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Geographic Variations and Trends in Primary and Revision Knee and Total Hip Arthroplasties in the United States

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Background: Over 1 million joint arthroplasties are performed annually in the United States. Ideally, as devices and surgical techniques improve, the number of revision arthroplasties relative to primary arthroplasties should decrease. To our knowledge, this is the first study to evaluate state-by-state disparities in the ratio of revision to primary knee arthroplasty (unicompartmental and total) and total hip arthroplasty (THA).

Methods: The National Inpatient Sample was used to identify patients who had undergone primary or revision knee arthroplasty or primary or revision THA from 2001 to 2011. Demographic characteristics, surgical rates, and revision ratios (the number of revision procedures divided by the number of primary procedures) were determined for the United States as a whole and by state.

Results: During the study window, 47 states were sampled. For knee arthroplasty, 1,251,484 patients were identified: 91% underwent primary procedures and 9% underwent revision procedures. Compared with the primary knee arthroplasty cohort, the revision knee arthroplasty cohort had a younger mean age, had more male patients, and had more chronic conditions and longer hospitalizations ($p < 0.001$ for each). Over the years studied, the mean age of patients who had undergone primary knee arthroplasty decreased 1.8 years ($p < 0.0001$) and the mean age of those who had undergone revision knee arthroplasties decreased 2.4 years ($p < 0.0001$). The national revision ratio remained unchanged at around 0.1 ($p = 0.8792$). However, there was a 2.2-fold variation in revision ratio by state (revision ratio state range, 0.065 to 0.141). For THA, 614,638 patients were identified: 85% underwent primary procedures and 15% underwent revision procedures. Compared with the primary THA cohort, the revision THA cohort had an older mean age, had fewer male patients, and had more chronic conditions and longer hospitalizations ($p < 0.001$ for each). Over the years studied, the mean age of patients who had undergone primary THA decreased 1.5 years ($p = 0.0016$), whereas patients who had undergone revision had no significant age trend ($p = 1.0000$). Unlike for knee arthroplasty, the national THA revision ratio trended downward (0.24 evolved to 0.18, $p = 0.0016$), and there was a 2.1-fold variation in the revision ratio by state (revision ratio state range, 0.119 to 0.248).

Conclusions: This study found significant variability in state-by-state revision ratios. It also found that the national revision ratio stayed relatively steady for knee arthroplasty but was decreasing for THA, and that patients who had undergone revision knee arthroplasty were getting younger, whereas patients who had undergone revision THA were not. These discrepancies suggest divergent histories for primary knee arthroplasty and THA and warrant further detailed evaluation.

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

The first total hip and total knee arthroplasties were performed in the United States in the 1960s[1,2]. Subsequently, the rate of total hip arthroplasty (THA) and total knee arthroplasty (TKA) has markedly increased to >1 million hip and knee arthroplasties (combined) performed annually in the United States[3,4]. It has thus been estimated that >7 million Americans are living with a total hip replacement and/or a total knee replacement[5]. Because of wear, loosening,

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and infection, some of these devices will require a revision surgical procedure. Such revision procedures are generally more technically difficult, have higher failure rates, pose greater risk to patients, and are more expensive to the health-care system than primary surgical procedures[6-8]. Some authors have previously described this as a revision burden to society and have estimated its magnitude and cost[6,9].

It is possible that the revision burden can be reduced through innovation in implant technology, additional surgeon training, and adoption of best practices. If these factors can limit the revision burden, then state-level analyses of revision rates might highlight states that provide better care. The U.S. National Inpatient Sample (NIS)[10] provides data on a large patient population that can be subdivided by state and can be used to evaluate such geographic disparities in revision arthroplasties.

The purpose of the current study was to analyze geographic and temporal differences in primary and revision knee arthroplasties (unicompartmental and total knee arthroplasties) and THAs using a revision ratio (the number of revision procedures divided by the number of primary procedures in a specific time period and location). This analysis sought to identify trends in these nationwide ratios and to utilize state-specific data from the NIS to calculate them on a state-by-state basis.

Materials and Methods

Data Source

This study utilized the NIS data from 2001 to 2011; the NIS is an all-payer, U.S. inpatient database collected by the U.S. federal Healthcare Cost and Utilization Project. Across this study period, the database captured all discharges from a randomly selected 20% of the hospital universe within each of its sampling strata, which include geographic regions (Northeast, Midwest, West, and South)[10]. The current study was determined to be exempt from review by our Human Investigation Committee.

Study Population

To identify primary and revision knee arthroplasty and THA cases, the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes were used. For knee arthroplasty, primary procedures were identified by code 81.54 and revision procedures were identified by codes 00.80 through 00.84, 80.06, and 81.55. For THA, primary procedures were identified by code 81.51, and revision procedures were identified by codes 00.70 to 00.73, 80.05, and 81.53.

Prior to October 2005, only 1 code existed for revision knee arthroplasty (81.55), as well as 1 code for arthrotomy and removal of the prosthesis (80.06). To increase the descriptive nature of the ICD-9-CM procedure codes, 5 new codes were created for revision knee arthroplasty (00.80 through 00.84) in 2005[8].

For THA, there was also 1 original code for a revision (81.53) and 1 code for arthrotomy and removal of the prosthesis (80.05). Similar to knee arthroplasty, 4 new codes were created in 2005 for revision THA (00.70 through 00.73)[7]. Because these new knee and hip ICD-9 codes were subsets of the original codes, they were grouped to compare procedures before and after 2005.

Additionally, as patients undergoing THA for hip fracture are different from patients without fracture undergoing THA in demographic characteristics and outcomes, patients

TABLE I Demographic Characteristics of Patients Who Underwent Primary or Revision Knee Arthroplasty

	Primary Knee Arthroplasty (N = 1,138,359)	Revision Knee Arthroplasty (N = 114,828)	P Value*
Age† *(yr)*	66.53 ± 10.49	65.80 ± 11.91	<0.0001‡
Sex§			<0.001
Male	413,239 (36.40%)	47,970 (42.46%)	
Female	722,031 (63.60%)	64,995 (57.54%)	
Race§			<0.001
White	734,023 (83.98%)	72,479 (82.35%)	
Black/African American	62,324 (7.13%)	8,679 (9.86%)	
Hispanic	45,659 (5.22%)	4,251 (4.83%)	
Asian or Pacific Islander	9,902 (1.13%)	694 (0.79%)	
Native American	3,833 (0.44%)	365 (0.41%)	
Other	18,261 (2.09%)	1,542 (1.75%)	
ICD-9-CM no. of chronic conditions†	4.66 ± 2.27	4.96 ± 2.61	<0.0001‡
Length of stay† *(days)*	3.62 ± 1.91	4.98 ± 5.10	<0.0001‡
Died§	1,155 (0.10%)	366 (0.32%)	<0.001

*Unless otherwise specified, p values were calculated using a Pearson chi-square analysis of the number of patients in each category. †The values are given as the mean and the standard deviation. ‡Calculated using a 2-sample t test. §The values are given as the number of patients with available data in each subgroup, with the percentage in parentheses.

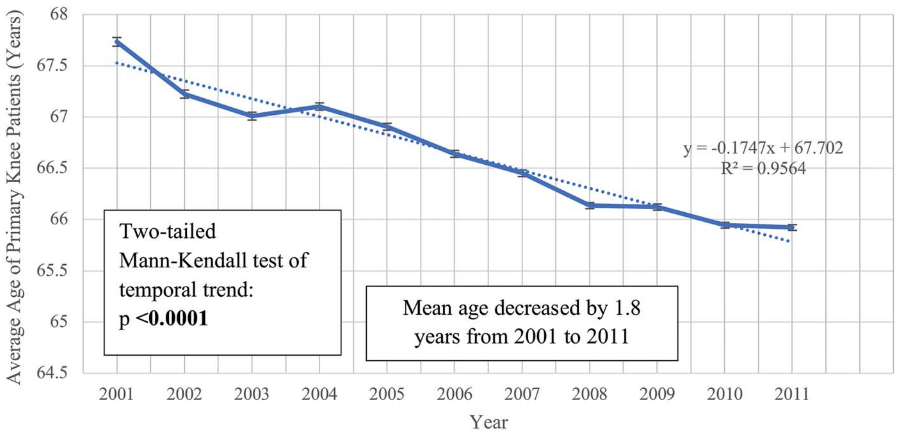

Fig. 1-A

Figs. 1-A and 1-B Knee arthroplasty analysis. The error bars indicate the standard error of the mean. **Fig. 1-A** The mean age of the patients who had undergone primary knee arthroplasty in each year of the study. From 2001 to 2011, the mean age decreased by 1.8 years ($p < 0.0001$; 2-tailed Mann-Kendall trend test).

with hip fracture-related ICD-9-CM diagnosis codes were not included in the study (fracture codes excluded: 73314, 73315, 73381, 73382, 73396, 8080, 8081, 82000, 82001, 82002, 82003, 82009, 82010, 82011, 82012, 82013, 82019, 82020, 82021, 82022, 82030, 82031, 82032, 8208, and 8209[11]). These patients accounted for 5.80% of the NIS THA population.

One challenge of using the NIS is that a small number of patients have incomplete data elements. Therefore, demographic characteristics and outcomes data were analyzed for all patients with reported values for that data element.

Data Analysis

Two distinct sets of analyses were performed: 1 for primary and revision knee arthroplasty and 1 for primary and revision THA. First, the differences in demographic characteristics between the revision and primary cohorts of each respective surgical procedure were evaluated using Pearson chi-square analyses as well as 2-sample t tests. Next, the mean ages of the primary and revisions cohorts of each surgical procedure were calculated for each year and were analyzed for trends using 2-tailed Mann-Kendall tests. Then national revision ratios were constructed for knee arthroplasty and THA for each year and also evaluated for trends across the study period using 2-tailed Mann-Kendall tests. Finally, revision ratios for both surgical procedures were constructed for each state, were mapped, and were analyzed with Pearson chi-square analyses (of the numbers of primary and revision surgical procedures in each state). To avoid skewing the data because of a low denominator of primary arthroplasties, states were only included in the state-level variation analyses if they had at least 300 primary arthroplasties in the NIS from 2001 to 2011.

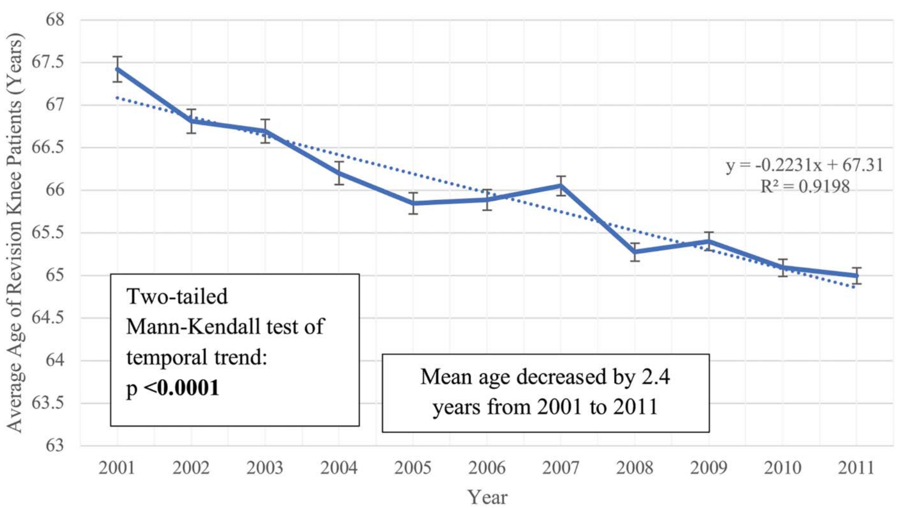

Fig. 1-B

The mean age of the patients who had undergone revision knee arthroplasty in each year of the study. From 2001 to 2011, the mean age decreased by 2.4 years ($p < 0.0001$; 2-tailed Mann-Kendall trend test).

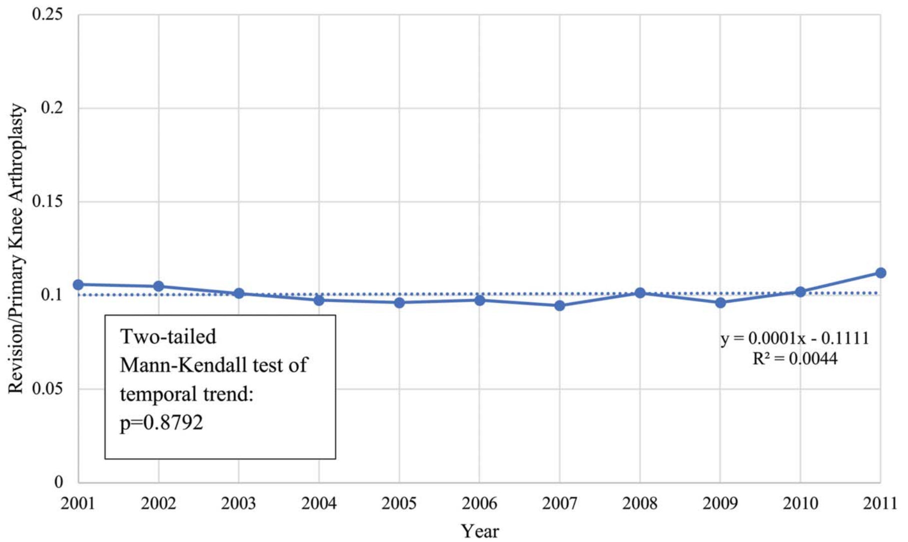

Fig. 2

Knee arthroplasty analysis. Nationwide knee arthroplasty revision ratio from 2001 to 2011 (defined as total revision procedures divided by total primary procedures in each year). Over the study period, the ratio stayed near 0.1 and, when analyzed using a 2-tailed Mann-Kendall trend test, yielded no significant trend (p = 0.8792).

Statistical analyses were performed using Stata MP 13 (StataCorp) and Microsoft Excel with XLSTAT (Addinsoft). Graphics were generated from Microsoft Excel and JMP Pro 13 (SAS Institute).

Results

Overview

Using the NIS data from 2001 to 2011, the patient cohorts who had undergone knee arthroplasty or THA were further subdivided into cohorts who had undergone primary or revision procedures. During this period, 47 of the 50 states had been sampled and had data for analysis. Two states, Alaska and North Dakota, were excluded from both state-level variation analyses because of an insufficient number of patients who had undergone primary knee arthroplasty (100 patients in Alaska and 275 patients in North Dakota) and an insufficient number of patients who had undergone primary THA (44 patients in Alaska and 105 patients in North Dakota). Alabama, Delaware, and Idaho did not contribute data to the NIS.

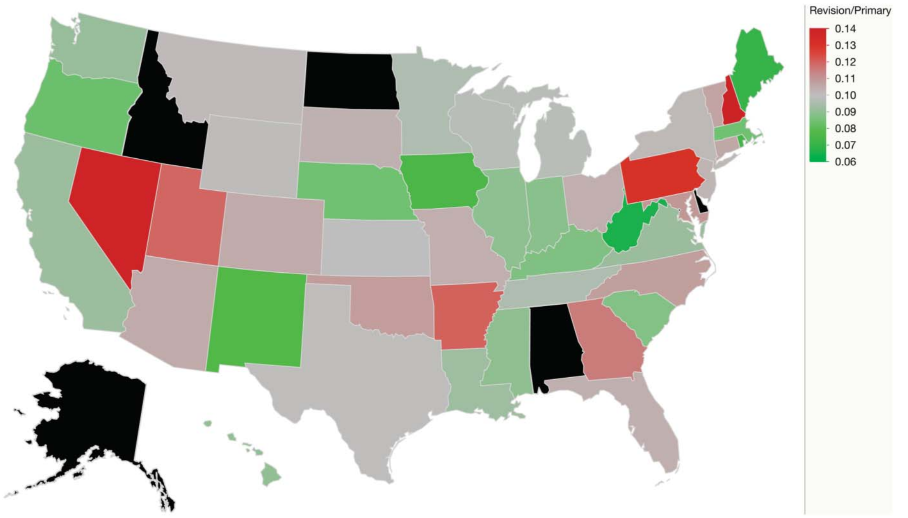

Fig. 3

Knee arthroplasty analysis. Geographic representation of knee arthroplasty revision ratios by state. Red states have ratios higher than the nationwide ratio, and green states have ratios lower than the nationwide ratio. Increasing color intensity indicates higher (red) or lower (green) ratios. There were no NIS data for Alabama, Delaware, or Idaho and an insufficient number of primary surgical procedures in Alaska and North Dakota (shown in black).

TABLE II Demographic Characteristics of Patients Who Underwent Primary THA or Revision THA

	Primary THA (N = 521,877)	Revision THA (N = 94,187)	P Value*
Age† *(yr)*	64.96 ± 12.78	66.96 ± 14.01	<0.0001‡
Sex§			<0.001
Male	228,136 (43.88%)	39,381 (42.53%)	
Female	291,749 (56.12%)	53,220 (57.47%)	
Race§			<0.001
White	346,445 (87.07%)	61,415 (86.12%)	
Black/African American	27,192 (6.83%)	5,169 (7.25%)	
Hispanic	12,283 (3.09%)	2,681 (3.76%)	
Asian or Pacific Islander	3,347 (0.84%)	570 (0.80%)	
Native American	1,161 (0.29%)	246 (0.34%)	
Other	7,462 (1.88%)	1,230 (1.72%)	
ICD-9-CM no. of chronic conditions†	4.45 ± 2.30	4.80 ± 2.65	<0.0001‡
Length of stay† *(days)*	3.70 ± 2.29	5.79 ± 6.14	<0.0001‡
Died§	660 (0.13%)	746 (0.81%)	<0.001

*Unless otherwise specified, p values are calculated using a Pearson chi-square analysis of the number of patients in each category. †The values are given as the mean and the standard deviation. ‡Calculated using a 2-sample t test. §The values are given as the number of patients with available data in each subgroup, with the percentage in parentheses.

Knee Arthroplasty

For knee arthroplasty, 1,251,484 patients were identified: 91% underwent primary procedures and 9% underwent revision procedures. When compared with the primary knee arthroplasty cohort, the revision knee arthroplasty cohort had a younger mean age (65.80 compared with 66.53 years), had more male patients (42.46% compared with 36.40%), and had more chronic conditions (4.96 compared with 4.66 conditions), longer hospitalizations (4.98 compared with 3.62 days), and a higher mortality rate (0.32% compared with 0.10%) ($p < 0.001$ for all comparisons) (Table I). Over the study period, the mean age of patients who had undergone primary knee arthroplasty decreased from 67.7 years in 2001 to 65.9 years in 2011 ($p < 0.0001$ for trend) (Fig. 1-A). Similarly, the mean age of patients who had undergone revision knee arthroplasty decreased from 67.4 years in 2001 to 65.0 years in 2011 ($p < 0.0001$ for trend) (Fig. 1-B).

Over the study period, the annual number of primary knee arthroplasties increased from 62,843 in 2001 to 133,772 in 2011. The annual number of knee revisions also increased from

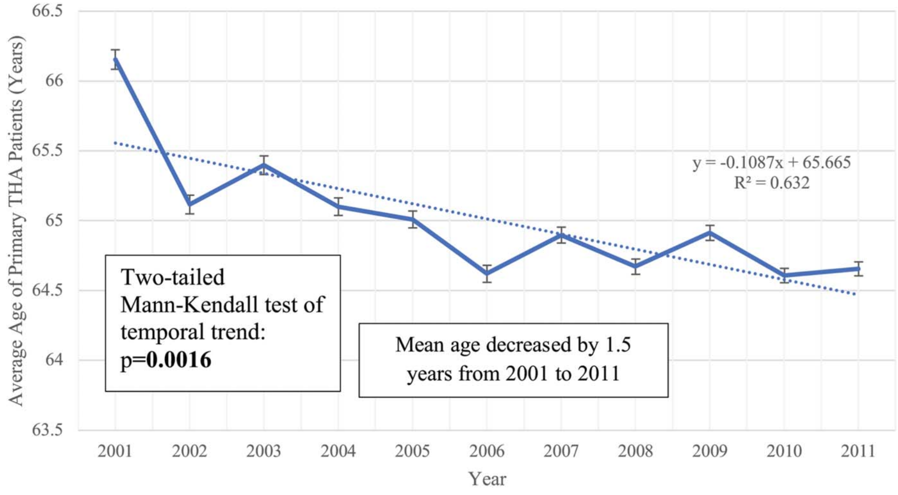

Fig. 4-A

Figs. 4-A and 4-B THA analysis. The error bars indicate the standard error of the mean. **Fig. 4-A** The mean age of patients who had undergone primary THA in each year of the study. From 2001 to 2011, the mean age decreased by 1.5 years ($p = 0.0016$; 2-tailed Mann-Kendall trend test).

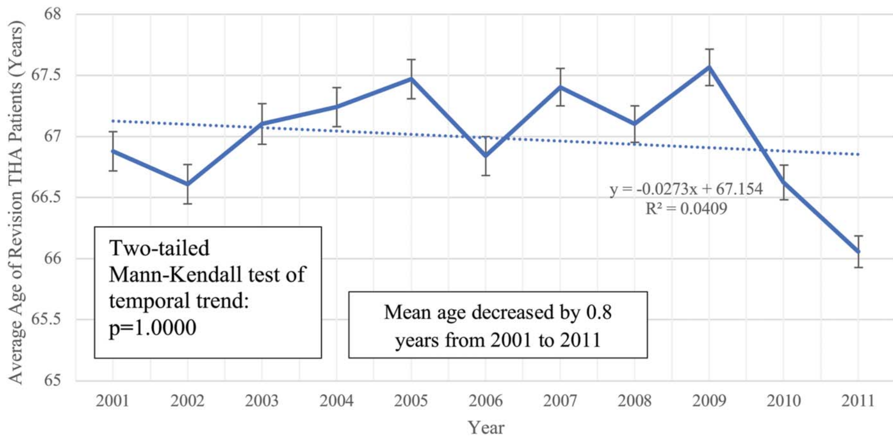

Fig. 4-B

The mean age of patients who had undergone revision THA in each year of the study. From 2001 to 2011, the mean age decreased by 0.8 year, which, when analyzed using a 2-tailed Mann-Kendall trend test, yielded no significant trend ($p = 1.0000$).

6,656 in 2001 to 15,008 in 2011. Thus, the revision ratio, calculated as the number of revision procedures divided by the number of primary knee replacements, was without significant change, ranging from a low of 0.095 in 2007 to a high of 0.112 in 2011 ($p = 0.8792$ for trend) (Fig. 2).

State-level analysis revealed a 2.2-fold difference in knee revision ratios between West Virginia (0.065) and New Hampshire (0.141) (Fig. 3) (Appendix I). Among the states, the mean revision ratio (and standard deviation) for knee arthroplasty was 0.099 ± 0.016. The overall national revision ratio for the study period was 0.101. Further, chi-square analysis of the numbers of primary and revision knee arthroplasties in each state yielded a significance of $p < 0.001$, indicating that the differences between state revision ratios were not results of random chance.

Hip Arthroplasty

For THA, 614,638 patients were identified: 85% underwent primary procedures and 15% underwent revision procedures. When compared with the primary THA cohort, the revision THA cohort had an older mean age (66.96 compared with 64.96 years), had fewer male patients (42.53% compared with 43.88%), and had more chronic conditions (4.80 compared with 4.45 conditions), longer hospitalizations (5.79 compared with 3.70 days), and a higher mortality rate (0.81% compared with 0.13%) ($p < 0.001$ for all comparisons) (Table II). Further, the mean age of patients who had undergone primary THA decreased over the study period from 66.2 years in 2001 to 64.7 years in 2011 ($p = 0.0016$ for trend) (Fig. 4-A). In contrast, the mean age of patients who underwent revision THA had no significant trend, from 66.9 years in 2001 to 66.1 years in 2011 ($p = 1.0000$ for trend) (Fig. 4-B), although the data were fairly scattered.

The number of primary THAs also increased annually from 34,589 in 2001 to 60,133 in 2011. Over the same time, hip arthroplasty revisions increased annually at a lower rate, from a low of 8,153 in 2001 to a high of 10,891 in 2011. Therefore, the revision ratio (revision procedures divided by primary procedures) for hip replacements decreased from a high of 0.236 in 2001 to a low of 0.157 in 2009 ($p = 0.0016$ for trend) (Fig. 5).

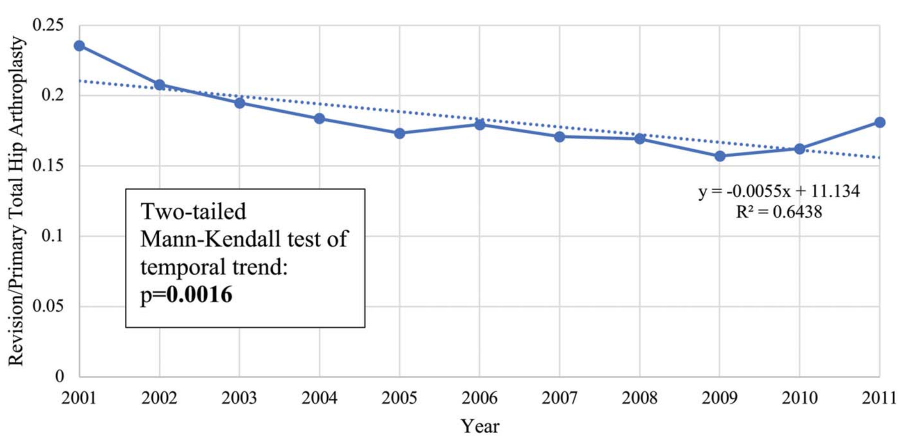

Fig. 5

THA analysis. Nationwide THA revision ratio from 2001 to 2011 (defined as total revision procedures divided by total primary procedures in each year). Over the study period, the ratio decreased ($p = 0.0016$; 2-tailed Mann-Kendall trend test).

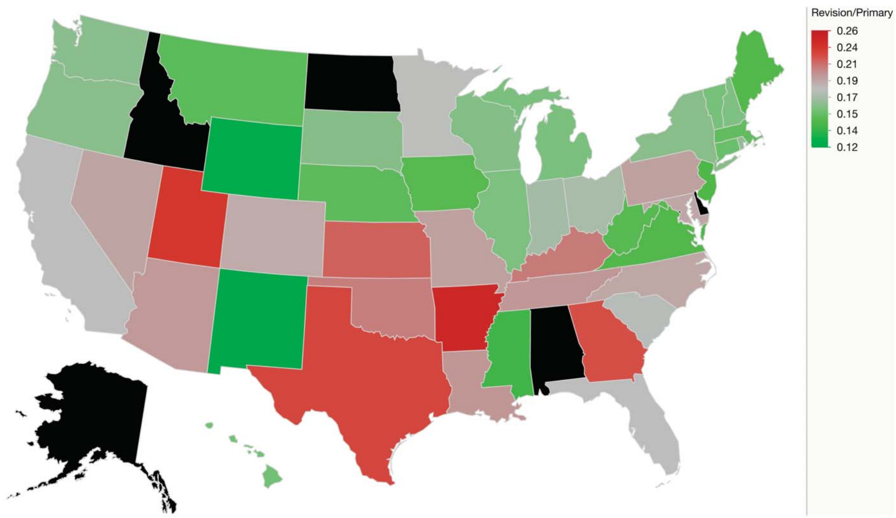

Fig. 6

THA analysis. Geographic representation of knee arthroplasty revision ratios by state. Red states have ratios higher than the nationwide ratio, and green states have ratios lower than the nationwide ratio. Increasing color intensity indicates higher (red) or lower (green) ratios. There were no NIS data for Alabama, Delaware, or Idaho and an insufficient number of primary surgical procedures in Alaska and North Dakota (shown in black).

The state-level analysis of the NIS indicated a 2.1-fold difference in hip revision ratios between New Mexico (0.119) and Arkansas (0.248) (Fig. 6) (Appendix II). The state-by-state data demonstrated a mean state revision ratio of 0.176 ± 0.029. The overall national revision ratio for the entire study period was 0.180. Further, chi-square analysis of the numbers of primary and revision THAs in each state yielded a significance of $p < 0.001$, indicating that the differences between state revision ratios were not results of random chance.

Discussion

In the absence of a universally accepted joint replacement registry during this time frame, the NIS has proven useful for identifying epidemiological changes in arthroplasties across the United States[4,5,7,8,12]. In this study, the NIS was used to identify nearly 2 million patients who had undergone knee arthroplasty or THA from 2001 to 2011.

The current study diverged from previous investigations by calculating a revision ratio (revision procedures divided by primary procedures) rather than a revision burden (revision procedures divided by total procedures)[9]. The revision ratio is more sensitive toward direct changes in the rates of revision procedures and primary procedures. By only counting primary procedures in the denominator, the revision ratio has a larger rate of change with respect to time that is not influenced by the difference between the number of revision procedures and primary procedures. This ratio helps to better identify variations across geography and time.

Revision ratios were assessed across the studied timeframe, and a decreasing trend for revision ratios was noted for THA, but not for knee arthroplasty. This was consistent with international registry data collected by McGrory et al. from 2011 to 2014 that showed a decrease in the hip revision burden but not in the knee revision burden[13]. Also discovered in the current study were substantial state-by-state variations in revision ratios for both hip and knee arthroplasty.

The analysis of revision ratios for individual states, rather than the larger regions considered in previous geographic studies, provides advantages. Because revision arthroplasties consume more economic, technical, and surgical resources than primary arthroplasties[6,12,14], identifying states with higher revision ratios may help to direct more resources to these areas and hospitals that handle more revision surgical procedures. Thus, analyzing variations on a more detailed basis can help to uncover more localized health-care needs.

The effect of this study's granularity is most evident when the variations are analyzed by the Northeast, Midwest, South, and West regions as reported by Bozic et al.[7,8]. In the present study, the state-level revision ratio variations were a 2.1-fold difference for THA and a 2.2-fold difference for knee arthroplasty. In contrast, analysis of the same data by these regions yielded only a 1.20-fold difference in revision ratios for THA and a 1.11-fold difference for knee arthroplasty.

The Dartmouth Atlas of Health Care has also used small-area analyses, but only measured absolute numbers of patients getting primary joint arthroplasty[14]. However, the current study's revision ratio considers the numbers of primary and revision procedures performed, evaluating the geographic disparities in care that so greatly impact patients.

One surprising finding of this study was the difference in the mean age trends of the revision cohorts of THA and knee arthroplasty. For THA, the age of patients who had undergone primary procedures trended significantly downward and the age of patients who had undergone revision varied year to year but exhibited no trend. This could imply that the time between implantation and revision increased or that fewer of the newer, younger patients were being incorporated into the revision cohort, both of which would keep the mean age of the revision cohort steady. This notion seems to be supported by the downward trend in the revision ratios for THA over the study period. By contrast, the mean ages of both the primary and revision knee arthroplasty groups trended significantly downward with similar slopes, which may suggest that there was no major improvement in implant performance. This was also supported by knee arthroplasty revision ratios, which held constant over the study period. These findings suggest that another potential indicator of surgical improvement is the extent to which the ages of patients who had undergone revision procedures remain stable despite the increasingly younger population of patients who had undergone primary procedures. However, it should be noted that the patients undergoing primary and revision arthroplasties in any given year are different patients. Consequently, these age trends could be affected by other factors: for example, more older patients undergoing revision THA offsetting a trend toward lower ages for revision THA, or more surgeons trained in revision knee arthroplasty improving patient access to the procedure at younger ages. It is also possible that younger patients undergoing unicompartmental knee arthroplasty then undergo a revision to TKA, lowering the mean age of patients who undergo revision knee arthroplasty.

One concern with regard to this study is the possibility that patients may have moved to another state between undergoing the primary and revision procedures. However, a recent study by Etkin et al. showed that <1% of their studied patients moved out of state each year[15]. Therefore, because previous studies have shown a very small incidence of patient migration, it is unlikely that our results were substantially skewed by this phenomenon. Further, investigating patient proclivities for traveling to care, FitzGerald et al. found that 95% of patients who underwent TKA received their care at a hospital within 50 miles of their residence[16]. In some parts of America, the 50-mile (80-km) radius can include multiple states. However, if patients are willing to travel to undergo the primary surgical procedures in a nearby state, then they may also undergo the revision procedure in that same state, which would still appropriately reflect the care in that state.

There were a few further limitations to the present study. Most notably, the NIS is an administrative data set that is dependent on manual data entry usually performed by hospital administrators. In addition, there were incomplete demographic data elements for some patients. However, because the key data elements of age, sex, length of stay, and mortality were available for >99% of the patients, this study followed the guidelines of Basques et al.[17] and ran analyses on all available data for each variable in the subgroups of interest.

The NIS data were also limited by the small number of cases in Alaska and North Dakota, including fewer than 300 primary THAs and 300 primary knee arthroplasties each from 2001 to 2011. Thus, these states were excluded from the state-level analysis because of the potential for the small set of primary arthroplasties to skew the revision ratio. Had these states been included, the revision ratio disparities would have been much greater: 19.3-fold for knee arthroplasty and 3.6-fold for THA. These 2 states are individually reported in Appendices I and II. Also, the patients from these states were included in the nationwide arthroplasty analyses.

This study's greatest strengths are its size and granularity. The NIS is a large data set, representing approximately one-fifth of the U.S. hospital universe in each of its sampling strata. This study also includes data across an 11-year study period, allowing better discernment of trends in the revision of hips and knees over time. Also, to our knowledge, this is the first article to examine revision rates on a state-by-state basis. Our data suggest that when such data are subdivided into smaller regions, larger disparities in revision ratios become apparent.

In the future, studies could derive data from the American Joint Replacement Registry (AJRR). Founded in 2009, the AJRR now has >1 million cases collected and includes hospitals from all 50 states[18]. The AJRR will also help to bolster studies seeking to investigate geographic spread of care and patient migration.

This study determined that, unlike THA revision ratios, knee arthroplasty revision ratios did not decrease. In addition, although the ages of patients who had undergone primary procedures decreased for both knee arthroplasty and THA, the ages of patients who had undergone revision only trended down for knee arthroplasty. These differences may be the result of advances in hip implant technology or surgeon training. Future studies should investigate these differences to improve knee arthroplasty care. The studied data demonstrate that much larger disparities in revision ratios are apparent when data are analyzed on a state basis instead of a regional basis. Such comprehensive small-area analyses may explain whether these disparities are the signature of the local surgeons who perform arthroplasty[19] or the result of patients seeking more complex revision surgical procedures in other states.

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/A176). ■

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