Original Article

Total Knee Arthroplasty After Meniscectomy Is More Likely in Patients With Bicompartmental or Complex Tears

Elyse J. Berlinberg, B.S., Melissa Song, B.A., Lakshmanan Sivasundaram, M.D., Harsh H. Patel, B.A., Randy Mascarenhas, M.D., and Brian Forsythe, M.D.

Purpose: To determine the relationship between meniscus tear morphologies, stratified by location and pattern, and knee arthroplasty rates in a commercial insurance population. **Methods:** The PearlDiver database was queried for patients ≥35 years old with a meniscus tear of specified laterality and ≥2 years follow-up between 2015 and 2018. Two analyses were conducted with cohorts matched on age, sex, Charlson Comorbidity Index, obesity, osteoarthritis (OA), and treatment (meniscectomy vs conservative): one with equal-sized subgroups by tear location (medial only, lateral only, or both medial and lateral) and another by tear pattern (bucket-handle, complex, or peripheral). The rate of subsequent total knee arthroplasty (TKA) was compared between matched groups. **Results:** In total, 129,987 patients (mean age: 57.8 ± 10.5 years) were matched by tear location; 1,734 patients with medial-only tears (4.0%), 1,786 with lateral-only tears (4.1%), and 2,611 with medial plus lateral tears (6.0%) underwent a TKA within 5 years ($P < .001$). Patients with both medial and lateral tears were 1.55-fold more likely to undergo TKA. In total, 24,213 patients (mean age: 56.0 ± 10.5 years) were matched by tear pattern; 296 patients with bucket-handle tears (3.7%), 373 with complex tears (4.6%), and 336 with peripheral tears (4.2%) underwent TKA ($P = .01$). Patients with complex tears were 1.29-fold more likely to undergo TKA than patients with bucket-handle tears ($P = .002$). **Conclusions:** In matched cohorts of patients with degenerative meniscus tears, having both medial plus lateral tears conferred a 1.5-fold risk of TKA, whereas complex tears conferred a 1.3-fold risk within 5 years. Specific meniscal tear patterns and locations harbor varying risk in progressing to end-stage knee OA, and these data may help counsel patients about their likelihood of progressing to end-stage OA warranting an arthroplasty procedure. **Level of Evidence:** Level III, retrospective comparative study.

Meniscus tears are one of the most common pathologies managed by orthopaedic surgeons in the United States.[1] With more than 850,000 meniscus surgeries performed annually, direct costs to the health system approach 5 billion dollars every year.[2,3] Historically, the mainstay treatment for meniscus injuries was total meniscectomy.[4] In the 1980s, it was found that patients with subtotal and total meniscectomy developed significant articular cartilage degeneration, and the risk of arthritis directly correlated with the amount of meniscal tissue removed.[4] This discovery validated the critical role the meniscus has in protecting the knee articular cartilage by serving as a load transmitter and stabilizer between the femur and tibia.[5] These

From Midwest Orthopedics at Rush, Chicago, Illinois, U.S.A. (E.J.B., L.S., H.H.P., B.F.); NYU Grossman School of Medicine, New York, New York, U.S.A. (E.J.B., M.S.); and Winnipeg Clinic, Winnipeg, Manitoba, Canada (R.M.).

The authors report the following potential conflicts of interest or sources of funding: E.J.B. reports stock or stock options in Amgen, Johnson & Johnson, and Pfizer, outside the submitted work. R.M. reports leadership or fiduciary role in other board, society, committee or advocacy group, paid or unpaid: American Orthopaedic Society for Sports Medicine, International Society of Arthroscopy, Knee Surgery, and Orthopaedic Sports Medicine, and Journal of Bone and Joint Surgery - American*; and stock or stock options in ROMTech. B.F. reports grants for contracts from Arthrex, Smith & Nephew, and Stryker; royalties or licenses from Elsevier; consulting fees from Smith & Nephew; leadership or fiduciary role in other board, society, committee or advocacy group, paid or unpaid: American Orthopaedic Society for Sports Medicine and* Video Journal of Sports Medicine*; stock or stock options from i-BrainTech, Jace Medical, and Sparta Biopharma; and receipt of equipment, materials, drugs, medical writing, gifts or other services from Elsevier. Full ICMJE author disclosure forms are available for this article online, as supplementary material.*

Received December 14, 2021; accepted February 16, 2023.

Address correspondence to Brian Forsythe, M.D., 1611 W. Harrison St, Suite 360, Chicago, IL 60612. E-mail: brian.forsythe@rushortho.com or forsythe.research@rushortho.com

2666-061X/211772

https://doi.org/10.1016/j.asmr.2023.02.010

fibrocartilaginous pads reduce contact forces in the tibiofemoral joint by redistributing compressive loads into circumferential tensile forces, a phenomenon described as the "hoop stress mechanism."[6,7] Since injury to the meniscus results in loss of this protective mechanism and chronic stress upon the joint,[6] the patient with meniscal deficiency may develop degenerative joint disease at an accelerated rate.

Although the relationship between meniscectomy and progression of osteoarthritis is well-established,[8,9] the impact of different tear morphologies on this process remains controversial.[10-13] Meniscus tears may be the result of traumatic or degenerative processes, resulting in different tear morphologies.[14] These tears can be further stratified by location (medial, lateral, or both medial plus lateral) and pattern. It is well-described that the medial and lateral menisci differ in their biomechanical properties[15] and blood supply,[16] which may contribute to the differences in the long-term impacts of medial versus lateral meniscus tears. Certain tear patterns, including bucket-handle and complex tears, have been posited to cause more significant joint degeneration.[17-19] However, the connection between meniscus tear morphology and end-stage osteoarthritis progression has yet to be defined in a large, human population, with the existing literature focusing on animal models with divergent findings.[11,15,20,21] As the gold standard treatment for end-stage knee osteoarthritis, a tibiofemoral arthroplasty procedure (either unicompartmental [UKA] or total knee arthroplasty [TKA]) is a clear indicator of significant osteoarthritis burden.[22] Therefore, it is imperative to elucidate whether particular tear morphologies harbor a greater risk of developing osteoarthritis, to better counsel patients about their knee's prognosis postmeniscectomy.

The purpose of this study is to determine the relationship between meniscus tear morphologies, stratified by location and pattern, and knee arthroplasty rates in a commercial insurance population. We hypothesized that knee arthroplasty rates would vary by meniscus tear locations and patterns, with a greater risk of knee arthroplasty for lateral-sided tears and complex tear patterns.

Methods

Data Collection

Data were extracted from the PearlDiver Patient Record Database (PearlDiver Technologies, Colorado Springs, CO), which maintains an all-claims dataset (Mariner) that reflects data collected for patients insured by commercial, Medicare, Medicaid, government, and cash payers. The dataset represents 144 million patients from 2010 through quarter 1 (Q1) of 2020. We queried the subset M91Ortho, which contains a sampling of 91 million patients from the Mariner database. Variables collected included age, sex, comorbidities, complications, and subsequent procedures. This study was granted approval from our institutional review board, and study procedures were compliant with the Declaration of Helsinki and the Health Insurance Portability and Accountability Act (HIPAA).

Inclusion Criteria

We queried the dataset for all patients older than 35 years old with a primary *International Classification of Diseases, Tenth Revision* (ICD-10) code for a meniscus tear of specified laterality between 2013 and Q1.2020. Patients without specified laterality, less than 2 years of follow-up, and/or lack of meniscus tear as their primary visit diagnosis were excluded. Patients also were excluded if they had a concurrent or subsequent open or mini-open procedure, including reconstructions of the anterior cruciate ligament, posterior cruciate ligament, posterolateral corner, or medial collateral ligament; distal femoral or high tibial osteotomy; microfracture; osteochondral allograft; and implantations of autologous chondrocyte or meniscal allograft (Appendix Table 1, available at www.arthroscopyjournal.org). These additional procedures may additionally affect the likelihood of a subsequent arthroplasty.

Tear Descriptors

Tear locations were defined as medial or lateral sided via ICD-10 codes, or both medial and lateral (medial plus lateral) sided via either ICD-10 codes for medial plus lateral tear at the same visit and/or Current Procedural Terminology (CPT) code 29880 (medial and lateral compartment meniscectomy). CPT codes were used to identify medial plus lateral tears found intraoperatively that were not initially coded at diagnosis via ICD-10 coding. Similarly, tear patterns were specified by ICD-10 coding, including bucket-handle tears, peripheral tears, or complex tears. Other tear patterns (e.g., horizontal tears, flap tears) were not specified due to a lack of specific ICD-10 codes. Codes used to specify tear descriptors are described in Appendix Table 2, available at www.arthroscopyjournal.org.

Matching

A matched case—control analysis was completed to compare the rates of TKA after meniscal tears based on tear pattern or tear location. Two separate instances of matching occurred: one for tear pattern, and one for tear location. In both instances, patients were matched by age, sex, Charlson Comorbidity Index (CCI), comorbid obesity, concomitant ipsilateral knee osteoarthritis, and intervention (meniscectomy or no knee arthroscopy, which was presumed to represent conservative treatment). Intervention was identified via a

CPT code for a meniscectomy (CPT-29880, CPT-29881) or absence of any code for an arthroscopic procedure.

Statistical Analysis

The primary outcome was rate of TKA, defined by CPT code 27447, or UKA, defined by CPT code 27446, conducted on the same side as the ICD-10 code for meniscal tear. The secondary outcome was time between diagnosis of the meniscal tear and the arthroplasty procedure. Demographics and complications were described using counts and proportions or median and interquartile range. Categorical variables were compared via χ^2; continuous variables were compared via one-way analysis of variance. Predictors of subsequent arthroplasty were modeled using multivariable logistic regression, with prespecified independent variables including age, sex, CCI, obesity, osteoarthritis, and tear pattern/tear location.

Our sample sizes of 129,987 patients for the tear location analysis and 24,213 patients for the tear pattern analysis provided more than 80% power to detect a 0.1% difference in arthroplasty rates. Significance was set at 0.05 with Bonferroni corrections for multiple comparisons. Analyses were performed in the PearlDiver BellWether platform, which uses statistical packages from R (The R Project, Vienna, Austria).

Results

Demographics: Tear Location Analysis

A total of 2.47 million potential subjects were identified. Of these, 1.97 million were excluded. In total, 344,884 eligible patients (13.5% of total meniscal tears in database) were identified in the dataset with a primary ICD-10 code for meniscus tear with specified laterality and location (Fig 1). Of these, 129,987 patients were matched 1:1:1 by age, sex, CCI, comorbid obesity, concomitant ipsilateral knee osteoarthritis, and surgical intervention to yield 3 equal-sized cohorts representing medial-only, lateral-only, and medial plus lateral-sided tears. Demographics were similar among the groups and are displayed in Table 1.

Knee Arthroplasty by Tear Location

Of the 43,329 matched patients with a medial-sided tear, 2,034 underwent a knee arthroplasty procedure (4.7%): 1,718 with a TKA (4.0%), 316 with a UKA (0.7%), and 16 with sequential UKA converted to a TKA (0.04%). In total, 1,949 patients (4.5%) with a lateral tear had a knee arthroplasty procedure: 1,778 with a TKA (4.1%), 171 with a UKA (0.4%), and 8 (0.02%) with a UKA eventually converted to a TKA. Finally, among patients with both a medial- and lateral-sided tear, 2,810 (6.5%) had a tibiofemoral knee arthroplasty: 2,794 (6.4%) patients with a TKA alone, 215 patients with a UKA (0.5%), and 16 with a UKA followed by TKA (0.04%). The rates of a knee arthroplasty procedure ($P < .001$), TKA ($P < .001$), and UKA ($P < .001$) differed between patients with medial, lateral, and medial- and lateral-sided tears (Table 2). In pairwise comparisons, patients with medial- or lateral-sided tears did not have differing rates of knee arthroplasty in general, but patients with medial plus lateral tears were more likely to have a UKA or TKA than

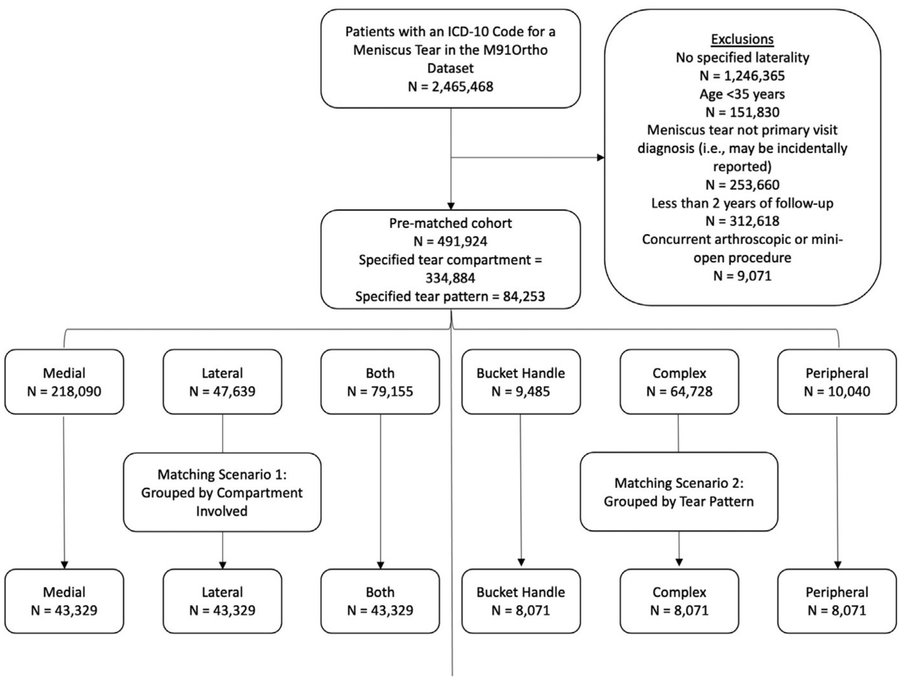

Fig 1. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) flowchart of population cohort selection. (ICD-10, *International Classification of Diseases, Tenth Revision.*)

Table 1. Demographics for Matched Groups by Tear Location

	Medial (N = 43,329)		Lateral (N = 43,329)		Medial Plus Lateral (N = 43,329)		*P* Value
Female sex, n (%)*	28,248	(65.2)	28,248	(65.2)	28,248	(65.2)	>.99
Mean age, y (SD)*	57.8	(10.5)	57.8	(10.5)	57.8	(10.5)	.45
Obesity, n (%)*	19,013	(43.9)	19,013	(43.9)	19,013	(43.9)	>.99
Mean CCI (SD)*	1.3	(1.8)	1.3	(1.8)	1.3	(1.8)	.65
Meniscectomy, n (%)*	7,678	(17.7)	7,678	(17.7)	7,678	(17.7)	>.99

CCI, Charlson Comorbidity Index; SD, standard deviation.
*Matching criteria.

patients with unicompartmental tears (*P* < .001). Arthroplasty-free survival did not differ by tear location (Table 2, Fig 2).

Predictors of TKA When Matched by Tear Location

Multivariable logistic regression identified several predictors of TKA in patients matched by meniscal tear location (Table 3). Factors associated with an increased risk of TKA included a diagnosis of ipsilateral knee osteoarthritis (odds ratio [OR] 1.74, 95% confidence interval [CI] 1.52-1.99, *P* < .001), older age (OR 1.04, 95% CI 1.03-1.04, *P* < .001), female sex (OR 1.43, 95% CI 1.35-1.52, *P* < .001), CCI (OR 1.04, 95% CI 1.03-1.06, *P* < .001), and obesity (OR 2.05, 95% CI 1.94-2.17, *P* < .001). When we controlled for the aforementioned factors, having a lateral tear was not associated with a TKA compared with medial tears (OR 1.01, 95% CI 0.95-1.09, *P* = .42), but having both medial- and lateral-sided tears was associated with 1.55-fold odds of TKA compared with a medial-only tear (95% CI 1.45-1.65, *P* < .001). Having a meniscectomy was associated with a 15% reduction in likelihood of a TKA (95% CI 0.78-0.92, *P* = .0002), corresponding to a number needed to treat of 6.67.

Demographics: Tear Pattern Analysis

A total of 84,254 eligible patients (3.4% of total meniscal tears in database) were identified in the dataset with ICD-10 codes for bucket-handle, peripheral, and complex tear patterns. After matching by age, sex, CCI, comorbid obesity, concomitant ipsilateral knee osteoarthritis, and surgical intervention, 3 cohorts comprising of 8,071 patients were established with comparable demographics (Table 4).

Knee Arthroplasty by Tear Pattern

Of 8,071 patients with a bucket-handle tear, 296 underwent a knee arthroplasty procedure (3.7%): 268 with a TKA (3.3%) and 28 with a UKA that was converted to a TKA within 5 years of follow-up (0.3%). In total, 375 patients (4.6%) with a complex tear had a knee arthroplasty, including 373 with a TKA (4.6%), 2 with a UKA alone (0.02%), and 49 (0.6%) with a UKA followed by a TKA. A total of 345 patients (4.3%) with

Table 2. Rate and Time to Arthroplasty by Tear Location

N, %	Medial (N = 43,329)		Lateral (N = 43,329)		Medial Plus Lateral (N = 43,329)	%	*P* Value
Subsequent TKA/UKA	2,034	(4.7)	1,949	(4.5)	2,810	(6.5)	<.001
Pairwise comparisons							
	2,034	(4.7)	1,949	(4.5)	–	–	.17
	2,034	(4.7)	–	–	2,810	(6.5)	<.001
	–	–	1,949	(4.5)	2,810	(6.5)	<.001
Time to TKA/UKA**,** Median Days, IQR	412	172-785	410	166-777	438	226-813	.65
Subsequent TKA	1,734	(4.0)	1,786	(4.1)	2,611	(6.0)	<.001
Pairwise comparisons							
	1,734	(4.0)	1,786	(4.1)	–	–	.002
	1,734	(4.0)	–	–	2,611	(6.0)	<.001
	–	–	1,786	(4.1)	2,611	(6.0)	<.001
Time to TKA, median days, IQR	440	185-813	415	169-787	448	231-827	.69
Subsequent UKA	316	(0.7)	171	(0.4)	215	(0.5)	<.001
Pairwise comparisons							
	316	(0.7)	171	(0.4)	–	–	
	316	(0.7)	–	–	215	(0.5)	<.001
	–	–	171	(0.4)	215	(0.5)	.03
Time to UKA, median days, IQR	301	108-570	348	135-678	385	210-721	.18

TKA, total knee arthroplasty; UKA, unicompartmental knee arthroplasty.

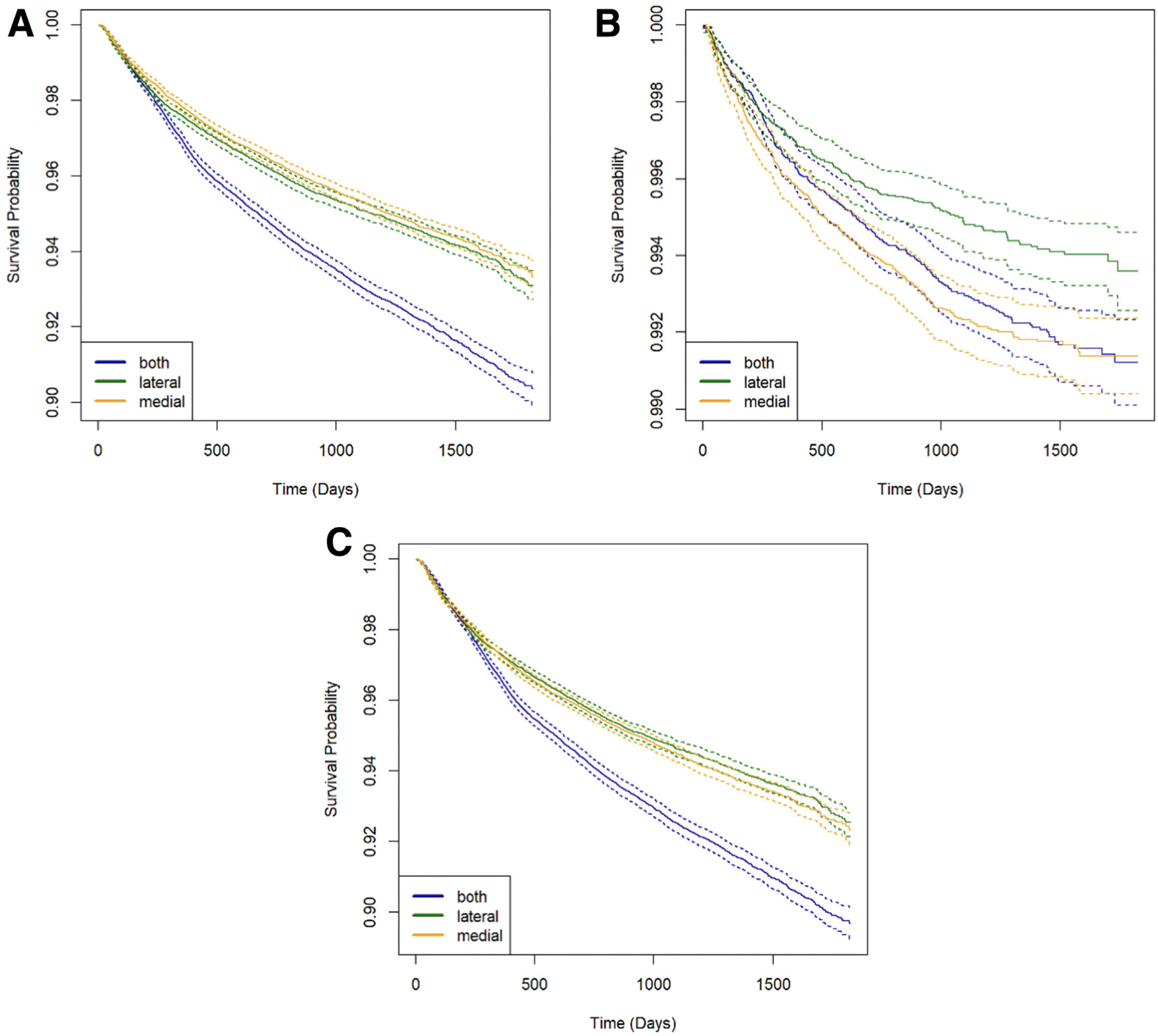

Fig 2. (A) Knee arthroplasty-free survival, (B) TKA-free survival, and (C) UKA-free survival for medial, lateral, and medial plus lateral meniscal tears after meniscectomy. (TKA, total knee arthroplasty; UKA, unicompartmental knee arthroplasty.)

Table 3. Multivariable Predictors of TKA in Matched Cohorts Based on Tear Location

Risk factor	OR	(95% CI)		*P* Value
Ipsilateral knee OA	1.74	1.52	1.99	<.0001
Age	1.04	1.03	1.04	<.0001
Male sex	0.70	0.66	0.74	<.0001
Charlson Comorbidity Index	1.04	1.03	1.06	<.0001
Obesity	2.05	1.94	2.17	<.0001
Tear location				
Medial tear (ref)	1.00	–	–	–
Lateral tear	1.01	0.95	1.09	.42
Medial plus lateral tear	1.55	1.45	1.65	<.0001
Treatment				
Conservative (ref)	1.00	–	–	–
Meniscectomy	0.85	0.78	0.92	.0002

CI, confidence interval; OA, osteoarthritis; OR, odds ratio; TKA, total knee arthroplasty.

a peripheral tear underwent a subsequent TKA or UKA, 296 with a TKA alone (3.7%), 9 with a UKA alone (0.1%), and 40 with a UKA followed by TKA (0.5%). The rates of any knee arthroplasty (P = .002), TKA (P = .01), and UKA (P = .02), differed by tear pattern (Table 5). In pairwise comparisons, patients with complex tears (P < .001) and peripheral tears (P = .02) were more likely to undergo a knee arthroplasty than patients with bucket-handle tears; this was also true for UKA, with twice the rate of UKA in patients with peripheral and complex tears compared with those with bucket-handle tears. TKA rates after complex and peripheral tears, however, were comparable (P = .11). Arthroplasty-free survival did not differ by tear pattern (Table 5, Fig 3).

Table 4. Demographics for Matched Groups by Tear Pattern

	Bucket-Handle (N = 8,071)	%	Complex (N = 8,071)	%	Peripheral (N = 8,071)	%	*P* Value
Female sex, n (%)*	4,536	(56.2)	4,536	(56.2)	4,536	(56.2)	>.99
Mean Age (SD)*	56.0	10.5	56.1	10.4	56.1	10.4	.46
Obesity, n (%)*	4,747	(58.8)	4,747	(58.8)	4,747	(58.8)	>.99
Mean CCI (SD)*	1.1	(1.5)	1.1	(1.5)	1.1	(1.5)	.60
Meniscectomy, n (%)*	3,611	(44.7)	3,611	(44.7)	3,611	(44.7)	>.99

CCI, Charlson Comorbidity Index; SD, standard deviation.
*The characteristic was used as a matching criterion.

Predictors of TKA When Matched by Tear Pattern

A multivariable logistic regression identified several predictors of TKA in patients matched by meniscal tear pattern (Table 6). Ipsilateral knee osteoarthritis (OR 1.89, 95% CI 1.55-2.29, $P < .001$), older age (OR 1.04, 95% CI 1.04-1.05, $P < .001$), female sex (OR 1.50, 95% CI 1.30-1.72, $P = .007$), CCI (OR 1.05, 95% CI 1.01-1.09, $P < .001$), and obesity (OR 2.10, 95% CI 1.83-2.41, $P < .001$) were associated with TKA. After controlling for these features, a complex tear was associated with a 29% increase in TKA compared with a bucket-handle tear, but there were no significant differences in likelihood of TKA between peripheral and bucket-handle tears. Among patients with these 3 tear types, having a tear debridement was associated with a 17% increased risk of TKA at mid-term follow-up, which was associated with a number needed to harm of 5.9 ($P = .03$).

Discussion

In this study, we found that patients with lateral and medial plus lateral tears have significantly greater rates of TKA compared with those with isolated medial tears, even when controlling for important confounders such as knee osteoarthritis, obesity, and age; patients with complex tears have greater rates of TKA than patients with bucket-handle tears, and in a multivariable model controlling for age, ipsilateral knee osteoarthritis, obesity, and meniscus treatment, complex tears were associated with an increased likelihood of TKA.

This analysis found that medial plus lateral meniscal tears are associated with an approximately 1.5-fold greater likelihood of TKA within 2-5 years, compared with medial or lateral tears in isolation (6% vs 4% TKA, respectively). Previous studies have also shown an association between worsening osteoarthritis and both-compartment involvement tears.[7,23-25] Isolated medial tears are often representative of smoldering, degenerative changes within the knee and may progress slowly over time to symptomatic medial compartment osteoarthritis.[26] Patients with degenerative meniscal pathology may have a greater degree of overall osteoarthritis progression. An increased risk of TKA after a lateral meniscus tear may be attributable to differences in contact pressures and blood supply across the tibiofemoral joint. Although both the medial and lateral

Table 5. Rate and Time to Arthroplasty by Tear Pattern

	Bucket-Handle (N = 8,071)	%	Complex (N = 8,071)	%	Peripheral (N = 8,071)	%	*P* Value
Subsequent TKA/UKA	296	3.7	375	4.6	345	4.3	.002
Pairwise comparisons							
	296	3.7	375	4.6	–	–	<.001
	296	3.7	–	–	345	4.3	.02
	–	–	375	4.6	345	4.3	.27
Time to TKA/UKA, median days, IQR	476	204-896	398	187-772	467	242-808	.50
Subsequent TKA	296	3.7	373	4.6	336	4.2	.01
Pairwise comparisons							
	296	3.7	373	4.6	–		.003
	296	3.7	–		336	4.2	.11
	–	–	373	4.6	336	4.2	.17
Time to TKA, median days, IQR	461	204-945	412	193-784	467	243-810	.60
Subsequent UKA	28	0.3	51	0.6	49	0.6	.02
Pairwise comparisons							
	28	0.3	51	0.6	–	–	.01
	28	0.3	–	–	49	0.6	.02
	–	–	51	0.6	49	0.6	.92
Time to UKA, median days, IQR	582	215-767	362	184-742	529	205-855	.06

IQR, interquartile range; TKA, total knee arthroplasty; UKA, unicompartmental knee arthroplasty.

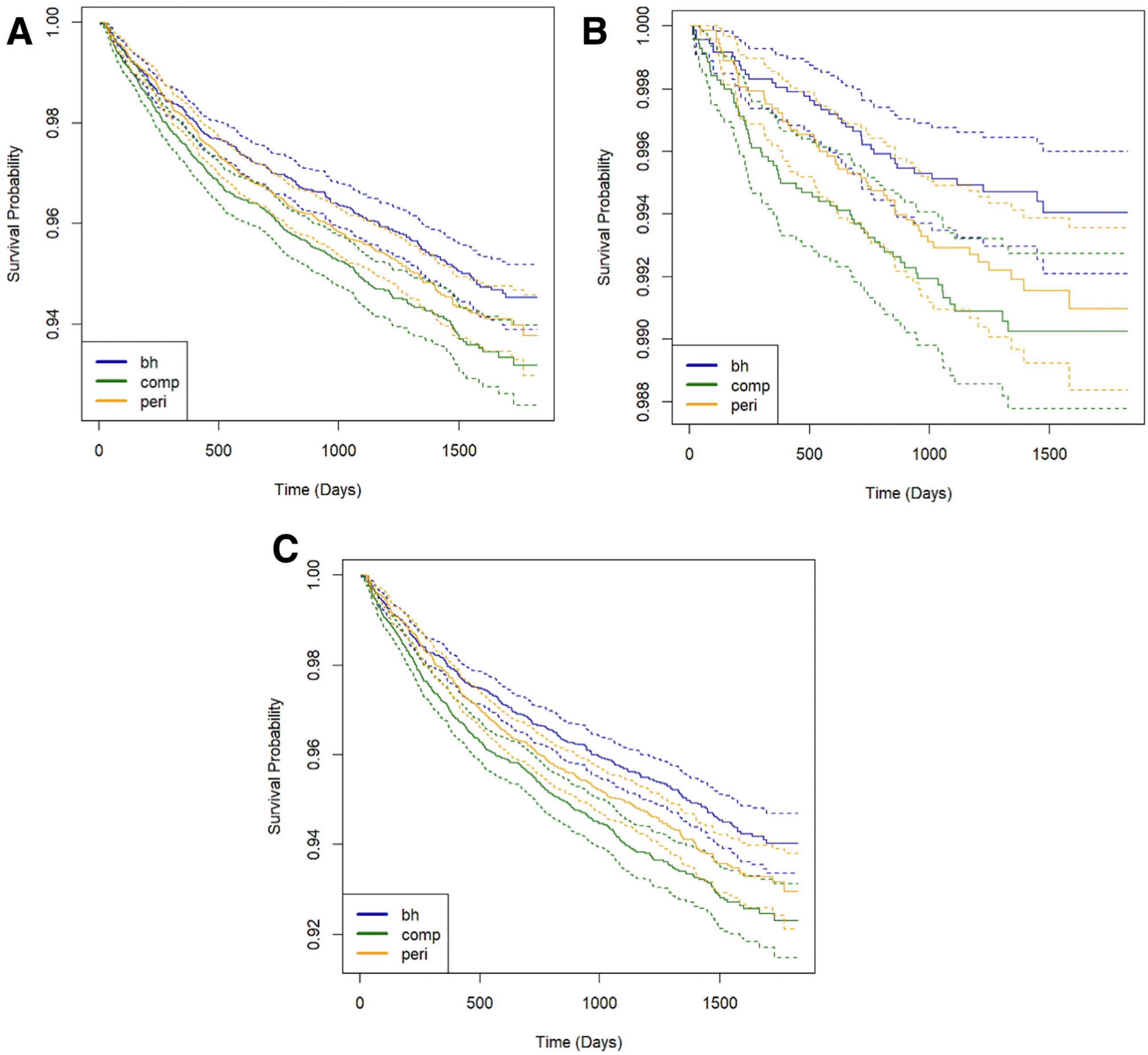

Fig 3. (A) Knee arthroplasty-free survival, (B) TKA-free survival, and (C) UKA-free survival for bucket-handle, complex, and peripheral meniscal tears after meniscectomy. (TKA, total knee arthroplasty; UKA, unicompartmental knee arthroplasty.)

menisci transform axial loads to tensile forces via the hoop stress mechanism, the lateral meniscus bears 100% of the lateral compartment load while the medial meniscus bears only 50% of the medial compartment load.[15] This differential load-bearing may contribute to the greater rates of radiographic changes seen after lateral meniscectomy compared with medial meniscectomy.[23] The medial meniscus is also known to have superior blood supply compared with the lateral meniscus.[16,26] Consequently, peripheral tears in the medial meniscus have demonstrated a greater healing potential than those in the lateral meniscus and may be more likely to heal in situ without surgical intervention.[7] Finally, a lateral meniscectomy may harbor greater risk for osteoarthritis due to the convex shape of the lateral tibial plateau. The medial tibial plateau may more favorably tolerate meniscectomy due to its concave morphology, which better complements the curvature of the medial femoral condyle.[23,27,28] Overall, the current analysis is consistent with a growing body of literature suggesting the biomechanical and anatomic features of the lateral meniscus may confer a greater risk of progression to symptomatic knee osteoarthritis after injury.[24,25] Surgeons should, therefore, counsel patients with lateral and medial plus lateral tears about having a greater likelihood of

Table 6. Multivariable Predictors of TKA in Matched Cohorts Based on Tear Pattern

Risk factor	OR	(95% CI)		*P* Value
Ipsilateral knee OA	1.89	1.55	2.29	**<.001**
Age	1.04	1.04	1.05	**<.001**
Male sex	0.67	0.58	0.77	**.007**
Charlson Comorbidity Index	1.05	1.01	1.09	**<.001**
Obesity	2.10	1.83	2.41	**<.001**
Tear type				
Bucket-handle tear (ref)	1.00	–	–	–
Complex tear	1.29	1.10	1.51	**.002**
Peripheral tear	1.14	0.97	1.34	.12
Treatment				
Conservative (ref)	1.00	–	–	–
Meniscectomy	1.17	1.02	1.36	**.03**

NOTE. Bold indicates statistically significant.

CI, confidence interval; OA, osteoarthritis; OR, odds ratio; TKA, total knee arthroplasty.

ongoing degenerative changes within their knee than in patients with isolated medial-sided tears.

In a matched analysis of progression to TKA by meniscal tear pattern, patients with complex tears were found to have significantly greater rates of TKA than patients with bucket-handle tears. Previous studies have demonstrated inconsistent results about whether tear pattern impacts the likelihood of developing knee osteoarthritis.[6,11,19-21,29-31] In general, certain tear patterns are more likely to occur following traumatic versus degenerative mechanisms, and it is thought that the mechanism of injury may have greater impact on the likelihood of ongoing degenerative changes than the tear pattern. Traumatic tears typically occur in younger patients due to excessive shearing forces, leading to vertical splitting parallel to the circumferential meniscus and thus producing vertical or bucket-handle tear patterns.[18] Degenerative tears often are related to meniscal stiffening, which may redistribute loads to the articular cartilage and accelerate wear.[32,33] Tear patterns commonly seen in degenerative menisci include horizontal cleavage, flap, and complex tears.[34] In a prospective study of cartilage damage found upon arthroscopic examination in more than 100 knees with meniscal tears, complex and flap tear types were associated with a greater degree of lateral compartment degeneration.[31] Henry et al.[31] concluded that tear types compromising circumferential meniscal fibers potentiate degenerative cartilage lesions. In this study, we examined bucket-handle and peripheral tears, which are more commonly seen in traumatic injuries, and complex tears, which are usually related to degenerative joint disease.[14] We found complex tears to be associated with greater rates of TKA when compared with bucket-handle tears, which supports the growing evidence that degenerative tears are a part of the natural history of knee osteoarthritis.[33]

Limitations

Limitations of our study include the use of a retrospective analysis, limited specificity for describing tears, interpersonal variability in thresholds for seeking treatment and standards for treatment. Retrospective studies are inherently biased due to lack of control over exposures, potential confounders, and missing data. While a prospective study could address these issues, the slow progression of degenerative joint disease warrants long-term studies that are logistically cumbersome. In addition, given the small differences in TKA rates between groups, a large sample size is required to adequately power the primary analysis. The sample size achievable in this retrospective, population-based analysis is not likely feasible for a prospective study. Second, although use of a commercial database can provide an adequately powered study, it limits data granularity that could impact the study findings such as tear etiology, tear chronicity, indications for meniscectomy, and surgeon expertise. Further, this administrative claims database could only specify broad categories of tear characteristics that could be described by an ICD-10 code. For both analyses, the treating provider may opt for a more general code of an “other/unspecified” tear instead of describing the location or tear type in the billing code. This limitation was mitigated by querying all meniscus-related billing codes within 3 months of when a patient was diagnosed with a meniscus tear, to catch specific codes that may have been billed at other visits. The analysis by tear pattern was limited, as only bucket-handle, complex, and peripheral tears are specified by ICD-10 codes. Other tear patterns such as horizontal tears, vertical tears, flap tears, free edge tears, or other would all be considered “other/unspecified” tears via ICD codes, and given the heterogeneity of this category it was excluded from the present analysis.

Importantly, the results are limited by the inability to assess underlying cartilage pathology. Dependence of time to TKA and TKA rates on tear morphology could both be confounded by degree of cartilage pathology at time of injury. Further, there is variation in pain and symptom tolerance amongst patients, leading to variability in time to seeking treatment with an arthroplasty procedure. We attempted to mitigate these risks by matching our cohorts based on known risk factors for symptomatology such as age, sex, obesity, preexisting osteoarthritis, and intervention (i.e., meniscectomy vs. no arthroscopy).[35] However, since we did not have radiographic data, such as Kellgren and Lawrence or Outterbridge scores for these patients, we could only match on the presence or absence of ipsilateral knee osteoarthritis rather than its severity. In addition, there is interpersonal variability in treatment options and timing pursued by different surgeons, which could impact both time to TKA and TKA rates.

However, the large size of the cohort analyzed minimizes the chance of interpersonal variability skewing the data. Finally, similar to all large database studies, the accuracy of the results relies on accurate coding and reporting. To limit this risk, PearlDiver maintains a dedicated staff person who conducts regularly quality checks.

Conclusions

In matched cohorts of patients with degenerative meniscus tears, having both medial plus lateral tears conferred a 1.5-fold risk of TKA, whereas complex tears conferred a 1.3-fold risk within 5 years. Specific meniscal tear patterns and locations harbor varying risk in progressing to end-stage knee osteoarthritis, and these data may help counsel patients about their likelihood of progressing to end-stage osteoarthritis warranting an arthroplasty procedure.

References

1. Salata MJ, Gibbs AE, Sekiya JK. A systematic review of clinical outcomes in patients undergoing meniscectomy. *Am J Sports Med* 2010;38:1907-1916.
2. Kim S, Bosque J, Meehan JP, Jamali A, Marder R. Increase in outpatient knee arthroscopy in the United States: A comparison of National Surveys of Ambulatory Surgery, 1996 and 2006. *J Bone Joint Surg* 2011;93: 994-1000.
3. Sihvonen R, Paavola M, Malmivaara A, et al. Arthroscopic partial meniscectomy for a degenerative meniscus tear: A 5 year follow-up of the placebo-surgery controlled FIDELITY (Finnish Degenerative Meniscus Lesion Study) trial. *Br J Sports Med* 2020;54:1332-1339.
4. Fairbank TJ. Knee joint changes after meniscectomy. *J Bone Joint Surg Br* 1948;30-B:664-670.
5. Fox AJS, Wanivenhaus F, Burge AJ, Warren RF, Rodeo SA. The human meniscus: A review of anatomy, function, injury, and advances in treatment. *Clin Anat* 2015;28:269-287.
6. Jones RS, Keene GCR, Learmonth DJA, et al. Direct measurement of hoop strains in the intact and torn human medial meniscus. *Clin Biomech* 1996;11:295-300.
7. Bedrin MD, Kartalias K, Yow BG, Dickens JF. Degenerative joint disease after meniscectomy. *Sports Med Arthrosc* 2021;29:e44-e50.
8. Chahla J, Cinque ME, Godin JA, et al. Meniscectomy and resultant articular cartilage lesions of the knee among prospective National Football League players: An imaging and performance analysis. *Am J Sports Med* 2018;46:200-207.
9. Hede A, Svalastoga E, Reimann I. Articular cartilage changes following meniscal lesions: Repair and meniscectomy studied in the rabbit knee. *Acta Orthop Scand* 1991;62:319-322.
10. Fahmy NR, Williams EA, Noble J. Meniscal pathology and osteoarthritis of the knee. *J Bone Joint Surg Br* 1983;65: 24-28.
11. Appleyard RC, Burkhardt D, Ghosh P, et al. Topographical analysis of the structural, biochemical and dynamic biomechanical properties of cartilage in an ovine model of osteoarthritis. *Osteoarthr Cartil* 2003;11:65-77.
12. Pelletier J-P, Raynauld J-P, Berthiaume M-J, et al. Risk factors associated with the loss of cartilage volume on weight-bearing areas in knee osteoarthritis patients assessed by quantitative magnetic resonance imaging: A longitudinal study. *Arthritis Res Ther* 2007;9:R74.
13. Adams BG, Houston MN, Cameron KL. The Epidemiology of Meniscus Injury. *Sports Med Arthrosc* 2021;29: e24-e33.
14. Bryceland JK, Powell AJ, Nunn T. *Knee Menisci.* Cartilage 2017;8:99-104.
15. Steineman BD, LaPrade RF, Santangelo KS, Warner BT, Goodrich LR, Haut Donahue TL. Early osteoarthritis after untreated anterior meniscal root tears: An in vivo animal study. *Orthop J Sport Med* 2017;5:2325967117702452.
16. Arnoczky SP, Warren RF. Microvasculature of the human meniscus. *Am J Sports Med* 1982;10:90-95.
17. Christoforakis J, Pradhan R, Sanchez-Ballester J, Hunt N, Strachan RK. Is there an association between articular cartilage changes and degenerative meniscus tears? *Arthroscopy* 2005;21:1366-1369.
18. Englund M, Guermazi A, Lohmander SL. The role of the meniscus in knee osteoarthritis: A cause or consequence? *Radiol Clin North Am* 2009;47:703-712.
19. Lewandrowski KU, Müller J, Schollmeier G. Concomitant meniscal and articular cartilage lesions in the femorotibial joint. *Am J Sports Med* 1997;25:486-494.
20. Janusz MJ, Bendele AM, Brown KK, Taiwo YO, Hsieh L, Heitmeyer SA. Induction of osteoarthritis in the rat by surgical tear of the meniscus: Inhibition of joint damage by a matrix metalloproteinase inhibitor. *Osteoarthr Cartil* 2002;10:785-791.
21. Wyland DJ, Guilak F, Elliott DM, Setton LA, Vail TP. Chondropathy after meniscal tear or partial meniscectomy in a canine model. *J Orthop Res* 2002;20:996-1002.
22. Carr AJ, Robertsson O, Graves S, et al. Knee replacement. *Lancet* 2012;379:1331-1340.
23. Chatain F, Adeleine P, Chambat P, Neyret P. A comparative study of medial versus lateral arthroscopic partial meniscectomy on stable knees: 10-year minimum follow-up. *Arthroscopy* 2003;19:842-849.
24. Arnoczky SP, Warren RF. The microvasculature of the meniscus and its response to injury. An experimental study in the dog. *Am J Sports Med* 1983;11:131-141.
25. Noyes FR, Barber-Westin SD. Arthroscopic repair of meniscal tears extending into the avascular zone in patients younger than twenty years of age. *Am J Sports Med* 2002;30:589-600.
26. Shelbourne KD, Gray T. Meniscus tears that can be left in situ, with or without trephination or synovial abrasion to stimulate healing. *Sports Med Arthrosc* 2012;20(2).
27. Hoser C, Fink C, Brown C, Reichkendler M, Hackl W, Bartlett J. Long-term results of arthroscopic partial lateral meniscectomy in knees without associated damage. *J Bone Joint Surg Br* 2001;83-B:513-516.

28. Peña E, Calvo B, Martinez MA, Palanca D, Doblaré M. Why lateral meniscectomy is more dangerous than medial meniscectomy. A finite element study. *J Orthop Res* 2006;24:1001-1010.
29. Muriuki MG, Tuason DA, Tucker BG, Harner CD. Changes in tibiofemoral contact mechanics following radial split and vertical tears of the medial meniscus an in vitro investigation of the efficacy of arthroscopic repair. *J Bone Joint Surg* 2011;93:1089-1095.
30. Jarraya M, Roemer FW, Englund M, et al. Meniscus morphology: Does tear type matter? A narrative review with focus on relevance for osteoarthritis research. *Semin Arthritis Rheum* 2017;46:552-561.
31. Henry S, Mascarenhas R, Kowalchuk D, Forsythe B, Irrgang JJ, Harner CD. Medial meniscus tear morphology and chondral degeneration of the knee: Is there a relationship? *Arthroscopy* 2012;28:1124-1134.e2.
32. Bhattacharyya T, Gale D, Dewire P, et al. The clinical importance of meniscal tears demonstrated by magnetic resonance imaging in osteoarthritis of the knee. *J Bone Joint Surg* 2003;85:4-9.
33. Seitz AM, Osthaus F, Schwer J, et al. Osteoarthritis-related degeneration alters the biomechanical properties of human menisci before the articular cartilage. *Front Bioeng Biotechnol* 2021;9:659989.
34. Poehling GG, Ruch DS, Chabon SJ. The landscape of meniscal injuries. *Clin Sports Med* 1990;9:539-549.
35. Blagojevic M, Jinks C, Jeffery A, Jordan KP. Risk factors for onset of osteoarthritis of the knee in older adults: A systematic review and meta-analysis. *Osteoarthr Cartil* 2010;18:24-33.

Appendix Table 1. CPT Codes Used to Exclude Patients With Partial or Fully Open Knee Procedures

Procedure	CPT Code
Anterior cruciate ligament reconstruction	CPT-29888
Posterior cruciate ligament reconstruction	CPT-29889
Posterolateral corner reconstruction	CPT-27427
Medial collateral ligament reconstruction	CPT-27428
Distal femoral osteotomy	CPT-27450
High tibial osteotomy	CPT-27457
Microfracture	CPT-29879
Osteochondral allograft	CPT-27415
Autologous chondrocyte implantation	CPT-27412
Meniscal allograft transplantation	CPT-29868

CPT, Current Procedural Terminology.

Appendix Table 2. ICD-10 Codes Used to Specify Tear Types

Tear Descriptor	ICD Codes
Medial	ICD-10-D-S83211A, ICD-10-D-S83221A, ICD-10-D-S83231A, ICD-10-D-S83241A, ICD-10-D-S83212A, ICD-10-D-S83222A, ICD-10-D-S83232A, ICD-10-D-S83242A
Lateral	ICD-10-D-S83251A, ICD-10-D-S83261A, ICD-10-D-S83271A, ICD-10-D-S83281A, ICD-10-D-S83252A, ICD-10-D-S83262A, ICD-10-D-S83272A, ICD-10-D-S83282A
Bucket-handle	ICD-10-D-S83200A, ICD-10-D-S83201A, ICD-10-D-S83211A, ICD-10-D-S83212A, ICD-10-D-S83251A, ICD-10-D-S83252A
Peripheral	ICD-10-D-S83221A, ICD-10-D-S83222A, ICD-10-D-S83261A, ICD-10-D-S83262A
Complex	ICD-10-D-S83231A, ICD-10-D-S83232A, ICD-10-D-S83271A, ICD-10-D-S83272A

ICD-10, *International Classifications of Diseases, Tenth Revision*.