Prevalence of Total Hip and Knee Replacement in the United States

Hilal Maradit Kremers, MD, MSc, Dirk R. Larson, MS, Cynthia S. Crowson, MS, Walter K. Kremers, PhD, Raynard E. Washington, PhD, MPH, Claudia A. Steiner, MD, MPH, William A. Jiranek, MD, and Daniel J. Berry, MD

Investigation performed at the Department of Health Sciences Research and the Department of Orthopedic Surgery, Mayo Clinic, Rochester, Minnesota

Background: Descriptive epidemiology of total joint replacement procedures is limited to annual procedure volumes (incidence). The prevalence of the growing number of individuals living with a total hip or total knee replacement is currently unknown. Our objective was to estimate the prevalence of total hip and total knee replacement in the United States.

Methods: Prevalence was estimated using the counting method by combining historical incidence data from the National Hospital Discharge Survey and the Healthcare Cost and Utilization Project (HCUP) State Inpatient Databases from 1969 to 2010 with general population census and mortality counts. We accounted for relative differences in mortality rates between those who have had total hip or knee replacement and the general population.

Results: The 2010 prevalence of total hip and total knee replacement in the total U.S. population was 0.83% and 1.52%, respectively. Prevalence was higher among women than among men and increased with age, reaching 5.26% for total hip replacement and 10.38% for total knee replacement at eighty years. These estimates corresponded to 2.5 million individuals (1.4 million women and 1.1 million men) with total hip replacement and 4.7 million individuals (3.0 million women and 1.7 million men) with total knee replacement in 2010. Secular trends indicated a substantial rise in prevalence over time and a shift to younger ages.

Conclusions: Around 7 million Americans are living with a hip or knee replacement, and consequently, in most cases, are mobile, despite advanced arthritis. These numbers underscore the substantial public health impact of total hip and knee arthroplasties.

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The incidence of joint replacement procedures is high, with over 1 million total hip and total knee replacement procedures performed each year in the United States¹. With the aging of the “baby boomers,” higher rates of diagnosis and treatment of advanced arthritis, and growing demand for improved mobility and quality of life, the annual procedure volumes are projected to increase considerably in the future, making joint replacements the most common elective surgical procedures in the coming decades^{2,3}. Such a large increase in demand is unprecedented and must be addressed with effective planning of health-care services for these individuals, not only

during the perioperative period but throughout the lifelong continued care of this population.

To date, studies involving the descriptive epidemiology of total hip and total knee replacement have focused almost exclusively on annual procedure volumes (i.e., incidence)²⁻⁹. Although incidence data are informative, they offer an incomplete assessment of the impact of total hip and total knee replacement on the population and the health-care system. The prevalence of individuals who are currently living with an artificial hip or knee joint in the United States is currently unknown. Indeed, the increasing use of joint replacement in younger individuals,

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TABLE I Estimated 2010 Prevalence of Total Hip and Total Knee Replacement in the United States

	Total Hip Replacement		Total Knee Replacement	
	No. of Individuals	Prevalence*	No. of Individuals	Prevalence*
Overall	2,552,815	0.83 (0.83-0.83)	4,700,621	1.52 (1.52-1.52)
Population ≥50 years of age	2,330,539	2.34 (2.34-2.35)	4,526,451	4.55 (4.55-4.56)
Sex				
Women	1,452,495	0.93 (0.92-0.93)	2,965,541	1.89 (1.89-1.89)
Men	1,100,320	0.72 (0.72-0.73)	1,735,080	1.14 (1.14-1.14)
Age group (yr)				
<50	222,276	0.11 (0.11-0.11)	174,170	0.08 (0.08-0.08)
50-59	383,517	0.91 (0.91-0.91)	624,468	1.48 (1.48-1.49)
60-69	625,416	2.12 (2.12-2.13)	1,350,693	4.59 (4.58-4.59)
70-79	681,136	4.10 (4.09-4.11)	1,463,890	8.80 (8.79-8.82)
80-89	534,048	5.69 (5.68-5.71)	950,942	10.13 (10.11-10.15)
≥90	106,422	5.77 (5.73-5.80)	136,458	7.40 (7.36-7.44)
Age (yr)				
50	27,006	0.58 (0.57-0.59)	31,553	0.68 (0.67-0.69)
60	53,809	1.49 (1.48-1.50)	105,432	2.92 (2.90-2.94)
70	66,972	3.25 (3.23-3.28)	150,071	7.29 (7.25-7.33)
80	69,294	5.26 (5.22-5.30)	136,690	10.38 (10.32-10.43)
90	26,269	5.87 (5.80-5.94)	37,970	8.48 (8.40-8.57)

*Values are shown as the percentage, with the 95% confidence interval (CI) in parentheses. CIs were calculated assuming a Poisson distribution.

coupled with improvements in life expectancy, has created a large pool of individuals with hip and knee replacements in the United States^{2,10}. These individuals not only have specialized

needs, but in some cases, will outlive their implants and require expensive revision surgeries with substantial implications related to cost and resource use. Therefore, estimates of prevalence are

TABLE II Estimated Number of Individuals Who Had Both Total Hip and Total Knee Replacement Among the Total U.S. Population in 2010*

Olmsted County, Minnesota						United States			
Age Group (yr)	No. with Either THR or TKR	No. with Both THR and TKR	County Population	% Prevalent Cases with Both Procedures (A)	Prevalence of Both in Olmsted County (B)	Estimated No. with Either THR or TKR	Total 2010 U.S. Population	Estimated No. with Both Procedures (Assuming Prevalence from A)†	Estimated No. (Assuming Prevalence from B)†
Female									
<50	156	12	48,814	7.69%	0.02%	188,850	103,577,271	14,527	25,463
50-59	334	21	9,707	6.29%	0.22%	556,055	21,559,563	34,962	46,642
60-69	577	54	6,048	9.36%	0.89%	1,169,996	15,427,351	109,497	137,744
70-79	554	50	3,834	9.03%	1.30%	1,323,605	9,178,735	119,459	119,702
80+	304	36	3,247	11.84%	1.11%	1,179,530	7,126,835	139,681	79,016
All age groups	1,925	173	71,650	8.99%	0.24%	4,418,036	156,869,755	418,126	408,567
Male									
<50	128	9	48,961	7.03%	0.02%	207,596	105,709,894	14,597	19,432
50-59	225	10	9,153	4.44%	0.11%	451,930	20,512,532	20,086	22,411
60-69	350	27	5,432	7.71%	0.50%	806,113	14,029,131	62,186	69,732
70-79	350	27	3,236	7.71%	0.83%	821,421	7,447,964	63,367	62,143
80+	123	16	1,826	13.01%	0.88%	548,340	4,101,693	71,329	35,940
All age groups	1,176	89	68,608	7.57%	0.13%	2,835,400	151,801,214	231,565	209,658
Total	3,101	262	140,258	8.45%	0.19%	7,253,436	308,670,969	649,691	618,225

*Estimated based on Olmsted County data and published literature²⁷. THR = total hip replacement, and TKR = total knee replacement. †Estimated numbers differ from the product of table columns because of rounding.

Fig. 1-A

Fig. 1-B

Fig. 1-A Age and sex-specific prevalence of total hip replacement (THR) and total knee replacement (TKR) among the total population of the United States in 2010. The lines represent the percentage of the 2010 total U.S. population with total hip and total knee replacement by age group. **Fig. 1-B** The number of individuals among the 2010 total U.S. population who had undergone total hip replacement (THR) and total knee replacement (TKR) according to age group.

vital to agencies charged with planning for the provision of health-care services for these individuals. We know of only one study to date that has provided prevalence estimates of total knee replacement¹¹, but the methodology used to estimate prevalence was based on a computer-simulation model of the natural history of osteoarthritis and did not take into account the substantial increase in procedure volumes in recent years⁵. Therefore, we sought to estimate the current prevalence and historical trends in the prevalence of total hip and total knee replacement in the United States using multiple data sources and accounting for the secular increase in procedure volumes in recent years.

Materials and Methods

The prevalence of total hip or total knee replacement is the proportion of individuals who are alive on a certain date and had total hip or total knee replacement (or both), regardless of how long ago the initial procedure was performed. We used counting methods^{12,13} to estimate prevalence, starting from 1969 and 1971, when total hip and total knee replacement procedures, respectively, were first performed in the United States. Details of the methods are outlined in the Appendix and briefly summarized below. This study was approved by the institutional review board.

Briefly, incidence (procedure volume) data were obtained from two data sources. For the period of 1990 to 2010, we collaborated with the U.S. Department of Health & Human Services Agency for Healthcare Research and

TABLE III Distribution of Individuals in Prevalence Pool by Age Group and Time Since Initial Procedure

Age Group (yr)	Total Hip Replacement*				Total Knee Replacement*			
	<10 Yr	10-20 Yr	>20 Yr	Total No. Hip Arthroplasty	<10 Yr	10-20 Yr	>20 Yr	Total No. Knee Arthroplasty
<50	136,395	47,721	38,160	222,276	104,308	28,968	40,894	174,170
50-59	280,584	64,084	38,849	383,517	537,467	47,092	39,909	624,468
60-69	450,553	125,750	49,113	625,416	1,117,588	188,681	44,424	1,350,693
70-79	447,920	168,097	65,119	681,136	1,046,717	348,568	68,605	1,463,890
80-89	294,119	165,978	73,951	534,048	547,054	323,444	80,444	950,942
≥90	40,754	43,969	21,699	106,422	50,865	67,476	18,117	136,458
All	1,650,325 (65%)	615,599 (24%)	286,891 (11%)	2,552,815	3,403,999 (72%)	1,004,229 (21%)	292,393 (6%)	4,700,621

*Values are presented as the number of individuals, with the percentage of the total in parentheses.

Quality (AHRQ) and relied on the Healthcare Cost and Utilization Project (HCUP) State Inpatient Databases (SID) to estimate total hip and total knee replacement procedure counts by calendar year, state, sex, and single-year age groups. For the period of 1969 to 1989, we relied on the National Hospital Discharge Survey (NHDS) to estimate the annual number of total hip and total knee replacement procedures by calendar year, four major census regions, sex, and single-year age groups¹⁴. Calendar-year, state, sex, and single year of age-specific U.S. population estimates from 1969 to 2010 were obtained from the United States Census Bureau¹⁵. Historical population mortality data were obtained from the National Center for Health Statistics (NCHS) vital statistics¹⁶. We also accounted for procedure-specific relative death rates using published literature¹⁷⁻¹⁹ and unpublished regional U.S. data and applied them to calendar-year, state, sex, and single year of age-specific mortality data obtained from the NCHS.

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Results

We estimate that the 2010 prevalence of total hip and total knee replacement among the total U.S. population was

0.83% and 1.52%, respectively (Table I and Figs. 1-A and 1-B). The prevalence of total hip and total knee replacement among adults fifty years of age or older was 2.34% and 4.55%, respectively. For both procedures, the prevalence was higher among women than among men. Prevalence increased with age, and more steeply for total knee replacement than for total hip replacement. The prevalence of total hip replacement at fifty years of age was 0.58% and increased to 1.49% at sixty years, 3.25% at seventy years, 5.26% at eighty years, and 5.87% at ninety years of age. The prevalence of total knee replacement at fifty years of age was 0.68% and increased to 2.92% at sixty years, 7.29% at seventy years, 10.38% at eighty years, and 8.48% at ninety years of age. These prevalence estimates corresponded to 2.5 million individuals (1.4 million women and 1.1 million men) with total hip replacement and 4.7 million individuals (3.0 million women and 1.7 million men) with total knee replacement in the United States in 2010 (Table I). Comparing these prevalence estimates with cumulative incidence, we found that about 62% of all individuals who underwent total hip replacement and about 73% of all individuals who underwent total knee replacement in the United States were still alive in 2010. Assuming

Fig. 2-A

Fig. 2-B

Age-specific 2010 prevalence of total hip arthroplasty (THA) (**Fig. 2-A**) and total knee arthroplasty (TKA) (**Fig. 2-B**) among the total U.S. population according to duration of time since the initial procedure.

TABLE IV Trends in Age and Sex-Specific Prevalence of Total Hip and Total Knee Replacement Among Total U.S. Population Between 1980 and 2010

Age Group (yr)	1980			1990		
	No.	Population	Prevalence	No.	Population	Prevalence
Total hip replacement						
Female						
<50	27,315	83,585,575	0.03%	64,581	91,999,727	0.07%
50-59	19,008	12,175,416	0.16%	58,940	11,294,203	0.52%
60-69	33,566	10,306,337	0.33%	151,676	11,209,278	1.35%
70-79	33,539	6,915,806	0.49%	211,015	8,315,470	2.54%
80-89	15,620	2,919,371	0.54%	131,782	3,955,284	3.33%
90+	2,347	562,503	0.42%	20,260	785,256	2.58%
Male						
<50	43,860	84,020,171	0.05%	80,717	93,447,372	0.09%
50-59	18,174	11,064,189	0.16%	56,198	10,507,941	0.53%
60-69	24,049	8,589,510	0.28%	107,044	9,443,061	1.13%
70-79	16,658	4,720,856	0.35%	119,360	5,821,430	2.05%
80-89	4,855	1,510,125	0.32%	47,830	1,964,825	2.43%
90+	566	196,201	0.29%	4,872	242,645	2.01%
Total	239,557	226,566,060	0.11%	1,054,275	248,986,492	0.42%
Total knee replacement						
Female						
<50	22,520	83,585,575	0.03%	46,327	91,999,727	0.05%
50-59	19,267	12,175,416	0.16%	65,812	11,294,203	0.58%
60-69	28,901	10,306,337	0.28%	154,102	11,209,278	1.37%
70-79	26,937	6,915,806	0.39%	190,024	8,315,470	2.29%
80-89	11,069	2,919,371	0.38%	91,367	3,955,284	2.31%
90+	1,286	562,503	0.23%	10,365	785,256	1.32%
Male						
<50	78,715	84,020,171	0.09%	91,346	93,447,372	0.10%
50-59	39,319	11,064,189	0.36%	52,850	10,507,941	0.50%
60-69	37,036	8,589,510	0.43%	113,504	9,443,061	1.20%
70-79	23,324	4,720,856	0.49%	101,278	5,821,430	1.74%
80-89	8,501	1,510,125	0.56%	34,138	1,964,825	1.74%
90+	954	196,201	0.49%	3,560	242,645	1.47%
Total	297,829	226,566,060	0.13%	954,673	248,986,492	0.38%

that roughly 8.5% of these individuals had both procedures (Table II), we estimate that there were about 620,000 individuals (410,000 women and 210,000 men) who had both procedures, corresponding to about 0.2% of the U.S. population in 2010.

Figures 2-A and 2-B show the age-specific 2010 prevalence of total hip and total knee replacement according to the duration of time since the initial procedure. The majority of the individuals in the prevalence pool (65% of total hip and 72% of total knee replacement patients) had undergone the initial procedure less than ten years earlier (Table III). Although the overall distributions looked similar, the total knee replacement curves shifted to the left, with the nadir of the prevalence curves for less than ten years and ten to twenty years corresponding to younger ages than for total hip replacement. About one-fourth of the total hip replacement patients (24%) and about one-fifth of the total knee replacement patients (21%) had undergone the initial procedure ten to twenty years earlier. In terms of absolute numbers,

the number of individuals who were more than twenty years from their initial total hip or total knee replacement was about the same.

Figures 3-A and 3-B show trends in age-specific prevalence since 1980. As illustrated by the distance between the lines, there was a notable increase in the prevalence of total hip replacement between 1980 and 1990 (Fig. 3-A). The overall prevalence of total hip replacement was 0.11% in 1980, increased fourfold to 0.42% in 1990, and then to 0.57% in 2000 and 0.83% in 2010 (Table IV). The most notable increase in the prevalence of total knee replacement occurred between 2000 and 2010 (Fig. 3-B). The overall prevalence of total knee replacement in 1980 was 0.13% and increased to 0.38% in 1990, 0.80% in 2000, and 1.52% in 2010. The increase in the prevalence of total knee replacement was evident in all age groups but most notably among elderly women (seventy to eighty-nine years of age). There was a shift in prevalence to younger ages over time, as illustrated by the slight leftward shift of the prevalence curves in Figure 3-B.

TABLE IV (continued)

2000			2010		
No.	Population	Prevalence	No.	Population	Prevalence
87,150	101,110,188	0.09%	99,875	103,577,271	0.10%
93,113	16,050,005	0.58%	177,522	21,559,563	0.82%
172,543	10,799,397	1.60%	329,547	15,427,351	2.14%
303,662	9,311,844	3.26%	400,753	9,178,735	4.37%
234,436	5,031,903	4.66%	363,080	5,798,465	6.26%
50,370	1,076,556	4.68%	81,718	1,328,370	6.15%
103,983	103,358,063	0.10%	122,401	105,709,894	0.12%
100,462	15,231,187	0.66%	205,995	20,512,532	1.00%
140,682	9,547,191	1.47%	295,869	14,029,131	2.11%
193,706	6,954,483	2.79%	280,383	7,447,964	3.76%
101,373	2,724,215	3.72%	170,968	3,585,161	4.77%
14,158	352,497	4.02%	24,704	516,532	4.78%
1,595,638	281,547,529	0.57%	2,552,815	308,670,969	0.83%
63,053	101,110,188	0.06%	88,975	103,577,271	0.09%
147,676	16,050,005	0.92%	378,533	21,559,563	1.76%
336,293	10,799,397	3.11%	840,449	15,427,351	5.45%
512,354	9,311,844	5.50%	922,852	9,178,735	10.05%
296,546	5,031,903	5.89%	636,571	5,798,465	10.98%
39,164	1,076,556	3.64%	98,161	1,328,370	7.39%
95,055	103,358,063	0.09%	85,195	105,709,894	0.08%
108,033	15,231,187	0.71%	245,935	20,512,532	1.20%
216,833	9,547,191	2.27%	510,244	14,029,131	3.64%
304,289	6,954,483	4.38%	541,038	7,447,964	7.26%
129,537	2,724,215	4.76%	314,371	3,585,161	8.77%
12,865	352,497	3.65%	38,297	516,532	7.41%
2,261,698	281,547,529	0.80%	4,700,621	308,670,969	1.52%

The three states with the highest prevalence of total hip and total knee replacement were Iowa, North Dakota, and Wisconsin (Figs. 4-A and 4-B). The prevalence of total hip replacement in these three states was 1.22% to 1.25%, whereas the national average was 0.83% (Fig. 4-A). The prevalence of total knee replacement in these three states was 2.36% to 2.63%, whereas the national average was 1.52% (Fig. 4-B). States with the highest number of individuals with total hip and total knee replacement were the three states with the largest populations (California, Florida, and Texas), despite a relatively low prevalence. The ranking of individual states was different for total hip and total knee replacements. For example, New York ranked twenty-third in prevalence (0.81%) of total hip replacement but ranked fourth in prevalence (1.09%) of total knee replacement.

Discussion

We estimate that a little over 2% of individuals in the United States were living with a total hip or total knee replacement

in 2010. This corresponds to an estimated 7 million people, including 620,000 individuals who underwent both procedures. These numbers underscore the large number of Americans who have benefited from these procedures. Given the success of total hip and knee replacement in improving function and quality of life of individuals with severe arthritis, the current trends will likely continue in the coming decades.

Although there are many studies documenting the rapid increase in incidence of total hip and total knee replacement in the United States, there is only one study that we know of on the prevalence of total knee replacement¹¹. Our prevalence estimates for total knee replacement are about 20% higher than in this earlier study by Weinstein et al. This discrepancy may be due, in part, to statistical methodology, to the inclusion of more recent data in our analysis, and to differences in data sources used to derive incidence. Methodologically, the prior study used a state transition simulation model of the natural history of knee osteoarthritis, with transition estimates derived from multiple data sources. In contrast, we used the counting

Fig. 3-A

Fig. 3-B

Secular changes in the prevalence of total hip arthroplasty (THA) (**Fig. 3-A**) and total knee arthroplasty (TKA) (**Fig. 3-B**) in the total U.S. population between 1980 and 2010.

method, which is a more reliable method than the transition method when data are readily available¹². Also, the transition to total knee replacement (i.e., incidence) in the Weinstein study was derived from the Osteoarthritis Initiative and the Multi-center Osteoarthritis Study, two relatively selected patient

populations. Individuals included in these cohorts either had osteoarthritis at baseline or were at increased risk of developing osteoarthritis. In other words, incidence estimates were limited to the unique setting and limited duration of these two studies that included only patients with osteoarthritis and may not

Fig. 4-A

2010 prevalence of total hip arthroplasty (THA) (**Fig. 4-A**) and total knee arthroplasty (TKA) (**Fig. 4-B**) in individual states.

Fig. 4-B

necessarily reflect the general population and temporal trends. In contrast, we used almost complete national data and accounted for geographic variation in incidence and the substantial rise in procedure volumes in recent years. We also accounted for relative mortality differences, which was not the case in the earlier study. Nevertheless, we believe that the main driver of the higher prevalence estimates in our study was the use of complete national data, reflecting the substantial increase in incidence over time.

The implications of our findings are severalfold. First and foremost, our estimates indicate that total joint replacement is surprisingly more prevalent than several chronic diseases that catch the public's attention. Overall prevalence is similar to stroke (6.8 million) and myocardial infarction (7.6 million) and much higher than heart failure (5.1 million)²⁰. Clearly, living with a total joint replacement is a remarkably common condition in the United States, a trend which is likely to continue in coming decades as a result of the aging of the "baby boomer" generation and improvements in longevity. Even without a further rise in incidence, simply the aging of the population would result in an estimated 11 million individuals with total hip or knee replacement (4 million total hip and 7.4 million total knee) in 2030 (i.e., applying 2010 prevalence to 2030 population estimates²¹).

Second, although there has been considerable research and policy focus in recent years on issues that surround access

to, and costs and outcomes of, total joint replacement (e.g., Centers for Medicare & Medicaid Services bundled payments and inpatient quality reporting initiatives), much of these efforts are limited to the immediate perioperative period^{22,23}. Yet, the majority of individuals with joint replacement have a relatively long life expectancy and will need many years of specialized follow-up care and radiographic assessments. In fact, our findings indicate that the majority (about 70%) of individuals who underwent joint replacement over the last four decades are still alive today. There is a need for the medical profession and the policy makers to recognize and address the lifelong needs of this population.

Third, in contrast to other chronic diseases, there are essentially no evidence-based guidelines (for physicians or for patients) on subacute and chronic care of individuals with joint replacement. A number of common issues remain unresolved, such as the optimal frequency of clinical and radiographic joint replacement follow-up and how antibiotic prophylaxis for other procedures (e.g., dental) should be managed. Additional research is needed to address these important aspects of the long-term management of individuals with joint replacement.

Fourth, with little progress on the horizon for the prevention of osteoarthritis (the main indication for joint replacement) or effective alternative treatments for advanced osteoarthritis, the demand for total joint replacement is likely to continue to increase

in coming decades and will be amplified further with a growing population of individuals undergoing revision surgery. Current research funding and surveillance efforts in the United States have not been commensurate with the growing population impact of total joint replacement. There is a need to facilitate research and ongoing surveillance in order to fill important evidentiary gaps regarding the long-term health and health-care needs of individuals with total hip and total knee replacement, to develop effective models of care, to facilitate patient self-management, and to develop evidence-based, patient-centered guidelines.

Our estimates should be interpreted in light of some potential methodological limitations. The validity of our prevalence estimates relies on the representativeness of data used to derive these estimates, specifically, incidence data from the NHDS and SID, and relative mortality and contralateral procedure data derived from a local population. The dearth of data in earlier years is a potential limitation. Although the SID data cover 97% of all U.S. hospital discharges in recent years, including nearly all community, nonrehabilitation hospitals, data from federal and U.S. Department of Veterans Affairs hospitals and from three states were not included, and data from time periods before 1990 were not available, and therefore, needed to be imputed. Our imputation methodology relied on calendar-year, age, and sex-specific data provided by the AHRQ and did not take into account other factors that may have potentially influenced incidence rates, such as insurance status, race, ethnicity, or comorbidities. NHDS was the only data source regarding procedures prior to 1990, and it was not possible to exclude revision surgeries or obtain actual state-level estimates. Therefore, we assumed that the geographic variation in earlier years was similar to patterns observed in later years. Even if this assumption may not be true, the contribution of individuals who received total hip and total knee replacement prior to 1990 into the 2010 prevalence pool (i.e., individuals who were still alive in 2010) is small, and it is unlikely to have unduly influenced the 2010 prevalence estimates. Although the prevalence ranking of individual states in this study is broadly consistent with the incidence rankings based on data from the Medicare population²⁴ (i.e., states with higher incidence rates also have higher prevalence), there are notable differences. For example, when we examined the incidence ranking of states for total knee replacement in 2008 from the Dartmouth Atlas of Health Care, the three states with the highest incidence in the Medicare population were Minnesota, North Dakota, and Montana²⁴. Yet, these three states ranked eleventh, third, and ninth, respectively, in our total knee replacement prevalence ranking (Fig. 4-B). This suggests that the patterns of geographic variation in procedure rates among younger ages may not be the same as the variation for the elderly Medicare population. Additional studies are needed to examine whether this is indeed the case. Of note, there is a growing population of individuals undergoing joint replacement other than total hip and total knee replacement, such as partial hip or partial knee replacement and replacement of other joints. Although they were not included in our prevalence estimates, their health-care needs are in many ways similar to those of total hip and knee replacement patients.

There is an estimated 100,000 partial hip replacement procedures in the United States for hip fractures¹. These individuals probably have more complicated and costly health-care needs. Regarding relative mortality data post-total hip and knee replacement, our estimates are almost identical to patterns observed for other large cohorts or national data. Although the local population is less ethnically diverse than the entire U.S. population, mortality rates are similar^{25,26}. Similarly, the contralateral procedure estimates are consistent with those in the published literature²⁷. Finally, state-specific prevalence estimates may not be accurate in certain states with relatively high rates of migration into and out of the state.

In conclusion, the high prevalence of arthritis, the growing demand for increased mobility and quality of life, and the success of joint replacement surgery over the recent decades has resulted in an estimated 7 million individuals living with artificial hips and knees in the United States. Total joint replacement benefits the daily lives of most of these individuals. However, the high prevalence of joint replacement also creates a need to effectively manage the long-term health-care requirements of this population, and to reduce the burden of subsequent complications and reoperations. These needs can be addressed through targeted research and implementation of effective, evidence-based policies.

Appendix

Incidence (Procedure Volume) Data Sources

Two data sources were used to obtain incidence data. For the period of 1990 to 2010, we collaborated with the AHRQ and relied on the SID to estimate total hip and knee replacement procedure counts by calendar year, state, sex, and single-year age groups. SID are a set of databases that include nearly all inpatient discharge data from states participating in the HCUP^{1,28}. We used the SID instead of the Nationwide Inpatient Sample (NIS) in order to reduce sampling error in incidence estimates while capturing state-specific variations in incidence. The SID data collection dates back to 1988, and the number of participating states has increased over time. By 2010, the SID included forty-seven states and about 96% of all U.S. community, nonrehabilitation hospital discharges, regardless of payer (including persons covered by Medicare, Medicaid, and private insurance as well as the uninsured). We identified all hospital discharges using the ICD-9 (International Classification of Diseases, Ninth Revision) codes 81.51 (primary hip replacement) and 81.54 (primary knee replacement). Partial hip replacement (81.52), revision hip replacement (81.53), and revision knee replacement (81.55) procedures were excluded because joint replacement is an irreversible procedure, and a person with joint replacement remains in the prevalence pool irrespective of the number of subsequent revision surgeries.

Contralateral procedures are common for both total hip and knee replacement. In order to avoid the double counting of individuals who had contralateral primary procedures at different hospitalizations, the SID discharge counts were deflated using calendar year, sex, age, and procedure-specific

deflation estimates derived from the published literature²⁷ and population-based data from Olmsted County, Minnesota, population. Briefly, owing to the infrastructure created by the Rochester Epidemiology Project^{29,30}, we were able to longitudinally follow all residents with an initial total hip or total knee replacement and capture all subsequent total joint replacement surgeries on contralateral and ipsilateral joints. For each decade, sex, and age-group stratum, we calculated the percentage of individuals who previously had a procedure on the contralateral joint. Our findings indicated that the percentage of contralateral primary procedures at different hospitalizations was similar among males and females. The percentage of contralateral total knee replacement was higher in elderly individuals than in younger individuals, whereas the percentage of contralateral total hip replacement was lower in elderly individuals than in younger individuals. We also observed a calendar-year effect, i.e., contralateral procedures increased over time. In order to account for these trends, the SID procedure counts were deflated by appropriate age-group and time-period-specific deflation factors. Deflation factors for total hip replacement (and corresponding age group) ranged between 0.102 (eighty years or older) and 0.292 (sixty to sixty-nine years) in 1990 to 1999, and 0.184 (eighty years or older) and 0.245 (fifty to fifty-nine years) in 2000 to 2010. Similarly, deflation factors for total knee replacement (and corresponding age group) ranged between 0.00 (less than fifty years) and 0.255 (eighty years or older) for 1990 to 1999, and 0.169 (less than fifty years) and 0.299 (seventy to seventy-nine years) in 2000 to 2010.

The states participating in the SID increased over time from eleven states in 1990 to forty-seven states in 2010. Procedure counts for years prior to each state's inclusion into the SID were estimated with use of data from all available states during 1990 to 2010. Separate Poisson regression models for total hip replacements and for total knee replacements, including state, sex, age, and calendar-year terms, were used to produce these estimates. Age and calendar year were modeled using smoothing splines to allow for flexible, nonlinear relationships with procedure counts, and the state, sex, age, and calendar-year-specific populations were included as an offset to adjust for the varying population size associated with each procedure count. The predicted values from these models were used to estimate the procedure counts prior to each state's inclusion into the SID. No SID data were available from three states (Alabama, Delaware, and Idaho) throughout the entire time period. The numbers of procedures in Alabama, Delaware, and Idaho were estimated by applying the Dartmouth Atlas ratios²⁴ for these states to the procedure rates from two other large states (Florida and New York) with continuous SID data throughout the entire 1990 to 2010 period.

Incidence rate estimates for some state, sex, age, and calendar-year-specific intervals were based on small numbers, and their variability was large. To increase the stability of these estimates, gradient boosting machine methods were used¹³. These machine-learning methods smoothed the trends in incidence rates according to state, sex, age, and calendar year without

requiring restrictive assumptions regarding the functional forms of these effects. These models were chosen to avoid concerns about the validity of our estimates related to the modeling assumptions. However, when generalized additive models with smoothing splines were used in place of gradient boosting machines, the resulting prevalence estimates were nearly identical.

For the 1969 to 1989 period, we relied on the NHDS to estimate the annual number of total hip and total knee replacement procedures by calendar year, four major census regions, sex, and single-year age groups¹⁴. NHDS was a national probability survey of inpatient discharges from nonfederal, short-stay hospitals in the United States. Total hip and knee replacement procedures were identified using the ICD-8 (Eighth Revision) and ICD-9 codes 81.4, 81.41, and 81.54 (knee), and 81.5, 81.51, and 81.59 (hip), and procedure counts were weighted to produce national estimates. In order to estimate the numbers of procedures in individual states, we assumed that the state-specific variation in incidence between 1969 and 1989 followed the same pattern as in subsequent years. Using 1990 to 2000 ratios derived from the SID and the Dartmouth Atlas²⁴, we distributed the procedure counts to individual states. It was not possible to exclude revision procedures for the 1969 to 1989 period because ICD-9 revision codes were first introduced after October 1989.

General Population Data

Calendar-year, state, sex, and single year of age-specific U.S. population estimates for the 1969 to 2010 period were obtained from the United States Census Bureau³¹. Historical population mortality data were obtained from the NCHS vital statistics¹⁶. We compiled total population counts and the numbers of deceased individuals by calendar year, state, sex, and single-year age groups.

Mortality Data

In addition to incidence, prevalence of total hip and total knee replacement depends on relative patient mortality following surgery, which is not the same as mortality in the general population. Several prior studies suggest that individuals who underwent total hip and knee replacement have lower mortality rates than the general population, attributed mainly to the selection of healthier individuals for surgery¹⁷⁻¹⁹. These findings indicate that relative mortality differences should be accounted for in prevalence estimates. We estimated procedure-specific relative death rates (observed versus expected deaths) by the number of years after surgery, sex, and age group using four decades of population data. Estimated relative death rates ranged between 0.65 and 1.18 (for the first year post-surgery) and 0.99 and 1.74 (for fifteen years post-surgery) for total hip replacement, and between 0.40 and 0.48 (for the first year post-surgery) and 0.99 and 1.32 (for fifteen years post-surgery) for total knee replacement. These estimates are consistent with those of previous patient mortality studies from other populations¹⁷⁻¹⁹. Relative mortality ratios were then applied to calendar-year, state, sex, and single year of age-specific mortality data obtained from the NCHS.

Estimation of 2010 Prevalence

The 2010 prevalence of total hip and total knee replacement was estimated using the counting method^{12,13}. This direct estimation method counts the number of individuals with a history of total hip and total knee replacement known to be alive (i.e., survivors) on a certain date and adjusts for population mortality and relative mortality differences. Because the prevalence of total hip and total knee replacement was essentially “0” before 1969, no assumptions were needed for the period prior to 1969. We further estimated the prevalence of individuals by duration of time since the initial total hip and knee replacement procedure, i.e., percentage of prevalent individuals who were less than ten years from their initial procedure, ten to twenty years from their procedure, and greater than twenty years from their procedure.

We also estimated the prevalence among individuals who had both hip and knee replacement procedures, i.e., procedures on more than one joint, using estimates from Olmsted County, Minnesota, and the published literature²⁷ (Table II). Briefly, we identified all residents with a history of both hip and knee replacement in 2008. We then calculated the age and sex-specific percentage (column A) and population prevalence (column B) of prevalent individuals with both procedures and applied them to the total population of United States in 2010. Two estimates were obtained (see the last two columns in Table II): one based on the estimated percentage of prevalent cases and the other, based on estimated population prevalence.

Testing and Validation of the Estimation Procedures

We validated our counting method by comparing the estimated prevalence in Minnesota with actual prevalence among eighty-year-old individuals. We first identified all Olmsted County residents who were eighty years old in 2008 and who had a history of hip and knee replacement in their medical records. The comparisons revealed that the estimated prevalence (based on the counting method) was close to the upper limit of the 95% confidence intervals (CIs) for the actual prevalence for both total hip replacement (7.6% [95% CI, 5.3% to 9.8%] compared with an estimated 9.5% at age eighty) and total knee replacement

(9.8% [95% CI, 7.3% to 12.3%] compared with an estimated 12.5% at age eighty). We also assessed the impact of relative mortality estimates by producing 2010 prevalence estimates after ignoring the relative mortality differences (i.e., assuming that the mortality of individuals with total hip and knee replacement is identical to that of the general population). This assumption resulted in negligible differences in the overall prevalence estimates. Unless otherwise stated, all prevalence estimates were calculated with the total U.S. population as the denominator. ■

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Hilal Maradit Kremers, MD, MSc
Dirk R. Larson, MS
Cynthia S. Crowson, MS
Walter K. Kremers, PhD
Daniel J. Berry, MD
Department of Health Sciences Research
(H.M.K., D.R.L., C.S.C., and W.K.K.),
Department of Orthopedic Surgery (H.M.K. and D.J.B.),
and Division of Rheumatology (C.S.C.),
Mayo Clinic,
200 First Street S.W.,
Rochester, MN 55905.
E-mail address for H. Maradit Kremers: maradit@mayo.edu

Raynard E. Washington, PhD, MPH
Claudia A. Steiner, MD, MPH
Healthcare Cost and Utilization Project (HCUP),
Center for Delivery,
Organization and Markets (CDOM),
Agency for Healthcare Research and Quality (AHRQ),
540 Gaither Road,
Rockville, MD 20850

William A. Jiranek, MD
Department of Orthopedic Surgery,
Virginia Commonwealth University (VCU) Medical Center,
9000 Stony Point Parkway,
Richmond, VA 23235

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