1 Introduction: Epidemiology of Knee Arthroplasty in a Younger Patient Population

Sue Barber-Westin and Frank R. Noyes

1.1 Introduction

Total knee arthroplasty (TKA) is one of the most commonly performed elective surgical procedures in the USA, with an exponential growth in volume noted in the past few decades [1–7]. In 2011–2012, an estimated 14–15 million individuals in the USA had symptomatic knee osteoarthritis (OA), of whom more than half had sufficient progression of the disease to warrant consideration for TKA [8]. In 2012, over 700,000 TKAs were performed, for a rate of 223 per 100,000 individuals [9]. This was the highest rate of TKAs among 24 OECD (Organisation for Economic Co-operation and Development) countries studied that year. Other countries with high incidence rates included Austria (218 per 100,000 inhabitants), Germany (206 per 100,000 inhabitants), and Switzerland (205 per 100,000 inhabitants) [10]. Globally, from 2005 to 2011, the highest annual TKA growth rate occurred in patients <65 years of age, and significant associations were noted between increased TKA utilization rates and higher gross national product ($r = 0.53$, $P < 0.01$), greater health expenditures ($r = 0.68$, $P < 0.001$), and obesity ($r = 0.46$–0.72, $P < 0.05$).

Many studies have provided estimated future projections of TKA volume and incidence rates using different epidemiological models [6, 11–15]. Incidence rates are typically calculated as the number of TKAs during a specified time period divided by the size of the US population (using US Census Bureau data) during the same time period. This chapter assesses the most current data available as of May 2020 and discusses factors that affect models and projections for future TKA numbers in the USA. Factors such as age and gender are taken into account when

S. Barber-Westin (✉)
Noyes Knee Institute, Cincinnati, OH, USA
e-mail: sbwestin@csmref.org

F. R. Noyes
Cincinnati SportsMedicine and Orthopaedic Center, The Noyes Knee Institute, Cincinnati, OH, USA

F. R. Noyes, S. Barber-Westin (eds.), *Critical Rehabilitation for Partial and Total Knee Arthroplasty*, https://doi.org/10.1007/978-3-030-87003-4_1

available. The effect of long-term participation in athletics and sports injuries on the future development of knee osteoarthritis (OA) and potentially TKA is reviewed.

1.2 Historic Annual Numbers and Incidence Rates of Primary TKA in the USA

The number and incidence rates of primary TKA performed in the USA according to various studies are shown in Table 1.1 [3, 6, 7, 9, 12]. Although all of the studies except one [10] used the same databases – the National Inpatient Sample (NIS) taken from the US Healthcare Cost and Utilization Project (HCUP) and the US Census Bureau – the volume and incidence rates varied among the investigations. The NIS is an annual national survey of discharge information from approximately 1000 hospitals and is considered statistically valid because it represents 95% of the US population [12, 15].

In a published report from HCUP, Fingar et al. [9] reported that 421,700 TKAs were performed in 2003, which increased to 700,100 in 2012, representing an overall 66% increase in volume. This study included patients of all ages. Sloan et al. [6] reported fewer procedures (in patients of all ages): 369,405 TKAs in 2012 and 630,509 TKAs in 2013, for an overall 71% increase in volume from 2000. Interestingly, these authors found that the mean annual increase in TKA volume significantly decreased from 2008 to 2014 compared with the time period of 2000–2008 (3.6% and 10.2%, respectively, $P = 0.015$). Inacio et al. [12] reported numbers in patients >40 years of age that were very similar to those of Sloan et al.; however, the incidence rates were more than twice as those of Sloan's for unknown reasons.

Gender comparisons of TKA incidence rates have been conducted in two studies [6, 7], both of which found higher incidence rates in women compared with men (Table 1.2). Williams et al. [7] in a report from the US Department of Health and Human Services found similar increases in the rate of TKA for men and women from 2000 through 2010 (86% and 99%, respectively). However, the rate of TKA for women was higher compared with men in 2000 (33.0 and 24.3 per 10,000, respectively) and in 2010 (65.5 and 45.3 per 10,000, respectively). The difference in rates is most notable in patients aged 45 to 64. Sloan et al. [6] reported large differences in incidence rates between men and women in 2000 and again in 2014. This study also reported large increases in incidence rates according to patient age in 2014 compared with 2000. For instance, the incidence rate in patients aged 65–69 was 498.3 per 100,000 individuals in 2000 and 909.2 per 100,000 individuals in 2014.

As of the time of writing, only two studies estimated prevalence rates of TKA in the USA [16, 17]. Prevalence rates represent the proportion of patients who are alive on a certain date who had TKA, regardless of what year the procedure was performed. One study [16] estimated that in 2010, approximately 4.55% of the entire US population ≥50 years of age, or 4.7 million individuals, had a TKA. The rates increased with each decade of age until ≥90 years and were 1.48% for ages 50–59,

Table 1.1 Historic volume and incidence rates of primary total knee arthroplasty in the USA

Year TKA volume reported	Study	Patient ages studied (year)	Volume TKA	Incidence rate per 100,000 individuals
2000	Sloan et al. [6]	All	274,025	97
	Inacio et al. [12]	≥40	274,463	229
	Kim et al. [3]	All	281,534	Not done
2001	Sloan et al. [6]	All	305,108	107
	Inacio et al. [12]	≥40	305,572	249
	Kim et al. [3]	All	313,618	Not done
2002	Sloan et al. [6]	All	339,225	118
	Inacio et al. [12]	≥40	339,681	272
	Kim et al. [3]	All	350,122	All
2003	Sloan et al. [6]	All	369,405	127
	Inacio et al. [12]	≥40	369,985	290
	Kim et al. [3]	All	379,719	Not done
	Fingar et al. [9]	All	421,700	145.4
2004	Sloan et al. [6]	All	431,852	147
	Inacio et al. [12]	≥40	419,774	323
	Kim et al. [3]	All	431,485	Not done
2005	Sloan et al. [6]	All	482,369	163
	Inacio et al. [12]	≥40	483,067	365
	Kurtz et al. [15]	All	471,088	Not done
	Pabinger et al. [10]	All	Not done	185
2006	Sloan et al. [6]	All	481,941	161
	Inacio et al. [12]	≥40	482,689	358
	Pabinger et al. [10]	All	Not done	175
	Kurtz et al. [13]	All	524,600	Not done
		<45	9900	Not done
		45–54	59,100	Not done
		55–64	147,100	Not done
2007	Sloan et al. [6]	All	532,883	177
	Inacio et al. [12]	≥40	533,602	390
	Pabinger et al. [10]	All	Not done	172
2008	Sloan et al. [6]	All	591,564	194
	Inacio et al. [12]	≥40	592,323	427
	Losina et al. [41]	All	615,050	Not done
	Pabinger et al. [10]	All	Not done	201
2009	Sloan et al. [6]	All	596,939	194
	Inacio et al. [12]	≥40	597,541	424
	Pabinger et al. [10]	All	Not done	213
2010	Sloan et al. [6]	All	632,091	204
	Inacio et al. [12]	≥40	632,862	442
	Williams et al. [7]	≥45	693,400	Not done
	Pabinger et al. [10]	All	Not done	226
2011	Sloan et al. [6]	All	617,945	198
	Inacio et al. [12]	≥40	618,604	426
	Pabinger et al. [10]	All	Not done	235
2012	Sloan et al. [6]	All	630,509	201
	Inacio et al. [12]	≥40	631,214	429
	Fingar et al. [9]	All	700,100	223
2013	Sloan et al. [6]	All	661,695	209
2014	Sloan et al. [6]	All	680,150	213

Table 1.2 Historic annual incidence rates of primary total knee arthroplasty according to gender and age in the USA

Year TKA incidence rate reported	Study	Age (year): incidence rate	Gender: incidence rate	Age (year) and gender: incidence rate
2000	Sloan et al. [6]	<45: 3.0/100,000	Female: 120.7/100,000	Not done
		45–54: 66.7/100,000		
		55–64: 249.6/100,000		
		65–69: 498.3/100,000		
		70–74: 614.7/100,000	Male: 73.1/100,000	
		75–79: 635/100,000		
		80–84: 501.8/100,000		
		≥85: 209.9/100,000		
	Williams et al. [7]	Not done	Female: 33.0/10,000	Female 45–64: 16.4/10,000
			Male: 24.3/10,000	Male 45–64: 8.7/10,000
				Female ≥65: 58.8/10,000
				Male >65: 57.0/10,000
2005	Pabinger et al. [10]	≤64: 36/100,000 ≥65: 149/100,000	Not done	Not done
2006	Pabinger et al. [10]	≤64: 35/100,000 ≥65: 140/100,000	Not done	Not done
2007	Pabinger et al. [10]	≤64: 35/100,000 ≥65: 137/100,000	Not done	Not done
2008	Pabinger et al. [10]	≤64: 44/100,000 ≥65: 157/100,000	Not done	Not done
2009	Pabinger et al. [10]	≤64: 48/100,000 ≥65: 165/100,000	Not done	Not done
2010	Pabinger et al. [10]	≤64: 53/100,000 ≥65: 173/100,000	Not done	Not done
2011	Pabinger et al. [10]	≤64: 58/100,000 ≥65: 177/100,000	Not done	Not done
2014	Sloan et al. [6]	<45: 5.8/100,000	Female: 259.8/100,000	Not done
		45–54: 168.3/100,000		
		55–64: 525.3/100,000		
		65–69: 909.2/100,000		
		70–74: 1016.6/100,000	Male: 165.3/100,000	
		75–79: 966.6/100,000		
		80–84: 716.7/100,000		
		≥ 85: 259.2/100,000		

Table 1.2 (continued)

Year TKA incidence rate reported	Study	Age (year): incidence rate	Gender: incidence rate	Age (year) and gender: incidence rate
2015	Williams et al. [7]	Not done	Female: 65.5/10,000	Female 45–64: 46.6/10,000
			Male: 45.3/10,000	Male 45–64: 828.6/10,000
				Female ≥65: 99.3/10,000
				Male >65: 82.6/10,000

4.59% for ages 60–69, 8.80% for ages 70–79, 10.13% for ages 80–89, and 7.40% for ages >90. Women had higher prevalence rates than men for all ages except the ≥90 category (7.39% and 7.41%, respectively). An earlier study [17] published rates that were approximately 20% lower due to differing statistical methods and inclusion of older data. Even so, that study found prevalence rates higher among females than males and increasing rates with each decade of age.

1.3 Projected Volume of TKA

Investigations have used various models, including linear, Poisson, and logistic, to estimate or project future TKA volume and incidence rates [3, 6, 11–15]. Factors entered into the models typically include US Census Bureau data and historic TKA volume calculated from the NIS database, which provides an approximate 20% sample of patients discharged from 1000 hospitals in 44 states, which is 95% representative of the US population [12]. US population growth is projected, and other factors such as age, gender, ethnicity, obesity, and US census region that produce different incidence rates [6, 11, 14, 15] may be included. Poisson and linear regression models assume an exponential or continuous increase in demand for TKA throughout the study time period and have been used most frequently in recent literature [6, 11–14]. A logistic model uses an upper limit (estimated maximum incidence) in the number of TKAs as one of several parameters and produces a more conservative projection [12].

A comparison of projected volume and incidence rates from the most recent studies for the years 2025 to 2050 is shown in Table 1.3. Tremendous variability exists, even in studies that used the same model. For instance, the Poisson model estimates for the total number of TKA for the year 2030 ranged from 1,678,200 to 4,344,900. Two studies conducted analyses according to patient age [6, 13]. The projected volume for patients <45 years of age in 2030 ranged from 9800 to 95,200; for patients aged 45 to 54, from 51,500 to 994,600; and for patients aged 55 to 64, from 162,300 to 1,300,200. These models use historic data to predict data typically at least 10 years ahead, and authors acknowledge there are several limitations in projection methodology. These include the inability to account for future population

Table 1.3 Projected volume and incidence rates of primary total knee arthroplasty in the USA

Year TKA projected	Study/regression model	Age (year)/ gender studied	Volume TKA	Incidence rate per 100,000 individuals
2025	Bashinskaya et al. [11]/ linear	All	2,428,810	NA
	Inacio et al. [12]/ logistic/Poisson	>40	1,027,494/1,446,387	603/849
2030	Bashinskaya et al. [11]/ linear	All	3,008,718	NA
	Sloan et al. [6]/linear/ Poisson	All <45 years 45–54 years 55–64 years 65–69 years 70–74 years 75–79 years 80–84 years ≥85 years All men All women	1,252,900/1,678,200 17,900/25,600 123,500/158,600 334,800/452,800 284,400/400,500 278,200/410,600 209,400/310,500 104,600/163,800 28,600/49,800 491,100/643,900 761,800/1,026,100	NA NA NA NA NA NA NA NA NA NA NA
	Inacio et al. [12]/ logistic/Poisson	>40	1,163,697/1,950,967	645/1082
	Kurtz et al. [14]/Poisson	All	3,480,000	NA
	Kurtz et al. [13]/Poisson/ constant	All <45 years 45–54 years 55–64 years	4,344,900/792,200 95,200/9800 994,100/51,500 1,300,200/162,300	NA NA NA NA
2035	Bashinskaya et al. [11]/ linear	All	3,394,921	NA
	Inacio et al. [12]/ logistic/Poisson	>40	1,286,531/2,621,920	676/1379
2040	Bashinskaya et al. [11]/ linear	All	3,656,712	NA
	Inacio et al. [12]/ logistic/Poisson	>40	1,383,809/3,479,536	699/1757
2045	Bashinskaya et al. [11]/ linear	All	3,884,707	NA
	Inacio et al. [12]/ logistic/Poisson	>40	1,463,313/4,587,552	714/2239
2050	Bashinskaya et al. [11]/ linear	All	4,174,554	NA
	Inacio et al. [12]/ logistic/Poisson	>40	1,531,566/6,030,029	725/2854

numbers, unexpected changes in healthcare systems, politics, surgeon availability, more sports injuries, changes in life expectancy, increasing incidence of obesity, economic resources, recessions, and potential national disasters that limit accessibility to elective surgery (such as the recent COVID-19 pandemic). It is also difficult to project the prevalence of severe symptomatic knee OA, which is increasing

rapidly [8, 18]. In addition, these models do not take into account the impact of new technologies – such as cartilage restoration, tissue engineering, and drug therapies – that could lessen the need for TKA. Longer-term projections, such as those 30 years in advance, are expected to be more unreliable [12].

1.4 Impact of Athletic Knee Injuries on Future Osteoarthritis and TKA

Serious knee injuries are a strong risk factor for the development of OA [19–26]. These include anterior cruciate ligament (ACL) ruptures [25, 27, 28], especially those combined with complex meniscus tears requiring meniscectomy [20, 25, 29–31], as well as patellar dislocations [32–34] and complete knee dislocations [35–37]. Recent data suggests that ACL and meniscus injuries significantly increase the risk of a subsequent TKA. In a matched case-control study of 49,723 TKA patients and 104,353 controls in the UK, Khan et al. [38] reported that a history of an ACL injury increased the odds of a subsequent TKA by nearly sevenfold (odds ratio [OR], 6.96; 95% confidence interval [CI] 4.73 to 10.31) and a meniscus injury increased the odds by 15-fold (OR, 15.24; 95% CI 13.88–16.69). The study was based on 20-year longitudinal data, and unfortunately, the investigators were unable to determine the treatment of the ACL and meniscus injuries. However, the findings were similar to those reported by Leroux et al. [39] in a study from Canada that reported that the cumulative incidence of TKA following cruciate ligament reconstruction (ACL or posterior cruciate ligament) was seven times greater than that of a matched control group from the general population (OR, 7.26; 95% CI 5.79–9.11). This study involved 30,277 patients who had undergone cruciate ligament reconstruction and 151,362 individuals from the general population. The majority of patients followed were <50 years of age and had undergone TKA in a mean of 11 years after the knee ligament reconstruction.

A study from Australia found that a history of a sports knee injury more than doubled the odds of a TKA compared with injuries to other areas of the body (OR, 2.41; 95% CI 1.73–3.37), after adjusting for potential confounding factors including age, gender, insurance type, and length of hospital stay for the injury [40]. This study included 64,038 patients who sustained a sports injury between 2000 and 2005 and were followed until 2015. There were 357 patients (0.6%) that required TKA. Suter et al. [21] used the Osteoarthritis Policy Model to project the cumulative incidence of TKA in four patient cohorts: no knee injury, isolated ACL rupture treated conservatively, isolated ACL reconstruction, and ACL reconstruction and medial meniscus tear treated either conservatively or operatively (Table 1.4). Patients who sustained an ACL and meniscus tear by age 25 had a nearly fourfold increase in the estimated lifetime risk of TKA compared with individuals who had no injury (22.3%; 95% CI 16.8–27.9).

Table 1.4 Risk of symptomatic knee osteoarthritis and TKA[a]

Outcome	No injury	Isolated ACL reconstruction[b]	Isolated ACL tear treated conservatively[b]	ACL reconstruction with meniscus tear[b, c]
Lifetime risk of symptomatic knee osteoarthritis	13.5%	16.2%	17.3%	34.2%
Lifetime risk of TKA	6.0%	8.0%	8.9%	22.3%

[a]From Suter et al. [21]
[b]Injured by age 25
[c]Treated in any manner

1.5 Conclusions

In conclusion, the most recent data at the time of writing shows marked increases in the incidence of TKA by 60–70% over the last 15 years. Prior athletic injuries are an important aspect of TKA prevalence. Granted, over the past decade there have been many improved treatment options for common knee ligament injuries and meniscus tears which may be repaired instead of removed that likely will decrease the effect of athletic injuries on knee arthritis in the future. Still, a prior injury (whether athletic or other trauma) increases the odds for subsequent knee replacement surgery in younger and active patients. In addition, there have been major advances in TKA surgery including pre-emptive programs for patient optimization and prehabilitation before surgery, surgical advances of decreasing blood loss and need for transfusion, improved instrumentation for predictable results, and better understanding by patients that the risks of TKA are in fact very small. Patient-reported outcome measures (PROMs) after TKA show major improvements in symptoms and quality of life that have led to more patients requesting the surgery rather than living with advancing knee osteoarthritis. This is a dynamic issue with knee osteoarthritis affecting millions of patients worldwide, and this book is dedicated to showing the major advances that clinics and institutions have implemented that are important to acknowledge and disseminate.

References

1. Cram P, Lu X, Kates SL, Singh JA, Li Y, Wolf BR. Total knee arthroplasty volume, utilization, and outcomes among Medicare beneficiaries, 1991–2010. JAMA. 2012;308(12):1227–36. https://doi.org/10.1001/2012.jama.11153.
2. Jain NB, Higgins LD, Ozumba D, Guller U, Cronin M, Pietrobon R, Katz JN. Trends in epidemiology of knee arthroplasty in the United States, 1990–2000. Arthritis Rheum. 2005;52(12):3928–33. https://doi.org/10.1002/art.21420.
3. Kim S. Changes in surgical loads and economic burden of hip and knee replacements in the US: 1997–2004. Arthritis Rheum. 2008;59(4):481–8. https://doi.org/10.1002/art.23525.
4. Kurtz SM, Ong KL, Schmier J, Zhao K, Mowat F, Lau E. Primary and revision arthroplasty surgery caseloads in the United States from 1990 to 2004. J Arthroplasty. 2009;24(2):195–203. https://doi.org/10.1016/j.arth.2007.11.015.

5. Mehrotra C, Remington PL, Naimi TS, Washington W, Miller R. Trends in total knee replacement surgeries and implications for public health, 1990–2000. Public Health Rep. 2005;120(3):278–82.
6. Sloan M, Premkumar A, Sheth NP. Projected volume of primary total joint arthroplasty in the U.S., 2014 to 2030. J Bone Joint Surg Am. 2018;100(17):1455–60. https://doi.org/10.2106/JBJS.17.01617.
7. Williams SN, Wolford ML, Bercovitz A. Hospitalization for total knee replacement among inpatients aged 45 and over: United States, 2000–2010. NCHS Data Brief. 2015;210:1–8.
8. Deshpande BR, Katz JN, Solomon DH, Yelin EH, Hunter DJ, Messier SP, Suter LG, Losina E. Number of persons with symptomatic knee osteoarthritis in the US: impact of race and ethnicity, age, sex, and obesity. Arthritis Care Res. 2016;68(12):1743–50. https://doi.org/10.1002/acr.22897.
9. Fingar KR, Stocks C, Weiss AJ, Steiner CA. Most frequent operating room procedures performed in US hospitals, 2003–2012: statistical brief# 186. Healthcare Cost and Utilization Project (HCUP) Statistical Briefs. Rockville: Agency for Health Care Policy and Research (US); 2014.
10. Pabinger C, Lothaller H, Geissler A. Utilization rates of knee-arthroplasty in OECD countries. Osteoarthr Cartil. 2015;23(10):1664–73. https://doi.org/10.1016/j.joca.2015.05.008.
11. Bashinskaya B, Zimmerman RM, Walcott BP, Antoci V. arthroplasty utilization in the United States is predicted by age-specific population groups. ISRN Orthop. 2012. https://doi.org/10.5402/2012/185938.
12. Inacio MCS, Paxton EW, Graves SE, Namba RS, Nemes S. Projected increase in total knee arthroplasty in the United States - an alternative projection model. Osteoarthr Cartil. 2017;25(11):1797–803. https://doi.org/10.1016/j.joca.2017.07.022.
13. Kurtz SM, Lau E, Ong K, Zhao K, Kelly M, Bozic KJ. Future young patient demand for primary and revision joint replacement: national projections from 2010 to 2030. Clin Orthop Relat Res. 2009;467(10):2606–12. https://doi.org/10.1007/s11999-009-0834-6.
14. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am. 2007;89(4):780–5. https://doi.org/10.2106/JBJS.F.00222.
15. Kurtz SM, Ong KL, Lau E, Bozic KJ. Impact of the economic downturn on total joint replacement demand in the United States: updated projections to 2021. J Bone Joint Surg Am. 2014;96(8):624–30. https://doi.org/10.2106/JBJS.M.00285.
16. Maradit Kremers H, Larson DR, Crowson CS, Kremers WK, Washington RE, Steiner CA, Jiranek WA, Berry DJ. Prevalence of total hip and knee replacement in the United States. J Bone Joint Surg Am. 2015;97(17):1386–97. https://doi.org/10.2106/JBJS.N.01141.
17. Weinstein AM, Rome BN, Reichmann WM, Collins JE, Burbine SA, Thornhill TS, Wright J, Katz JN, Losina E. Estimating the burden of total knee replacement in the United States. J Bone Joint Surg Am. 2013;95(5):385–92. https://doi.org/10.2106/JBJS.L.00206.
18. Sebbag E, Felten R, Sagez F, Sibilia J, Devilliers H, Arnaud L. The world-wide burden of musculoskeletal diseases: a systematic analysis of the World Health Organization Burden of Diseases Database. Ann Rheum Dis. 2019;78(6):844–8.
19. Oiestad BE, Engebretsen L, Storheim K, Risberg MA. Knee osteoarthritis after anterior cruciate ligament injury: a systematic review. Am J Sports Med. 2009;37(7):1434–43. https://doi.org/10.1177/0363546509338827.
20. van Meer BL, Meuffels DE, van Eijsden WA, Verhaar JA, Bierma-Zeinstra SM, Reijman M. Which determinants predict tibiofemoral and patellofemoral osteoarthritis after anterior cruciate ligament injury? A systematic review. Br J Sports Med. 2015;49(15):975–83. https://doi.org/10.1136/bjsports-2013-093258.
21. Suter LG, Smith SR, Katz JN, Englund M, Hunter DJ, Frobell R, Losina E. Projecting lifetime risk of symptomatic knee osteoarthritis and total knee replacement in individuals sustaining a complete anterior cruciate ligament tear in early adulthood. Arthritis Care Res. 2017;69(2):201–8. https://doi.org/10.1002/acr.22940.

22. Prien A, Boudabous S, Junge A, Verhagen E, Delattre BMA, Tscholl PM. Every second retired elite female football player has MRI evidence of knee osteoarthritis before age 50 years: a cross-sectional study of clinical and MRI outcomes. Knee Surg Sports Traumatol Arthrosc. 2020;28(2):353–62. https://doi.org/10.1007/s00167-019-05560-w.
23. Poulsen E, Goncalves GH, Bricca A, Roos EM, Thorlund JB, Juhl CB. Knee osteoarthritis risk is increased 4–6 fold after knee injury - a systematic review and meta-analysis. Br J Sports Med. 2019;53(23):1454–63. https://doi.org/10.1136/bjsports-2018-100022.
24. Silverwood V, Blagojevic-Bucknall M, Jinks C, Jordan JL, Protheroe J, Jordan KP. Current evidence on risk factors for knee osteoarthritis in older adults: a systematic review and meta-analysis. Osteoarthr Cartil. 2015;23(4):507–15. https://doi.org/10.1016/j.joca.2014.11.019.
25. Sanders TL, Pareek A, Kremers HM, Bryan AJ, Levy BA, Stuart MJ, Dahm DL, Krych AJ. Long-term follow-up of isolated ACL tears treated without ligament reconstruction. Knee Surg Sports Traumatol Arthrosc. 2017;25(2):493–500. https://doi.org/10.1007/s00167-016-4172-4.
26. Noyes FR, Barber-Westin S. Advantages and potential consequences of return to sport after ACL reconstruction: quality of life, reinjury rates, and knee osteoarthritis. In: Noyes FR, Barber-Westin S, editors. Return to sport after ACL reconstruction and other knee operations: limiting the risk of reinjury and maximizing athletic performance. Cham: Springer International Publishing; 2019. p. 3–23. https://doi.org/10.1007/978-3-030-22361-8_1.
27. Chalmers PN, Mall NA, Moric M, Sherman SL, Paletta GP, Cole BJ, Bach BR Jr. Does ACL reconstruction alter natural history?: a systematic literature review of long-term outcomes. J Bone Joint Surg Am. 2014;96(4):292–300. https://doi.org/10.2106/JBJS.L.01713.
28. Nordenvall R, Bahmanyar S, Adami J, Mattila VM, Fellander-Tsai L. Cruciate ligament reconstruction and risk of knee osteoarthritis: the association between cruciate ligament injury and post-traumatic osteoarthritis. A population based nationwide study in Sweden, 1987–2009. PLoS One. 2014;9(8):e104681. https://doi.org/10.1371/journal.pone.0104681.
29. van Yperen DT, Reijman M, van Es EM, Bierma-Zeinstra SMA, Meuffels DE. Twenty-year follow-up study comparing operative versus nonoperative treatment of anterior cruciate ligament ruptures in high-level athletes. Am J Sports Med. 2018;46(5):1129–36. https://doi.org/10.1177/0363546517751683.
30. Claes S, Hermie L, Verdonk R, Bellemans J, Verdonk P. Is osteoarthritis an inevitable consequence of anterior cruciate ligament reconstruction? A meta-analysis. Knee Surg Sports Traumatol Arthrosc. 2013;21(9):1967–76. https://doi.org/10.1007/s00167-012-2251-8.
31. Barenius B, Ponzer S, Shalabi A, Bujak R, Norlen L, Eriksson K. Increased risk of osteoarthritis after anterior cruciate ligament reconstruction: a 14-year follow-up study of a randomized controlled trial. Am J Sports Med. 2014;42(5):1049–57. https://doi.org/10.1177/0363546514526139.
32. Sanders TL, Pareek A, Johnson NR, Stuart MJ, Dahm DL, Krych AJ. Patellofemoral arthritis after lateral patellar dislocation: a matched population-based analysis. Am J Sports Med. 2017;45(5):1012–7.
33. Sanders TL, Pareek A, Hewett TE, Stuart MJ, Dahm DL, Krych AJ. High rate of recurrent patellar dislocation in skeletally immature patients: a long-term population-based study. Knee Surg Sports Traumatol Arthrosc. 2018;26(4):1037–43. https://doi.org/10.1007/s00167-017-4505-y.
34. Conchie H, Clark D, Metcalfe A, Eldridge J, Whitehouse M. Adolescent knee pain and patellar dislocations are associated with patellofemoral osteoarthritis in adulthood: a case control study. Knee. 2016;23(4):708–11.
35. Moatshe G, Dornan GJ, Ludvigsen T, Løken S, LaPrade RF, Engebretsen L. High prevalence of knee osteoarthritis at a minimum 10-year follow-up after knee dislocation surgery. Knee Surg Sports Traumatol Arthrosc. 2017;25(12):3914–22.
36. Engebretsen L, Risberg MA, Robertson B, Ludvigsen TC, Johansen S. Outcome after knee dislocations: a 2-9 years follow-up of 85 consecutive patients. Knee Surg Sports Traumatol Arthrosc. 2009;17(9):1013–26. https://doi.org/10.1007/s00167-009-0869-y.

37. Hantes M, Fyllos A, Papageorgiou F, Alexiou K, Antoniou I. Long-term clinical and radiological outcomes after multiligament knee injury using a delayed ligament reconstruction approach: a single-center experience. Knee. 2019;26(6):1271–7.
38. Khan T, Alvand A, Prieto-Alhambra D, Culliford DJ, Judge A, Jackson WF, Scammell BE, Arden NK, Price AJ. ACL and meniscal injuries increase the risk of primary total knee replacement for osteoarthritis: a matched case-control study using the Clinical Practice Research Datalink (CPRD). Br J Sports Med. 2019;53(15):965–8. https://doi.org/10.1136/bjsports-2017-097762.
39. Leroux T, Ogilvie-Harris D, Dwyer T, Chahal J, Gandhi R, Mahomed N, Wasserstein D. The risk of knee arthroplasty following cruciate ligament reconstruction: a population-based matched cohort study. J Bone Joint Surg Am. 2014;96(1):2–10. https://doi.org/10.2106/JBJS.M.00393.
40. Ackerman IN, Bohensky MA, Kemp JL, de Steiger R. Likelihood of knee replacement surgery up to 15 years after sports injury: a population-level data linkage study. J Sci Med Sport. 2019;22(6):629–34. https://doi.org/10.1016/j.jsams.2018.12.010.
41. Losina E, Thornhill TS, Rome BN, Wright J, Katz JN. The dramatic increase in total knee replacement utilization rates in the United States cannot be fully explained by growth in population size and the obesity epidemic. J Bone Joint Surg Am. 2012;94(3):201–7. https://doi.org/10.2106/JBJS.J.01958.