjust the effect of meniscal injury at primary ACL reconstruction, Bonferroni post hoc was performed to analyze the proportion of patients with a meniscal injury by each BMI group compared with the normal weight group.

RESULTS

In this study, 146,305 patients underwent ACL reconstruction between 2003 and 2021. Of them, 183 patients were excluded for insufficient demographic data. Of 146,122 patients, 60,809 had a health screening within 1 year before or after ACL reconstruction. After excluding patients <20 years of age, 56,734 patients were included in this study. A total of 311 (0.5%) patients were underweight, 26,613 (46.9%) were normal weight, 24,372 (43.0%) were overweight, 5324 (9.4%) were obese, and 114 (0.2%) patients were morbidly obese.

Overall, 15.5% of patients were between 20 and 29 years of age, while 28.0% were between 30 and 39 years, 31.7% were between 40 and 49 years, 19.5% were between 50 and 59 years, and 5.3% were ≥60 years. The age distribution of each group is shown in Table 2.

The proportions of male patients were 53.7%, 75.5%, 83.0%, 75.7%, and 53.5%, respectively, for the

TABLE 3
Risk of Revision ACL Reconstruction, HTO, TKA, HTO or TKA, and Meniscectomy compared with normal weight group[a]

	Underweight	Normal Weight	Overweight	Obese	Morbidly Obese[b]
Revision surgery					
P	.0273	1.00	.1322	.3739	.8697
HR	0.54		0.95	0.95	0.94
95% CI	0.31-0.93		0.89-1.02	0.85-1.07	0.45-1.98
HTO					
P	.7755	1.00	<.0001	<.0001	.1291
HR	0.82		1.72	2.58	2.95
95% CI	0.20-3.29		1.44-2.04	2.00-3.31	0.73-11.90
TKA					
P	.9695	1.00	<.0001	<.0001	
HR	1.023		2.467	1.933	
95% CI	0.33-3.20		2.1-2.97	1.44-2.60	
HTO or TKA					
P	.5158	1.00	<.0001	<.0001	.3743
HR	1.34		1.93	2.71	1.88
95% CI	0.55-3.24		1.70-2.19	2.23-3.30	0.47-7.56
Meniscectomy					
P	.1058	1.00	.002	.0351	.336
HR	0.73		1.09	1.1	1.31
95% CI	0.49-1.07		1.03-1.15	1.01-1.21	0.76-2.26

[a]ACL, anterior cruciate ligament; HR, hazard ratio; HTO, high tibial osteotomy; TKA, total knee arthroplasty.
[b]Morbidly obese group on the TKA row are blank due to lack of patients.

underweight, normal, overweight, obese, and morbidly obese groups. The risk of subsequent revision ACL reconstruction, HTO, TKA, HTO or TKA, or meniscectomy for each group is shown in Table 3.

Risk of Revision ACL Reconstruction

Of 56,734 patients, 3783 (6.7%) underwent revision ACL reconstruction. In the underweight group, 4.2% (13/311) underwent revision surgery, while 7.0% (1850/26,613) of the normal weight group, 6.4% (1566/24,372) of the overweight group, 6.5% (347/5324) of the obese group, and 6.1% (7/114) of the morbidly obese group underwent revision surgery.

In the underweight group, revision surgery risk was significantly lower than in the normal weight group (HR, 0.54; 95% CI, 0.31-0.93; P = .0273). However, the overweight group (HR, 0.95; 95% CI, 0.89-1.02; P = .1322), obese group (HR, 0.95; 95% CI, 0.85-1.07; P = .3739), and morbidly obese group (HR, 0.94; 95% CI, 0.45-1.98; P = .8697) had no significant difference in risk of revision compared with the normal weight group.

Risk of Subsequent Meniscectomy

Of 56,734 patients, 6119 (10.8%) underwent revision ACL reconstruction. In the underweight group, 8.4% (26/311) underwent subsequent meniscectomy, while 10.7% (2852/26,613) of the normal weight group, 11.0% (2671/24,372) of the overweight group, 10.5% (557/5324) of the obese group, and 11.4% (13/114) of the morbidly obese group underwent meniscectomy.

Patients who required subsequent meniscectomy due to secondary meniscal tears showed no significant difference in the underweight (HR, 0.73; 95% CI, 0.49-1.07; P = .1058) and morbidly obese (HR, 1.31; 95% CI, 0.76-2.26; P = .3360) groups. The overweight group showed a 1.09 times increased risk (95% CI, 1.03-1.15; P = .0020), and the obese group showed a 1.10 times increased risk (95% CI, 1.01-1.21; P = .0351) for the need of meniscectomy.

Risk of HTO

Of 56,734 patients, 620 (1.1%) underwent HTO. Out of 620 patients, 506 patients were aged ≥40. In the underweight group, 0.6% (2/311) underwent HTO, while 0.8% (220/26,613) of the normal weight group, 1.3% (310/24,372) of the overweight group, 1.6% (86/5324) of the obese group, and 1.8% (2/114) of the morbidly obese group underwent HTO.

The risk of HTO had no significant difference in the underweight (HR, 0.82; 95% CI, 0.20-3.29; P = .7755) and morbidly obese (HR, 2.95; 95% CI, 0.73-11.90; P = .1291) groups. In contrast, the overweight group had a 1.72 times increased risk (95% CI, 1.44-2.04; $P < .0001$), and the obese group had a 2.58 times greater risk (95% CI, 2.00-3.31; $P < .0001$). Considering the optimal age for HTO, subgroup analysis was done for patients aged ≥40 years (Table 4). The HRs were 0.595, 1.89, 2.8, and 3.99, respectively, for the underweight (95% CI, 0.08-4.25; P = .6052), overweight (95% CI, 1.56-2.29; $P < .0001$), obese (95% CI, 2.10-3.69; P

TABLE 4
Risk of HTO for Patients Aged ≥40[a]

	Risk of HTO		
	P	HR	95% CI
Underweight	.6052	0.595	0.083-4.254
Normal		1.000	
Overweight	<.0001	1.889	1.557-2.292
Obese	<.0001	2.784	2.102-3.687
Morbidly obese	.0523	3.990	0.986-16.136

[a]HR, hazard ratio; HTO, high tibial osteotomy.

TABLE 5
Risk of TKA for Patients Aged ≥50[a]

	Risk of TKA		
	P	HR	95% CI
Underweight	.2962	2.105	0.521-8.500
Normal		1.000	
Overweight	<.0001	2.030	1.670-2.467
Obese	<.0001	2.532	1.830-3.501

[a]HR, hazard ratio; TKA, total knee arthroplasty.

< .0001), and morbidly obese (95% CI, 0.986-16.14; *P* = .0523) groups, showing a significant increase for the overweight and obese groups.

Risk of TKA

Overall, 1.0% (3/311), 0.7% (179/26,613), 1.3% (319/24,372), and 1.1% (59/5324) of patients underwent TKA for the underweight, normal, overweight, and obese groups, respectively. Out of 560 patients, 484 patients aged ≥50 years. None of the morbidly obese group had TKA. Because no patients in the morbidly obese group underwent TKA, analysis was done after excluding this group. The analysis of 56,620 patients showed no significant difference in the underweight group (HR, 1.02; 95% CI, 0.33-3.20; *P* = .9695). In contrast, the overweight group had a 2.47 times increased risk (95% CI, 2.05-2.97; *P* < .0001), and the obese group had a 1.93 times greater risk (95% CI, 1.44-2.60; *P* < .0001) of TKA. Subgroup analysis was also done for patients ≥50 years considering the optimal age for TKA (Table 5). The HRs of each group were 2.11, 2.03, and 2.53, respectively, for the underweight (95% CI, 0.52-8.50; *P* = .2962), overweight (95% CI, 1.67-2.47; *P* < .0001), and obese (95% CI, 1.83-3.50; *P* < .0001) groups, showing a significant increase for the overweight and obese groups.

Risk of HTO or TKA

The risk of the need for either HTO or TKA was also significantly increased in the overweight and obese groups, but the underweight and morbidly obese groups showed no significant differences. The overweight group showed a 1.93 times higher risk (95% CI, 1.70-2.19; *P* < .0001) and the obese group showed a 2.71 times higher risk (95% CI, 2.23-3.30; *P* < .0001) compared with the normal weight group.

Risk of Meniscal Procedures in the Index Surgery

Because meniscal injury could lead to rapid progression of osteoarthritis, our study analyzed the risk of meniscal injury at the index surgery by each BMI group (Tables 6-8).

The proportion of patients who had undergone a meniscal procedure at the index surgery was significantly increased for the overweight and obese groups. The morbidly obese group had a higher rate of meniscal procedures, but it was not statistically significant compared with that of the normal weight group.

Multivariate Regression Analysis

Considering that a meniscal injury at the time of the index surgical procedure could accelerate the progression of osteoarthritis, and the distributions of the patients with a meniscal injury at index surgery among the BMI groups were different, multivariate regression analysis was done for the risk of HTO in patients aged ≥40 years and TKA in patients aged ≥50 years. The type of graft, sex, smoking history, BMI, and meniscal procedure at the index surgery were analyzed.

Multivariate analysis for the risk of HTO in patients aged ≥40 years showed that the overweight group (HR, 1.87; 95% CI, 1.54-2.27; *P* < .0001) and the obese group (HR, 2.75; 95% CI, 2.08-3.64; p < 0.0001) had a significantly increased risk of HTO, while the morbidly obese group showed no significant difference.

The overweight (HR, 2.02; 95% CI, 1.66-2.45; *P* < .0001) and obese (HR, 2.52; 95% CI, 1.82-3.48; *P* < .0001) groups also showed a significantly increased risk of TKA according to the multivariate analysis.

DISCUSSION

In our study, the risk of revision ACL reconstruction did not increase in comparison with the normal weight group, while additional surgical procedures for secondary meniscal lesions or osteoarthritis increased in the overweight and obese groups. Revision ACL reconstruction is considered when instability persists after primary ACL reconstruction. The most well-known causes of graft failure are rerupture due to trauma, technical error in the primary ACL reconstruction, tunnel widening, and infection. Increased loading in the knee joint and a higher risk of low-velocity knee injury could increase the risk while lowering the possibility of trauma because of the tendency of obese patients to participate less in physical activities, thus lowering the risk of revision. Another possible explanation for the lack of significant increase in ACL revision surgery could be the different treatment strategies in obese patients. Revision ACL reconstruction is decided with caution, considering various factors. Some surgeons consider obesity to be a relative contraindication of revision ACL surgery,[21] while for others,

TABLE 6
Post Hoc Risk Analysis of Meniscal Injury in the Index Surgery[a]

	Underweight	Normal Weight	Overweight	Obese	Morbidly Obese	P
Total No. of patients	311	26,613	24,372	5324	114	
Meniscus or meniscal repair	125 (40.2)	13,673 (51.4)	13,459 (55.2)	2961 (55.6)	68 (59.6)	<.0001
Post hoc analysis	125 (40.2)	13,673 (51.4)				<.0001
		13,673 (51.4)	13,459 (55.2)			<.0001
		13,673 (51.4)		2961 (55.6)		<.0001
		13,673 (51.4)			68 (59.6)	.0778
Total No. of patients aged >40 y	146	15,638	13,901	2334	40	
Meniscus or meniscal repair	62 (42.5)	8501 (54.4)	8061 (58.0)	1342 (57.5)	19 (47.5)	<.0001
Post hoc analysis	62 (42.5)	8501 (54.4)				.0041
		8501 (54.4)	8061 (58.0)			<.0001
		8501 (54.4)		1342 (57.5)		.0045
		8501 (54.4)			19 (47.5)	.3843
Total No. of patients aged >50 y	58	7031	6184	808	11	
Meniscus or meniscal repair	28 (48.3)	4054 (57.7)	3792 (61.3)	484 (59.9)	5 (45.5)	.0002
Post hoc analysis	28 (48.3)	4054 (57.7)				.1499
		4054 (57.7)	3792 (61.3)			<.0001
		4054 (57.7)		484 (59.9)		.2215
		4054 (57.7)			5 (45.5)	.5440

[a]Data are presented as n (%) unless otherwise indicated.

TABLE 7
Multivariate Regression Analysis of Risk of HTO for Patients Aged ≥40[a]

	Age >40 y (n = 32,059)		
	P	HR	95% CI
Type of graft			
Autograft		1.00	
Allograft	.0953	1.28	0.96-1.72
Sex			
Male		1.00	
Female	<.0001	2.30	1.89-2.80
Smoking			
Nonsmoker or previous smoker		1.00	
Smoker	.4871	0.92	0.73-1.16
BMI			
Underweight	.6250	0.61	0.09-4.38
Normal		1.00	
Overweight	<.0001	1.87	1.54-2.27
Obese	<.0001	2.75	2.08-3.64
Morbidly obese	.0520	4.00	0.99-16.17
Meniscus or meniscal repair			
No		1.00	
Yes	.0012	1.35	1.13-1.62

[a]BMI, body mass index; HR, hazard ratio; HTO, high tibial osteotomy.

TABLE 8
Multivariate Regression Risk Analysis of TKA for Patients Aged ≥50[a]

	Age >50 y (n = 14,081; Morbidly Obese Group Excluded)		
	P	HR	95% CI
Type of graft			
Autograft		1.00	
Allograft	.0086	1.65	1.14-2.39
Sex			
Male		1.00	
Female	<.0001	2.99	2.44-3.65
Smoking			
Nonsmoker or previous smoker		1.00	
Smoker	.6982	0.95	0.72-1.25
BMI			
Underweight	.2834	2.15	0.53-8.67
Normal		1.00	
Overweight	<.0001	2.02	1.66-2.45
Obese	<.0001	2.52	1.82-3.48
Meniscus or meniscal repair			
No		1.00	
Yes	.0839	1.18	0.98-1.42

[a]BMI, body mass index; TKA, total knee arthroplasty.

obese patients not having a goal to return to highly demanding physical activities could affect the decision of revision surgery. Furthermore, considering that preexisting osteoarthritis could be a relative contraindication for revision ACL reconstruction, and obesity itself has higher risk of osteoarthritis, risk of graft failure needing revision ACL reconstruction could have been more underestimated in the higher BMI group. Regarding the results of our study, primary ACL reconstruction should not be avoided because of obesity itself, but further studies should focus on the differences in instability, subjective and objective outcomes, pre- and postoperative functional levels, and radiological outcomes in relation to obesity, which might be a more direct assessment of the outcome of ACL surgery.

Regarding the study design, age distribution, and follow-up period, the progression of osteoarthritis in patients <40 years of age could not be fully estimated. Hence, a long-term follow-up of these patients should be considered to precisely clarify the relationship between ACL reconstruction and osteoarthritis progression.

Because 43.5% of the ACL reconstructions were performed in patients aged <40 years and given the difference in age distribution between the BMI groups, subgroup analysis was done for patients ≥50 years for TKA and ≥40 years for HTO. Because TKA was performed for 86.4% (484/560) of patients aged ≥50 years and HTO was performed for 81.6% (506/620) of patients aged ≥40 years, it was thought that this subgroup analysis would better explain the risk of HTO and TKA.

Our study also analyzed the proportion of patients who had undergone a concomitant meniscal procedure at the index ACL reconstruction. Considering the various functions of the meniscus, injury of the meniscus could also be a factor in osteoarthritis progression. The proportion of meniscal procedures performed was significantly different between the BMI groups, which led to a multivariate regression analysis to identify whether BMI is a risk factor independent of an increased risk due to meniscal injury. This subgroup analysis also showed an increased risk in overweight and obese patients, which indicates that beyond the increased risk of osteoarthritis progression due to the increased risk of meniscal injury initially, an increased BMI itself is a risk factor for osteoarthritis progression after ACL reconstruction.

As shown in our study, the overweight and obese groups had a significantly increased risk of HTO, TKA, and HTO or TKA. HTO and TKA both share common surgical procedures for symptomatically progressed osteoarthritis. However, this result may not be due to only an inferior outcome of ACL reconstruction. Previous studies have shown that obesity is a risk factor for osteoarthritis in knee joints. Obesity is known as a mild risk factor for osteoarthritis according to a World Health Organization report,[27] and other studies have analyzed the risk of TKA in relation to obesity alone. A study by Hussain et al[12] showed that the risk of TKA in Australia is 2.49 times more than that in the normal weight group. Leyland et al[16] showed that those with a BMI between 25 and 30, 30 and 35, between 35 and 40, or >40 had 1.41, 1.97, 2.39, and 2.67 times increased risk of TKA, respectively, compared with the normal weight group. Considering this increased risk of TKA in patients with or without ACL reconstruction, further studies, such as a matched pair analysis with patients without ACL reconstruction, could more precisely analyze the impact of obesity in ACL reconstruction regarding progression to end-stage osteoarthritis.

Limitations and Strengths

Our study has some limitations. First, given our data collection method, our study could not identify every meniscal injury considering that a proportion of meniscal injuries are left in situ. Previous studies have reported that stable meniscal lesions left in situ during ACL reconstruction showed good clinical results. However, the complete healing rates confirmed by arthroscopy were 55% to 74% for the lateral meniscus and 50% to 61% for the medial meniscus.[4,25,28] The effect of an untreated meniscal tear in the index surgery was omitted because of the limitation of big data analysis. An unhealed meniscus could also be a confounder to the progression of osteoarthritis, which we were not able to analyze. Second, our study analysis was based only on BMI, which precludes the influence of different body compositions. Obesity could be classified as sarcopenic obesity and nonsarcopenic obesity. A recent study[17] has shown a higher risk of osteoarthritis and an inferior outcome of TKA in a sarcopenic obese group. Given our study design, muscle mass could not be analyzed, and further study regarding the difference in ACL reconstruction outcome between those with sarcopenic obesity and nonsarcopenic obesity is needed. Third, because of the data collection method, various factors affecting outcomes of ACL reconstruction were excluded. Not all patients with persistent instability after primary reconstruction undergo revision surgery unconditionally. The patient's level of physical activity, progression of osteoarthritis, obesity, alignment of the lower extremity, and other factors are considered comprehensively. However, our study could not obtain these data for individuals, which is a limitation considering that obesity also contributes to the decision of nonoperative care after a poor outcome of ACL reconstruction. The diagnostic and procedure codes were also not side specific. Indirect confirmation for identification of laterality was inevitable, and a new version of claims data including laterality should be considered for a more precise big data analysis. Despite these limitations, our study's strength is its size. To our knowledge, there has been no large-scale study regarding the surgical outcome of ACL reconstruction associated with obesity. Also, considering the mandatory national health insurance in the Republic of Korea, our data collection method could include and analyze patients without selection bias.

CONCLUSION

Based on our nationwide retrospective cohort study, the ACL reconstruction revision rate did not significantly increase in overweight, obese, or morbidly obese patients. The risk of subsequent surgical procedures due to secondary meniscal lesions and osteoarthritis increased in the overweight and obese groups. Further studies are needed to clarify the contributing factors to the outcome of ACL reconstruction in association with obesity.

REFERENCES

1. Almeida A, Valin MR, Ferreira R, de Almeida NC, Agostini AP. Correlation between the result from arthroscopic reconstruction of the anterior cruciate ligament of the knee and the return to sports activity. *Rev Bras Ortop*. 2014;49(3):240-244.

2. Almeida A, Valin MR, Ferreira R, Roveda G, de Almeida NC, Agostini AP. Evaluation of the results of arthroscopic ACL reconstruction with autogenous flexor tendons. *Rev Bras Ortop*. 2015;45(4): 404-408.
3. Ballal MS, Khan Y, Hastie G, Hatcher A, Coogan S, McNicholas MJ. Functional outcome of primary hamstring anterior cruciate ligament reconstruction in patients with different body mass index classes. *Arthroscopy*. 2013;29(8):1314-1321.
4. Beaufils P, Bastos R, Wakim E, Cho SH, Petit-Jouvet C. Meniscal injury in the plastic reconstruction of the anterior cruciate ligament. Meniscal suture or abstention. *Rev Chir Orthop Reparatrice Appar Mot*. 1992;78(5):285-291.
5. Brambilla L, Pulici L, Carimati G, et al. Prevalence of associated lesions in anterior cruciate ligament reconstruction: correlation with surgical timing and with patient age, sex, and body mass index. *Am J Sports Med*. 2015;43(12):2966-2973.
6. Burns EA, Collins AD, Jack RA, et al. Trends in the body mass index of pediatric and adult patients undergoing anterior cruciate ligament reconstruction. *Orthop J Sports Med*. 2018;6(4):2325967118767398.
7. de Oliveira FCL, Roy J, Pappas E. ACL injury, physical activity, and overweight/obesity: a vicious cycle? *Knee Surg Sports Traumatol Arthrosc*. 2020;28(3):667-669.
8. Diermeier T, Rothrauff BB, Engebretsen L, et al. Treatment after anterior cruciate ligament injury: Panther Symposium ACL Treatment Consensus Group. *Knee Surg Sports Traumatol Arthrosc*. 2020; 28(8):2390-2402.
9. Dobbs R, Sawers C, Thompson F, et al. *Overcoming Obesity: An Initial Economic Analysis*. McKinsey Global Institute; 2014. Accessed July 14, 2024. https://www.mckinsey.com/~/media/mckinsey/business%20functions/economic%20studies%20temp/our%20insights/how%20the%20world%20could%20better%20fight%20obesity/mgi_overcoming_obesity_full_report.ashx
10. Granan L, Bahr R, Lie SA, et al. Timing of anterior cruciate ligament reconstructive surgery and risk of cartilage lesions and meniscal tears: a cohort study based on the Norwegian National Knee Ligament Registry. *Am J Sports Med*. 2009;37(5):955-961.
11. Hewett TE, Myer GD, Ford KR. Anterior cruciate ligament injuries in female athletes: part 1, mechanisms and risk factors. *Am J Sports Med*. 2006;34(2):299-311.
12. Hussain SM, Wang Y, Shaw JE, et al. Relationship of weight and obesity with the risk of knee and hip arthroplasty for osteoarthritis across different levels of physical performance: a prospective cohort study. *Scand J Rheumatol*. 2019;48(1):64-71.
13. Inderhaug E, Drogset JO, Lygre SHL, Gifstad T. No effect of graft size or body mass index on risk of revision after ACL reconstruction using hamstrings autograft. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(3):707-713.
14. Jiang J, Teng Y, Fan Z, et al. Does obesity affect the surgical outcome and complication rates of spinal surgery? A meta-analysis. *Clin Orthop Relat Res*. 2014;472(3):968-975.
15. Kowalchuk DA, Harner CD, Fu FH, Irrgang JJ. Prediction of patient-reported outcome after single-bundle anterior cruciate ligament reconstruction. *Arthroscopy*. 2009;25(5):457-463.
16. Leyland KM, Judge A, Javaid MK, et al. Obesity and the relative risk of knee replacement surgery in patients with knee osteoarthritis: a prospective cohort study. *Arthritis Rheumatol*. 2016;68(4):817-825.
17. Liao CD, Huang SW, Huang YY, Lin CL. Effects of Sarcopenic Obesity and Its Confounders on Knee Range of Motion Outcome after Total Knee Replacement in Older Adults with Knee Osteoarthritis: A Retrospective Study. *Nutrients*. 2021 Oct 27;13(11):3817.
18. Maletis GB, Chen J, Inacio MC, et al. Age-related risk factors for revision anterior cruciate ligament reconstruction: a cohort study of 21,304 patients from the Kaiser Permanente anterior cruciate ligament registry. *Am J Sports Med*. 2016;44(2):331-336.
19. Maletis GB, Inacio MC, Funahashi TT. Risk factors associated with revision and contralateral anterior cruciate ligament reconstructions in the Kaiser Permanente ACLR registry. *Am J Sports Med*. 2015;43(3):641-647.
20. Martin JR, Jennings JM, Dennis DA. Morbid obesity and total knee arthroplasty: a growing problem. *J Am Acad Orthop Surg*. 2017;25(3):188-194.
21. Miller MD, Kew ME, Quinn CA. Anterior cruciate ligament revision reconstruction. *J Am Acad Orthop Surg*. 2021;29(17):723-731.
22. Pi-Sunyer FX. Comorbidities of overweight and obesity: current evidence and research issues. *Med Sci Sports Exerc*. 1999;31(11) (suppl):S602-S608.
23. Tremmel M, Gerdtham U, Nilsson PM, et al. Economic burden of obesity: a systematic literature review. *Int J Environ Res Public Health*. 2017;14(4):435.
24. Uhorchak JM, Scoville CR, Williams GN, et al. Risk factors associated with noncontact injury of the anterior cruciate ligament: a prospective four-year evaluation of 859 West Point cadets. *Am J Sports Med*. 2003;31(6):831-842.
25. Weiss CB, Lundberg M, Hamberg P, DeHaven KE, Gillquist J. Non-operative treatment of meniscal tears. *J Bone Joint Surg Am*. 1989;71(6):811-822.
26. Werner BC, Gwathmey FW, Higgins ST, et al. Ultra-low velocity knee dislocations: patient characteristics, complications, and outcomes. *Am J Sports Med*. 2014;42(2):358-363.
27. World Health Organization. Obesity: preventing and managing the global epidemic: report of a WHO consultation. 2000.
28. Yagishita K, Muneta T, Ogiuchi T, Sekiya I, Shinomiya K. Healing potential of meniscal tears without repair in knees with anterior cruciate ligament reconstruction. *Am J Sports Med*. 2004;32(8):1953-1961.