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Projections and Epidemiology of Primary Hip and Knee Arthroplasty in Medicare Patients to 2040-2060

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Background: National projections of future joint arthroplasties are useful for understanding the changing burden of surgery and related outcomes on the health system. The aim of this study is to update the literature by producing Medicare projections for primary total joint arthroplasty (TJA) procedures until 2040 and 2060.

Methods: The present study used data from the Centers for Medicare & Medicaid Services (CMS) Medicare/Medicaid Part B National Summary and combined procedure counts with use of Current Procedural Terminology (CPT) codes to identify whether the procedure was a primary total hip arthroplasty (THA) or total knee arthroplasty (TKA) procedure. In 2019, the annual volume of primary TKA was 480,958 and that of primary THA was 262,369. These values formed a baseline from which we generated point forecasts for 2020-2060 and 95% forecast intervals (FIs).

Results: Between 2000 and 2019, the estimated annual volume of THA increased by 177% and that of TKA increased by 156% on average. Regression analysis projected an annual growth rate of 5.2% for THA and 4.44% for TKA. Based on these yearly projected increases, an estimated increase of 28.84% and 24.28% is expected for each 5-year period after 2020 for THA and TKA, respectively. By 2040, the number of THAs is projected to be 719,364 (95% FI, 624,766 to 828,286) and the number of TKA is projected to be 1,222,988 (95% FI, 988,714 to 1,512,772). By 2060, the number of THAs is projected to be 1,982,099 (95% FI, 1,624,215 to 2,418,839) and the number of TKAs is projected to be 2,917,959 (95% FI, 2,160,951 to 3,940,156). In 2019, Medicare data showed that THA constituted approximately 35% of TJA procedures performed.

Conclusions: Based on 2019 total volume counts, our model forecasts an increase in THA procedures of 176% by 2040 and 659% by 2060. The estimated increase for TKA is projected to be 139% by 2040 and 469% by 2060. An accurate projection of future primary TJA procedure demands is important in order to understand future health-care utilization and surgeon demand. This finding is only applicable to a Medicare population and demands further analysis to see if this extends to other population groups.

Level of Evidence: Prognostic Level III. See Instructions for Authors for a complete description of levels of evidence.

Given the high success rates of modern total joint arthroplasty (TJA), the volume of primary TJA has risen dramatically over the past several decades, making it the most frequently performed orthopaedic procedure in the United States[1-5]. As a result, there are ongoing and evolving discussions surrounding TJA indications, patient-reported outcome measures, implant survivorship, and cost-effectiveness driven by surgeons and national health organizations worldwide[4,6]. To understand the future cost of TJA, in order to guide resource allocation, several studies have been performed in an attempt to project the future volume of TJA[1-4]. Kurtz et al. reported on the epidemiology of TJA in the United States, projecting that the annual volume of primary total knee arthroplasty (TKA) would reach 1.37 million by 2020 and 3.48 million by 2030 and that the annual volume of primary total hip arthroplasty (THA) would reach 511,000 by 2020 and 572,000 by 2030[2]. In a more recent study based on the 2000 to 2014 National Inpatient Sample (NIS) data, Sloan et al. reported that THA is projected to grow by 71% (to 635,000 procedures) by 2030 and that TKA is projected to grow by 85% (to 1.26 million procedures) by 2030[3]. Interestingly, that study showed that the TKA growth rate has been slowing over recent years, and models based on 2008 to 2014 data projected growth to only approximately 935,000 procedures by 2030[3]. Singh et al., in an analysis using the 2000 to 2014 U.S. NIS

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and Census Bureau data, projected a 401% increase in TKA (reaching a projected annual volume of 1.34 million procedures) and a 284% increase in THA (reaching a projected annual volume of 1.43 million procedures) by 2040[4]. While these projections have been frequently cited and used to formulate health-care policies, their conflicting findings and inconsistency with observed trends in TJA volume in the United States necessitate modeling of updated projections based on national data from recent years.

The purpose of the present report is to update the literature by producing U.S. Medicare projections for primary TJA procedures until 2040 and 2060 by using an alternative model based on past utilization data from the Centers for Medicare & Medicaid Services (CMS) Medicare/Medicaid Part B National Summary. We hypothesize that the demand for THA and TKA in the United States will increase substantially over the next 4 decades.

Materials and Methods

The present study used data from the CMS Medicare/Medicaid Part B National Summary and combined procedure counts with use of Current Procedural Terminology (CPT) codes to identify whether the procedure was a primary THA or TKA procedure[6]. The study replicated the well-documented approach used in the literature, involving ordinary least squares (OLS) regression and generalized linear modeling (GLM)[3,7,8]. The regressions were formed using annual data (2000 to 2019) from the CMS and include data on patients ≥65 years of age as well as Medicare Fee-for-Service (FFS) beneficiaries. Procedure counts and subsequent groupings were created on the basis of CPT codes and those considered to be most appropriate based on the provided description. The codes were divided into 2 categories: (1) primary THA and (2) primary TKA (see Appendix). As each category will likely exhibit a different trend over time, this study also modeled them separately. Data from 2020 were excluded because of COVID-19-related confounding. Thus, the projections in this analysis can be considered pre-pandemic projections.

As these procedure counts include only FFS patients (see Appendix) and not Medicare Advantage (MA) patients, we adjusted procedure counts using a ratio of FFS to MA patients provided by the Kaiser Family Foundation (Table I)[9]. Using the proportions reported in Table II, we then adjusted the total procedure counts for each CPT code.

Following this adjustment, we used annual primary total procedure counts for THA and TKA to generate log-linear (exponential growth) time series forecasts between 2020 and 2060. We generated point forecasts and 95% forecast intervals (FIs) for each year over the forecasted time period. To validate these results, findings were compared with alternative model

TABLE I Primary THA and TKA Volumes Between 2000 and 2019, Adjusted to Include Medicare Advantage Patients

		Primary THA		Primary TKA	
Year	Proportion of Medicare Advantage Patients (r)	Adjusted Volume (Volume/[1–r])	Annual Percentage Change	Adjusted Volume (Volume/[1–r])	Annual Percentage Change
2000	17%	94,846	—	188,118	—
2001	15%	103,662	9.30%	204,512	8.71%
2002	14%	108,430	4.60%	220,570	7.85%
2003	13%	115,747	6.75%	242,322	9.86%
2004	13%	122,976	6.25%	275,206	13.57%
2005	13%	123,949	0.79%	299,107	8.68%
2006	16%	125,165	0.98%	305,745	2.22%
2007	19%	129,675	3.60%	313,232	2.45%
2008	22%	135,129	4.21%	321,469	2.63%
2009	23%	142,858	5.72%	331,634	3.16%
2010	24%	149,601	4.72%	348,286	5.02%
2011	25%	153,471	2.59%	340,352	−2.28%
2012	26%	166,045	8.19%	354,089	4.04%
2013	28%	180,035	8.43%	374,390	5.73%
2014	30%	190,633	5.89%	377,311	0.78%
2015	31%	205,586	7.84%	394,259	4.49%
2016	31%	217,680	5.88%	424,338	7.63%
2017	33%	231,200	6.21%	444,191	4.68%
2018	35%	247,051	6.86%	463,586	4.37%
2019	36%	262,369	6.20%	480,958	3.75%

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TABLE II Comparison of Observed Primary THA and TKA Procedure Volumes from the CMS Part B National Summary (Panel A)

	Primary THA			Primary TKA		
Year	Adjusted Volume	Change from Prior 5-Year Period	Cumulative Growth from Base Year (2000)	Adjusted Volume	Change from Prior 5-Year Period	Cumulative Growth from Base Year (2000)
2000	94,846	—	—	188,118	—	—
2005	123,949	30.68%	30.68%	299,107	59.00%	59.00%
2010	149,601	20.70%	57.73%	348,286	16.44%	85.14%
2015	205,586	37.42%	116.76%	394,259	13.20%	109.58%
2019*	262,369	27.62%	176.63%	480,958	21.99%	155.67%

*2015 to 2019 represents a 4-year interval.

specifications. GLM methods in the form of Poisson and negative binomial regressions as well as the autoregressive integrated average (ARIMA) were found to yield similar estimates and annual growth rates (see Appendix). While many authors in the literature have turned to GLM estimation in the form of either Poisson or negative binomial regression, we found log-linear OLS regression to perform just as well for the data used in this study[2,3,10]. This technique involves a simple log-transformation prior to model creation and uses the widely understood OLS estimation method, which outperformed both the GLM and ARIMA for this analysis. Therefore, the OLS regression was ultimately chosen to calculate projections for this study.

Statistical analysis was performed with use of the R programming environment (version 4.1.2; R Core Team [2021], R Foundation for Statistical Computing).

Results

Based on CMS CPT codes adjusted to include MA patients, the estimated annual volume of primary THA procedures performed in Medicare patients in the U.S. increased from 94,846 in 2000 to 262,369 in 2019, a 177% increase. During this same period, the estimated annual volume of primary TKA procedures increased 156%, from 188,118 in 2000 to 480,958 in 2019 (Table I). When the raw CMS data (2000 to 2019) were subdivided into quartiles, 31% growth in THA and 59% growth in TKA were observed by 2005. By 2010, 58% growth in THA and 85% growth in TKA were observed. By 2015, 117% growth in THA and 110% TKA growth were observed. Last, by 2019, 177% growth in THA and 156% growth in TKA were observed (Table II). On average, the log-linear OLS regression model projected an annual growth rate of 5.2% for THA and 4.44% for TKA (Table III).

Table IV demonstrates the projected increase in THA and TKA from 2020 to 2060 in 5-year periods. Based on the yearly projected increase for THAs, an estimated increase of 28.84% is expected for each 5-year period after 2020. Similarly, based on yearly projected increases for TKA, the projected increase for each 5-year period after 2020 is 24.28%.

With use of the CMS Medicare MA-adjusted data presented in Table II, our OLS regression model estimated that, over the following 40 years (2020 to 2060), THA would grow 176% (95% FI, 624,766 to 828,286 procedures) by 2040 and 659% (95% FI, 1,624,215 to 2,418,839) by 2060, whereas TKA would grow 139% (95% FI, 988,714 to 1,512,772) by 2040 and 469% (95% FI, 2,160,951 to 3,940,156) by 2060. Together, primary TJA is projected to grow to 1,942,352 (95% FI, 1,613,479 to 2,341,059) by 2040 and to 4,900,058 (95% FI, 3,785,166 to 6,358,996) by 2060, which equates to a 559% forecasted increase from 2019 counts (Tables II and IV).

In 2019, Medicare data showed that THA constituted 35% of all TJA procedures performed. Over time, our model forecasts that THA will make up a higher proportion of TJA, reaching 40% by 2060 (Table IV). The relative difference in the rate of growth between THA and TKA from 2000 to 2060 can be appreciated in Figure 1.

TABLE III Log-Linear OLS Regression Estimates and Growth Rates

				Projected Annual Growth*		
Procedure Type (y)	Intercept ($\widehat{\beta_0}$)	Trend Estimate ($\widehat{\beta_1}$)	Standard Error ($\widehat{SE}$) of $\widehat{\beta_1}$	Average†	95% CI, Lower‡	95% CI, Upper§
Primary THA	11.4084	0.0507	0.0017	5.20%	4.86%	5.54%
Primary TKA	12.2342	0.0435	0.0025	4.44%	3.93%	4.96%

*Calculated using normal approximation. CI = confidence interval. †$(\exp[\widehat{\beta_1}]-1)\times100$. ‡$(\exp[\widehat{\beta_1}-(1.96\times\widehat{SE})]-1)\times100$. §$(\exp[\widehat{\beta_1}+(1.96\times\widehat{SE})]-1)\times100$.

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TABLE IV Log-Linear OLS Projections (2020 to 2060) for Primary THA, TKA, and TJA*

Year (5-Year Intervals)	Primary THA *(no. of procedures)*			Primary TKA *(no. of procedures)*			Primary TJA (Primary THA + Primary TKA) *(no. of procedures)*		
	Projection	95% FI, Lower	95% FI, Upper	Projection	95% FI, Lower	95% FI, Upper	Projection	95% FI, Lower	95% FI, Upper
2020	261,079	236,389	288,348	512,584	441,259	595,438	773,663	677,648	883,785
2025	336,369	302,227	374,369	637,058	542,090	748,664	973,428	844,316	1,123,034
2030	433,372	385,580	487,087	791,760	663,830	944,343	1,225,132	1,049,410	1,431,430
2035	558,348	491,117	634,782	984,029	810,905	1,194,114	1,542,376	1,302,022	1,828,896
2040	719,364	624,766	828,286	1,222,988	988,714	1,512,772	1,942,352	1,613,479	2,341,059
2045	926,815	794,041	1,081,789	1,519,975	1,203,813	1,919,171	2,446,789	1,997,854	3,000,960
2050	1,194,090	1,008,467	1,413,880	1,889,081	1,464,143	2,437,350	3,083,171	2,472,609	3,851,230
2055	1,538,442	1,280,100	1,848,921	2,347,820	1,779,312	3,097,973	3,886,263	3,059,412	4,946,894
2060	1,982,099	1,624,215	2,418,839	2,917,959	2,160,951	3,940,156	4,900,058	3,785,166	6,358,996

*FI = forecast interval.

Discussion

THA and TKA are extremely effective procedures that result in substantial improvement in patient quality of life. According to the U.S. Agency for Healthcare Research and Quality (AHRQ), 715,203 inpatient stays were related to knee arthroplasty and 599,494 were related to hip arthroplasty in 2018, up from 656,782 and 421,571, respectively, in 2008[11]. Given the rapid accessibility of and demand for these procedures, it is essential to have accurate models to predict the number of procedures that will be performed in the next 2 to 4 decades from now in order to ensure that the health-care system can plan for the required personnel, facilities, and implants to meet this rising demand. Numerous studies have attempted to model future TJA projections with use of various data sources and end points. As previously noted, Kurtz et al., in a widely cited study that was published in 2007, projected that the annual volume of TKA would reach 1.37 million by 2020 and 3.48 million by 2030 and that the annual volume of THA would reach 511,000 by 2020 and 572,000 by 2030[2]. More recently, Sloan et al. projected that THA was expected to grow to 635,000 procedures by 2030 and that TKA was expected to grow to 1.26 million procedures by 2030[3]. Finally, Singh et al. reported a projected annual volume of 1.34 million TKAs and 1.43 million THAs by 2040[4].

Given that we are presently in the year 2023, we can only assess the validity of the Kurtz model of TJA case volume

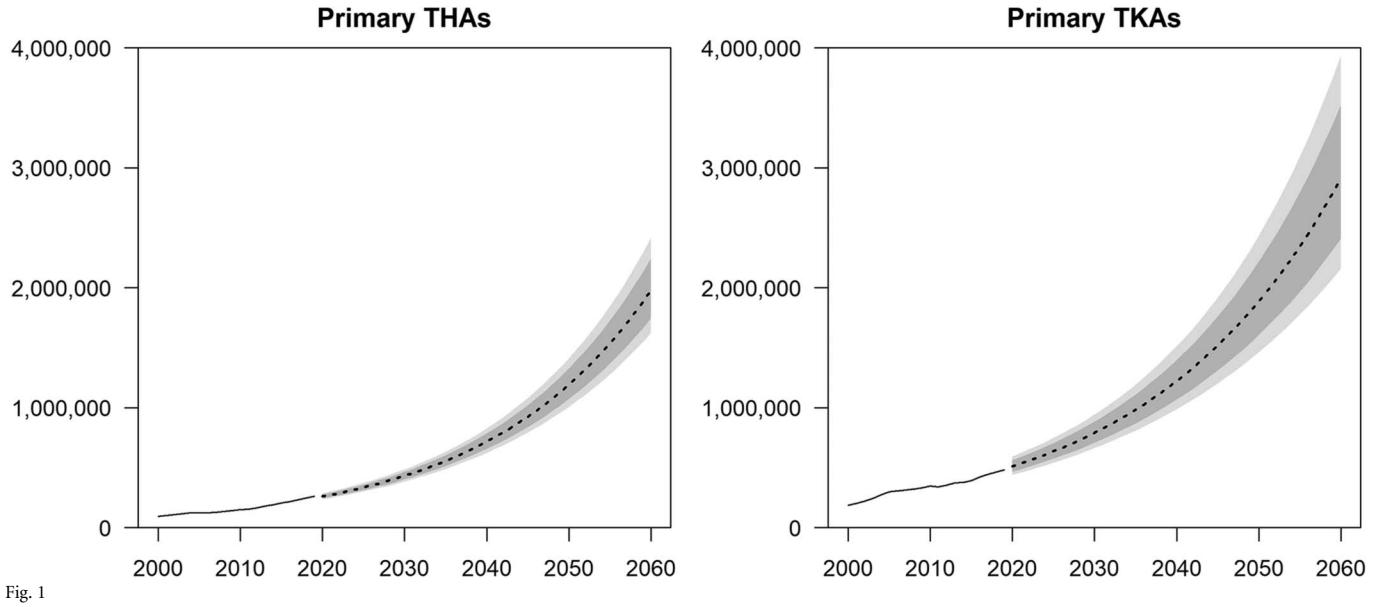

Fig. 1

Primary THAs and TKAs projected between 2020 and 2060 using log linear model. In each panel, the black line presents observed CMS data (2000-2019), the dotted line presents the point forecasts (2020-2060), the dark gray area is the 80% forecast interval, and the light gray area is the 95% forecast interval.

through 2020. According to the American Joint Replacement Registry (AJRR) 2020 Annual Report, 3,669 surgeons submitted data on 124,307 primary TKAs and 3,143 surgeons submitted data on 83,845 primary THAs performed in 2020[12]. Unfortunately, those data are not entirely reliable as not all hospital systems, practices, and surgeons participate in the AJRR and the COVID-19 pandemic resulted in intermittent restrictions on performing elective procedures, limiting the number of elective TKAs and THAs that could be performed[13]. Another data source, the CMS data from 2019, showed that 274,238 primary THAs and 392,908 primary TKAs were performed in the United States[6]. To our knowledge, there are no other reports clearly tallying the number of TKA and THA procedures performed in the United States in 2020.

This recent information indicates that the Kurtz model vastly overestimated the number of TKA and THA procedures that would be performed in 2020 (estimated at 1.37 million and 511,000 cases, respectively)[2]. The methodology used in that model relied on data from the NIS from 1993 to 2003, with primary and revision THAs and TKAs being identified with use of the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes. Additionally, the NIS is a federal-state cooperative that generates a representative sample of hospital discharge records in the United States[14]. At the time of the study, the NIS contained a sample size of approximately 8 million discharge records from approximately 1,000 hospitals, representing about 20% of all United States community hospitals. To extrapolate the projected number of procedures for the entire population, the authors applied the surgery prevalence estimated from their regression model to the projected population data for each race/ethnicity subgroup. The projected national total was the sum of the projected number of procedures from each subpopulation. The reliance on ICD-9-CM codes, which have been supplanted by more specific coding methodologies (ICD-10 Procedure Coding System [PCS]), as well as the multilevel extrapolation that occurred to generate these numbers on a national scale, likely introduced error into that model.

To improve this projections model, our study utilized data taken directly from the CMS Medicare/Medicaid Part B National Summary[6]. Given that this is a national database, our inputs were already scaled to represent the national prevalence of TKA and THA. Additionally, we were able to adjust the model with use of data from the Kaiser Family Foundation to ensure that our model not only included FFS patients but also incorporated MA patients[9]. Additionally, our model utilized data from a 19-year data-collection period, which is substantially greater than the 10-year period used by Kurtz et al.[2]. Incorporating more data into the model improved the accuracy of the projection, enabling us to have more useful projections on which to base health-care expenditures and resource allocation. Additionally, we utilized CPT codes instead of ICD-10 codes to identify cases for the present study. Given their longer duration of use and greater familiarity, CPT codes are typically the benchmark against which ICD-10 coding accuracy is assessed. Therefore, the use of CPT codes in the present study strengthened our results, given the increased validity of CPT codes compared with other coding schemas. A table in the Appendix compares previous estimation models and annual growth rates with those in the current study to illustrate how our findings differ from those of previous investigations. The present study chose to present projections using the OLS (log-linear) regression model. Interestingly, our GLM (Poisson and negative binomial) and ARIMA (0,1,1) models aligned with previous studies with similar annual growth rate of THA of roughly 5%. However, our models predict a smaller growth for TKA of 4% to 5% compared with the other studies, which projected an annual growth of 6% to 8.5%[2,3]. Differences may be explained by the fact that the other studies used NIS data from all age groups, whereas the present study utilized 19-year data on CPT codes from CMS Part B, which includes only Medicare and Medicaid patients ≥65 years of age.

The importance of modeling the future primary TKA and THA burden cannot be overstated. First, these models can help the health-care system to budget for future health-care expenditures[15]. As the numbers of primary TKAs and THAs rise, so too do the numbers of revision procedures performed. Revision procedures are more complicated and costly to the health-care system[16,17]. Understanding the financial impact of these procedures can help insurance companies and hospital systems to budget accordingly, and may potentially provide more data to adequately prepare for this future demand. Our work demonstrates that THAs are projected to grow 176% by 2040 and 659% by 2060, whereas TKAs are projected to grow 139% by 2040 and 469% by 2060. Together, primary TJAs are projected to grow 559% by 2060 from 2019 counts. Understanding this trajectory is essential for preparing the health-care field for the case volume and financial challenges associated with these procedures.

Second, these models can allow pre-professional schools, training programs, and hospital systems to work to ensure that there are adequately trained and available personnel. Taking care of patients undergoing TJA relies on a multidisciplinary team consisting of the surgical team, the anesthesia team, the medical team, the intraoperative and postoperative nursing teams, physical and occupational therapists, and pharmacists. Knowing the growing demand for these procedures can help to guide educators and trainees toward focusing on the care of such patients.

Finally, we can consider using these models to benchmark the work of national registries working to collect such data firsthand. Although the AJRR has been collecting data on TJA performed in the United States since 2009, many institutions and surgeons still do not contribute their data[12]. If full participation is reached nationally, the AJRR data will ultimately become the true representation of all THA and TKA procedures performed in the United States; however, it is a slow process that will continue to unfold over the next decades.

Having the present model extrapolated to 2040 and 2060 can serve as a comparison to help the AJRR map its participation as it continues to expand.

Limitations

One of the major limitations of the present study is its generalizability. Our study utilized data from the Medicare database, which only includes patients ≥65 years of age and does not include private payer insurance. One important trend that we can expect over the next 20+ years is that the proportion of TJAs performed in patients <65 years of age will likely increase. Given that most medical centers accept a wide range of insurers and patients both older and younger than 65 years of age, our results must be interpreted with this limitation in mind. Thus, our projections may be lower than what we may see, and that will be due to a larger increase in TJA in younger patients compared with the relative increase in the Medicare population. Furthermore, world events such as the 2008 economic recession (as seen by the relatively mild annual increase in TJA counts in 2008) have an indirect effect on TJA rates. Future national or world-disrupting events such as the COVID-19 pandemic may have a muting effect on future TJA annual rates as well, and our model cannot account for such events accurately. Second, alternative time series modeling approaches, including GLM (Poisson and binomial) and ARIMA modeling[18], were also used for the initial analysis. However, the literature suggests that, for the model to be accurate, raw data from more time points instead of annual volume are required. Given the available time-point data, the OLS regression model outperformed the GLM and was chosen for presenting the findings of the present study. If future registry sets can provide more time-point data, future studies utilizing the GLM model could provide even more accurate projections. Last, the accuracy of the OLS regression forecast model diminishes the closer we get to the end of our time series, as elucidated by the wider forecast intervals seen the closer we approach 2060.

Conclusions

The present study describes a novel methodology to predict the volume of primary THA and TKA in Medicare patients ≥65 years of age in the United States by 2020 and 2060. Our model projects that primary TJAs will grow 559% by 2060 from 2019 counts. These numbers certainly underestimate the true increase, as our data inputs did not include patients <65 years of age and non-Medicare-insured patients. Although projecting the number of primary TJAs is challenging for a variety of reasons, it is important for our system to have these data in order to properly allocate resources, budget costs, and plan for the future.

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJSOA/A483). ■

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References

1. 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. The Journal of Bone and Joint Surgery-American Volume 2015 Seph 2;97(17):1386-97.

2. 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. The Journal of Bone & Joint Surgery 2007 Apr;89(4):780-5.

3. Sloan M, Premkumar A, Sheth NP. Projected Volume of Primary Total Joint Arthroplasty in the U.S., 2014 to 2030. Journal of Bone and Joint Surgery 2018 Sep 5;100(17):1455-60.

4. Singh JA, Yu S, Chen L, Cleveland JD. Rates of Total Joint Replacement in the United States: Future Projections to 2020-2040 Using the National Inpatient Sample. J Rheumatol. 2019 Sep;46(9):1134-40.

5. 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. The Journal of Bone and Joint Surgery-American Volume 2012 Feb 1;94(3):201-7.

6. Centers for Medicare & Medicaid Services. Part B National Summary Data File. https://www.cms.gov/research-statistics-data-and-systems/downloadable-public-use-files/part-b-national-summary-data-file/overview

7. Schober P, Vetter TR. Linear Regression in Medical Research. Anesthesia & Analgesia. 2021 Jan;132(1):108-9.

8. Casals M, Girabent-Farrés M, Carrasco JL. Methodological quality and reporting of generalized linear mixed models in clinical medicine (2000-2012): a systematic review. PLoS One. 2014 Nov 18;9(11):e112653.

9. Kaiser Family Foundation - Medicare Advantage Enrollment Update. https://www.kff.org/medicare/issue-brief/medicare-advantage-in-2022-enrollment-update-and-key-trends/

10. Klug A, Gramlich Y, Rudert M, Drees P, Hoffmann R, Weißenberger M, Kutzner KP. The projected volume of primary and revision total knee arthroplasty will place an immense burden on future health care systems over the next 30 years. Knee Surg Sports Traumatol Arthrosc. 2021 Oct;29(10):3287-98.

11. Agency for Healthcare Research and Quality (AHRQ) - 2018 reports. https://www.ahrq.gov/research/findings/nhqrdr/nhqdr18/index.html

12. Siddiqi A, Levine BR, Springer BD. Highlights of the 2021 American Joint Replacement Registry Annual Report. Arthroplasty Today. 2022 Jan 29;13:205-7.

13. Bedard NA, Elkins JM, Brown TS. Effect of COVID-19 on Hip and Knee Arthroplasty Surgical Volume in the United States. The Journal of Arthroplasty. 2020 Jul;35(7):S45-8.

14. Pierce AZ, Menendez ME, Tybor DJ, Salzler MJ. Three Different Databases, Three Different Complication Rates for Knee and Hip Arthroplasty: Comparing the National Inpatient Sample, National Hospital Discharge Survey, and National Surgical Quality Improvement Program, 2006 to 2010. Journal of the American Academy of Orthopaedic Surgeons. 2019 Jun 15;27(12):e568-76.

15. Gwam CU, Mistry JB, Mohamed NS, Thomas M, Bigart KC, Mont MA, Delanois RE. Current Epidemiology of Revision Total Hip Arthroplasty in the United States: National Inpatient Sample 2009 to 2013. The Journal of Arthroplasty. 2017 Jul; 32(7):2088-92.

16. Weber M, Renkawitz T, Voellner F, Craiovan B, Greimel F, Worlicek M, Grifka J, Benditz A. Revision Surgery in Total Joint Replacement Is Cost-Intensive. Biomed Res Int. 2018 Sep 25; 2018:8987104.

17. Okafor C, Hodgkinson B, Nghiem S, Vertullo C, Byrnes J. Cost of septic and aseptic revision total knee arthroplasty: a systematic review. BMC Musculoskelet Disord. 2021 Aug 18;22(1):706.

18. Schaffer AL, Dobbins TA, Pearson SA. Interrupted time series analysis using autoregressive integrated moving average (ARIMA) models: a guide for evaluating large-scale health interventions. BMC Med Res Methodol. 2021 Mar 22;21(1):58.