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# Adverse Outcomes in Hip Arthroplasty: Long-Term Trends

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*Investigation performed at the University of Iowa, Iowa City, Iowa*

**Background:** Total hip arthroplasty is a common surgical procedure, but little is known about longitudinal trends in associated adverse outcomes. Our objective was to describe long-term trends in demographics, comorbidities, and adverse outcomes for older patients who underwent primary and revision total hip arthroplasty.

**Methods:** We identified a retrospective, observational cohort of 1,405,379 Medicare beneficiaries who underwent primary total hip arthroplasty and 337,874 who underwent revision total hip arthroplasty between 1991 and 2008. The primary outcome was a composite representing the occurrence of one or more of the following adverse outcomes during the index admission or during readmission within ninety days after discharge: death, hemorrhage, infection, pulmonary embolism, sepsis, deep venous thrombosis, and myocardial infarction. Secondary outcomes included each of these outcomes assessed individually.

**Results:** Between 1991 and 2008, the mean age and the mean comorbidity burden increased for all total hip arthroplasty patients. The length of hospital stay after primary and revision total hip arthroplasty declined by approximately 50% over the study period. However, the rate of readmission for any cause has recently increased and has surpassed 10% for primary total hip arthroplasty and 20% for revision total hip arthroplasty. The composite rate of adverse outcomes after primary total hip arthroplasty declined from 4% to 3.4% over the study period, whereas the composite adverse outcome rate after revision total hip arthroplasty slowly increased from 7% to 10.9%. We observed a steady decline in the rates of most individual adverse outcomes after primary total hip arthroplasty over the majority of the study period. Many of these rates stabilized or began to increase slightly near the end of the study period. In contrast, an increase in the rates of many adverse outcomes was observed in the revision total hip arthroplasty population even after accounting for changes in patient complexity. Postoperative hemorrhage has gradually increased after both primary and revision total hip arthroplasty.

**Conclusions:** Patients undergoing primary and revision total hip arthroplasty are becoming more complex. Despite this increasing complexity, patient outcomes for primary total hip arthroplasty improved markedly before stabilizing in recent years. In contrast, patient outcomes after revision total hip arthroplasty have gradually worsened, likely reflecting the increase in the medical comorbidities and surgical complexity of these patients. Length of hospital stay has demonstrated a substantial decline, which has recently been coupled with an increased readmission rate.

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

Total hip arthroplasty is well established to be a safe and effective therapy for patients with advanced degenerative joint disease[1,2]. As recognition of the benefits of total hip arthroplasty has increased, there has been a dramatic increase in utilization of this procedure both in the United States and internationally[3-6]. The increase in utilization of total hip arthroplasty has been driven by an array of factors including the aging of the population[7], improvements in surgical technique, and advances in joint implant design[8] that are widely thought to result in reduced operative risk and improved patient outcomes.

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**TABLE I Characteristics of Medicare Beneficiaries Receiving Primary Total Hip Arthroplasty Between 1991 and 2008***

| Characteristic | 1991-1993 | 1994-1996 | 1997-1999 | 2000-2002 | 2003-2005 | 2006-2008 |
|---|---|---|---|---|---|---|
| No. of hospitalizations | 188,646 | 214,726 | 218,865 | 243,402 | 260,113 | 279,627 |
| Age† *(yr)* | 74.1 ± 6.0 | 74.6 ± 6.1 | 75.1 ± 6.2 | 75.3 ± 6.2 | 75.6 ± 6.2 | 75.2 ± 6.5 |
| Female sex *(no. [%])* | 120,839 (64.1) | 137,707 (64.1) | 140,380 (64.1) | 156,933 (64.5) | 165,749 (63.7) | 174,821 (62.5) |
| Race *(no. [%])* | | | | | | |
| White | 172,665 (91.5) | 201,884 (94.0) | 206,304 (94.3) | 228,714 (94.0) | 243,271 (93.5) | 260,960 (93.3) |
| Black | 6938 (3.7) | 8304 (3.9) | 8558 (3.9) | 9963 (4.1) | 11,200 (4.3) | 12,678 (4.5) |
| Other‡ | 2926 (1.6) | 2391 (1.1) | 3163 (1.4) | 3788 (1.6) | 4654 (1.8) | 5183 (1.9) |
| Missing | 6117 (3.2) | 2147 (1.0) | 840 (0.4) | 937 (0.4) | 988 (0.4) | 806 (0.3) |
| Comorbidities *(no. [%])* | | | | | | |
| Diabetes | 13,854 (7.3) | 18,812 (8.8) | 21,983 (10.0) | 27,546 (11.3) | 34,217 (13.2) | 42,594 (15.2) |
| Congestive heart failure | 5746 (3.0) | 8157 (3.8) | 9080 (4.1) | 10,713 (4.4) | 12,339 (4.7) | 12,242 (4.4) |
| Obesity | 4424 (2.3) | 6580 (3.1) | 7776 (3.6) | 10,273 (4.2) | 13,535 (5.2) | 20,002 (7.2) |
| Renal failure | 857 (0.5) | 1171 (0.5) | 1299 (0.6) | 1732 (0.7) | 2560 (1.0) | 10,307 (3.7) |
| No. of comorbid conditions† | 1.1 ± 1.1 | 1.3 ± 1.3 | 1.4 ± 1.3 | 1.6 ± 1.3 | 1.8 ± 1.4 | 2.0 ± 1.4 |

*P < 0.001 for all comparisons. †Values are given as the mean and the standard deviation. ‡Asian, Hispanic, North American Native, or other not specified.

There have been very few rigorous empirical studies evaluating longitudinal trends in total hip arthroplasty outcomes and adverse events, and the studies that are available are largely from outside the United States[9-13]. One United States-based study recently examined adverse events in a relatively simplistic manner and failed to examine whether there might be different trends for different adverse outcomes[14]. Thus, on the basis of the available data, it is extremely difficult to know whether outcomes after primary and revision total hip arthroplasty are improving or whether certain complications are becoming more common. The lack of longitudinal data on total hip arthroplasty outcomes is striking when considered in comparison with other common and costly surgical procedures. For example, there have been numerous studies examining longitudinal trends in outcomes after cardiac surgery and angioplasty[15-19] but analogous studies of total hip arthroplasty are limited. Such studies are important in guiding physician and patient decision-making about the risks and benefits of surgery. Likewise, such longitudinal data are important for evaluating the potential impact of changing practice patterns and increasingly resistant bacterial pathogens. The objective of this study was to evaluate long-term trends in complications after primary and revision total hip arthroplasty among older adults enrolled in the United States Medicare program.

## Materials and Methods

### *Data*

We used Medicare Provider Analysis and Review (MedPAR) Part A data files to identify fee-for-service beneficiaries who underwent primary or revision total hip arthroplasty between 1991 and 2008. Patients were identified with use of ICD-9-CM (International Classification of Diseases, Ninth Revision, Clinical Modification) procedure codes (81.51 for primary total hip arthroplasty and 00.70, 00.71, 00.72, 00.73, 80.05, and 81.53 for revision arthroplasty)[20-23]. The Part A files contain a range of data collected from discharge abstracts for all hospitalized fee-for-service Medicare enrollees, including patient demographics, zip code of primary residence, ICD-9-CM codes for primary and secondary diagnoses and procedures (including 2005 coding revisions), admission source, admission and discharge dates, discharge disposition, death occurring up to three years after discharge, each patient's unique Medicare beneficiary number (allowing for identification of patient readmissions), and each hospital's unique six-digit identification number. Medicare data have been used extensively in evaluating orthopaedic outcomes. Comorbid illnesses present at the time of the index admission were identified on the basis of ICD-9-CM codes with use of algorithms described by Elixhauser et al.[24,25] that consider thirty specific conditions and exclude comorbid conditions that may represent complications of care or that are related to the primary reason for hospitalization.

Our intention was to examine trends in the outcomes of patients undergoing primary and revision total hip arthroplasty procedures. As primary total hip arthroplasty is most often an elective procedure whereas revision total hip arthroplasty can be either an elective or a more urgent procedure, we applied separate exclusion criteria to the primary and revision total hip arthroplasty populations in accordance with prior studies, as described below[14,21,26,27]. Our primary total hip arthroplasty population sequentially excluded patients with acute fractures (n = 136,888), patients admitted through the emergency department (n = 19,721), and patients admitted through transfer from another hospital (n = 2856). Our revision total hip arthroplasty population did not exclude any of these patient subgroups. However, given that the elective and urgent revision total hip arthroplasty populations may be heterogeneous in nature, the data were analyzed both including and excluding the more urgent revision total hip arthroplasty cases (identified by their admission through the emergency department or by hospital transfer). We defined ninety-day all-cause

**TABLE II Characteristics of Medicare Beneficiaries Receiving Revision Total Hip Arthroplasty Between 1991 and 2008***

| Characteristic | 1991-1993 | 1994-1996 | 1997-1999 | 2000-2002 | 2003-2005 | 2006-2008 |
|---|---|---|---|---|---|---|
| No. of hospitalizations | 48,528 | 53,622 | 57,886 | 62,604 | 57,903 | 57,331 |
| | 38,052 | 43,034 | 46,599 | 49,501 | 44,401 | 42,775 |
| Age† *(yr)* | 75.9 ± 6.9 | 76.4 ± 6.9 | 77.0 ± 6.9 | 77.2 ± 6.9 | 77.4 ± 6.9 | 77.4 ± 7.2 |
| | 75.1 (6.5) | 75.8 (6.5) | 76.4 (6.6) | 76.6 (6.7) | 76.9 (6.7) | 76.7 (6.9) |
| Female sex *(no. [%])* | 31,084 (64.1) | 34,124 (63.6) | 36,556 (63.2) | 39,353 (62.9) | 36,110 (62.4) | 35,500 (61.9) |
| | 23,854 (62.7) | 26,801 (62.3) | 28,835 (61.9) | 30,456 (61.5) | 26,974 (60.8) | 25,927 (60.6) |
| Race *(no. [%])* | | | | | | |
| White | 44,325 (91.3) | 50,031 (93.3) | 54,128 (93.5) | 58,327 (93.2) | 53,988 (93.2) | 53,499 (93.3) |
| | 34,788 (91.4) | 40,208 (93.4) | 43,648 (93.7) | 46,119 (93.2) | 41,441 (93.3) | 39,958 (93.4) |
| Black | 2072 (4.3) | 2431 (4.5) | 2688 (4.6) | 2967 (4.7) | 2675 (4.6) | 2553 (4.5) |
| | 1581 (4.2) | 1947 (4.5) | 2122 (4.6) | 2366 (4.8) | 2029 (4.6) | 1905 (4.5) |
| Other‡ | 634 (1.3) | 600 (1.1) | 828 (1.4) | 1081 (1.7) | 1084 (1.9) | 1162 (2.0) |
| | 504 (1.3) | 459 (1.1) | 650 (1.4) | 841 (1.7) | 814 (1.8) | 825 (1.9) |
| Missing | 1497 (3.1) | 560 (1.0) | 242 (0.4) | 229 (0.4) | 156 (0.3) | 117 (0.2) |
| | 1179 (3.1) | 420 (1.0) | 179 (0.4) | 175 (0.4) | 117 (0.3) | 87 (0.2) |
| Comorbidities *(no. [%])* | | | | | | |
| Diabetes | 3624 (7.5) | 5074 (9.5) | 6312 (10.9) | 7715 (12.3) | 8029 (13.9) | 8797 (15.3) |
| | 2714 (7.1) | 3889 (9.0) | 4991 (10.7) | 5980 (12.1) | 6090 (13.7) | 6605 (15.4) |
| Congestive heart failure | 2752 (5.7) | 4050 (7.6) | 4649 (8.0) | 5615 (9.0) | 5739 (9.9) | 5474 (9.6) |
| | 1723 (4.5) | 2665 (6.2) | 3112 (6.7) | 3688 (7.5) | 3625 (8.2) | 3308 (7.7) |
| Obesity | 695 (1.4) | 1120 (2.1) | 1351 (2.3) | 1747 (2.8) | 1992 (3.4) | 2559 (4.5) |
| | 594 (1.6) | 951 (2.2) | 1147 (2.5) | 1439 (2.9) | 1648 (3.7) | 2081 (4.9) |
| Renal failure | 414 (0.9) | 564 (1.1) | 756 (1.3) | 1048 (1.7) | 1283 (2.2) | 3531 (6.2) |
| | 275 (0.7) | 357 (0.8) | 506 (1.1) | 703 (1.4) | 788 (1.8) | 2301 (5.4) |
| No. of comorbid conditions† | 1.2 ± 1.2 | 1.5 ± 1.4 | 1.7 ± 1.4 | 1.9 ± 1.5 | 2.1 ± 1.5 | 2.3 ± 1.5 |
| | 1.1 ± 1.2 | 1.5 ± 1.4 | 1.6 ± 1.4 | 1.8 ± 1.4 | 2.0 ± 1.5 | 2.2 ± 1.5 |

*Gray shading indicates values for the elective cohort (i.e., excluding patients admitted through the emergency room or transferred in from another hospital). P < 0.001 for all comparisons except for Black race (p = 0.005 for all revision total hip arthroplasties and p = 0.04 for elective revision total hip arthroplasties). †Values are given as the mean and the standard deviation. ‡Asian, Hispanic, North American Native, or other not specified.

readmission as any inpatient admission within 90 days after the discharge date for the index admission, with the exception of staged procedures, which were excluded for the reasons described previously[14,21,26,27]. We also excluded index admissions that occurred after September 30, 2008, to allow for a full ninety-day follow-up period.

### *Outcomes of Interest*

Outcomes were chosen that were deemed to be clinically relevant and also feasibly analyzed with use of Medicare data by utilizing an inclusive list of diagnostic and procedural ICD-9-CM codes. We assessed joint arthroplasty outcomes by examining the incidence of seven separate adverse outcomes that either occurred during the index hospital stay or necessitated hospital readmission as defined above[14,20,21,26,27]. Sepsis, hemorrhage, pulmonary embolism, deep venous thrombosis, and myocardial infarction were assessed during readmissions after both primary and revision total hip arthroplasty. (Sepsis indicates disseminated systemic infection, whereas postoperative infection indicates a local [wound or joint] infection.) Wound infections were assessed during both the index hospital stay and readmissions in the primary total hip arthroplasty cohort, but only during readmissions in the revision total hip arthroplasty cohort because infection coded on the primary admission for revision total hip arthroplasty may actually constitute the indication for the revision. A return to the operating room was not a requirement for designation of an outcome of infection or hemorrhage. For both primary and revision total hip arthroplasty, mortality was defined as either death in the hospital during the index admission or death within ninety days after the discharge date for the index admission. The ICD-9-CM codes used for identification of the primary outcomes in this study are listed in the Appendix.

Our primary outcome was a composite representing the occurrence of one or more of the individual adverse outcomes within ninety days after the discharge date for the index admission. Secondary outcomes included the rates of each of the seven individual outcomes described above, all-cause readmission within ninety days, and postoperative length of hospital stay.

**TABLE III Adverse Outcomes Occurring in the Hospital or Within Ninety Days After Primary Total Hip Arthroplasty**

| | 1991-1993 (N = 188,646) | 1994-1996 (N = 214,726) | 1997-1999 (N = 218,865) | 2000-2002 (N = 243,402) | 2003-2005 (N = 260,113) | 2006-2008 (N = 279,627) | P Value |
|---|---|---|---|---|---|---|---|
| Length of hospital stay* | 8 (6-10) | 5 (4-7) | 4 (3-5) | 4 (3-5) | 4 (3-4) | 3 (3-4) | <0.0001 |
| Ninety-day mortality *(no. [%])* | 2237 (1.2) | 2348 (1.1) | 2337 (1.1) | 2348 (1.0) | 2328 (0.9) | 2194 (0.8) | <0.0001 |
| Postoperative infection *(no. [%])* | 1525 (0.8) | 1722 (0.8) | 1803 (0.8) | 1996 (0.8) | 1286 (0.5) | 1632 (0.6) | <0.0001 |
| Postoperative hemorrhage *(no. [%])* | 277 (0.1) | 388 (0.2) | 842 (0.4) | 966 (0.4) | 1120 (0.4) | 1821 (0.7) | <0.0001 |
| Deep venous thrombosis *(no. [%])* | 2273 (1.2) | 2458 (1.1) | 1899 (0.9) | 1612 (0.7) | 1409 (0.5) | 1794 (0.6) | <0.0001 |
| Pulmonary embolism *(no. [%])* | 924 (0.5) | 908 (0.4) | 651 (0.3) | 643 (0.3) | 686 (0.3) | 998 (0.4) | <0.0001 |
| Myocardial infarction *(no. [%])* | 773 (0.4) | 1002 (0.5) | 1164 (0.5) | 1218 (0.5) | 1326 (0.5) | 1836 (0.7) | <0.0001 |
| Sepsis *(no. [%])* | 291 (0.2) | 363 (0.2) | 402 (0.2) | 418 (0.2) | 577 (0.2) | 983 (0.4) | <0.0001 |
| Composite adverse outcome *(no. [%])* | 7560 (4.0) | 8314 (3.9) | 8137 (3.7) | 8172 (3.4) | 7597 (2.9) | 9574 (3.4) | <0.0001 |
| All-cause readmission rate *(no. [%])* | 18,030 (9.6) | 18,537 (8.6) | 18,149 (8.3) | 18,511 (7.6) | 19,538 (7.5) | 30,540 (10.9) | <0.0001 |

*The values are given as the median, with the interquartile range in parentheses.

### *Statistical Analysis*

First, we examined the demographic characteristics and the prevalence of comorbid illness for patients undergoing total hip arthroplasty during each year of the study period. The chi-square test was used for categorical variables, and analysis of variance was used for continuous variables. All analyses were performed separately for primary and revision total hip arthroplasty patients. For simplicity, tabular data are presented for each three-year segment of the study period. Second, we examined outcomes for each year. We compared the incidence of the composite outcome and of the seven individual study outcomes, the all-cause readmission rate, and the length of hospital stay according to year with use of similar statistical methods. Again, analyses were conducted separately for the primary and revision total hip arthroplasty cohorts. Third, we used hierarchical linear models that adjusted for patient demographics (age, race, and sex) and comorbidities and that accounted for clustering of patients within hospitals to calculate risk-standardized rates of each complication[28].

We examined the rates for each study outcome separately to determine whether different trends might exist for different outcomes. We examined changes in adverse outcomes over time by plotting the rate of each complication individually and the composite complication rate over time. To assess the robustness of our results, we conducted an array of sensitivity analyses, including repetition of the analyses after adding back the described previously excluded populations (e.g., fracture patients).

All p values were two-tailed, and a p value of <0.05 was considered significant. All statistical analyses were performed with use of SAS software (version 9.1.3; SAS Institute, Cary, North Carolina). This project was approved by the University of Iowa Institutional Review Board.

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## Results

Our final study population included 1,405,379 elective primary total hip arthroplasties (Table I) and 337,874 revision total hip arthroplasties (Table II) performed between 1991 and September 2008. Table II shows the characteristics of both the entire revision total hip arthroplasty patient cohort and the elective cohort (which excluded patients who were admitted through the emergency room or transferred in).

In both the primary and revision total hip arthroplasty cohorts, the mean patient age increased over time, the proportion of procedures performed on women declined, and the number of comorbid conditions present at the time of the operation (including heart failure, diabetes, obesity, and renal failure) increased substantially. For example, the prevalence of diabetes increased from 7.3% and 7.5% in primary and revision total hip arthroplasty, respectively, in the 1991-1993 period to 15.2% and 15.3% in the 2006-2008 period. Similarly, obesity increased from 2.3% and 1.4% to 7.2% and 4.5% over this time. The length of hospital stay declined from a median of 8 days for primary total hip arthroplasty and nine days for revision total hip arthroplasty in 1991-1993 to three days for primary total hip arthroplasty and four days for revision total hip arthroplasty in 2006-2008 (Tables III and IV and Appendix).

Relatively modest changes were seen in the composite rate of adverse outcomes over time after adjusting for patient demographic characteristics, comorbidity, and clustering (see Appendix). For primary total hip arthroplasty, the unadjusted incidence of the composite of adverse outcomes decreased from 4.0% in 1991-1993 to 2.9% in 2003-2005 before increasing again to 3.4% in the last three years of the study period (Table III and Appendix). Similarly, all-cause readmission within ninety days after discharge declined from an unadjusted rate of 9.6% in 1991-1993 to 7.5% in 2003-2005 before increasing again to 10.9% in 2006-2008 (Table III and Appendix).

**TABLE IV Adverse Outcomes Occurring in the Hospital or Within Ninety Days After Revision Total Hip Arthroplasty***

| | 1991-1993 | 1994–1996 | 1997–1999 | 2000–2002 | 2003–2005 | 2006–2008 | P Value |
|---|---|---|---|---|---|---|---|
| Length of hospital stay† | 9 (7-13) | 6 (5-9) | 5 (4-7) | 5 (4-7) | 5 (3-7) | 4 (3-7) | <0.0001 |
| | 8 (7-11) | 6 (4-8) | 5 (4-6) | 4 (4-6) | 4 (3-6) | 4 (3-6) | <0.0001 |
| Ninety-day mortality *(no. [%])* | 2016 (4.2) | 2215 (4.1) | 2674 (4.6) | 2986 (4.8) | 2826 (4.9) | 2872 (5.0) | <0.0001 |
| | 1023 (2.7) | 1182 (2.7) | 1428 (3.1) | 1492 (3.0) | 1334 (3.0) | 1273 (3.0) | 0.0023 |
| Postop. infection *(no. [%])* | 518 (1.1) | 701 (1.3) | 938 (1.6) | 1112 (1.8) | 1241 (2.1) | 1651 (2.9) | <0.0001 |
| | 384 (1.0) | 523 (1.2) | 662 (1.4) | 760 (1.5) | 836 (1.9) | 1051 (2.5) | <0.0001 |
| Postop. hemorrhage *(no. [%])* | 108 (0.2) | 158 (0.3) | 457 (0.8) | 528 (0.8) | 559 (1.0) | 847 (1.5) | <0.0001 |
| | 82 (0.2) | 114 (0.3) | 334 (0.7) | 372 (0.8) | 382 (0.9) | 588 (1.4) | <0.0001 |
| Deep venous thrombosis *(no. [%])* | 372 (0.8) | 467 (0.9) | 417 (0.7) | 418 (0.7) | 405 (0.7) | 491 (0.9) | 0.7290 |
| | 293 (0.8) | 361 (0.8) | 296 (0.6) | 297 (0.6) | 293 (0.7) | 307 (0.7) | 0.0145 |
| Pulmonary embolism *(no. [%])* | 169 (0.3) | 144 (0.3) | 116 (0.2) | 140 (0.2) | 143 (0.2) | 209 (0.4) | 0.5990 |
| | 139 (0.4) | 111 (0.3) | 83 (0.2) | 105 (0.2) | 102 (0.2) | 136 (0.3) | 0.2531 |
| Myocardial infarction *(no. [%])* | 241 (0.5) | 354 (0.7) | 405 (0.7) | 480 (0.8) | 532 (0.9) | 661 (1.2) | <0.0001 |
| | 183 (0.5) | 262 (0.6) | 306 (0.7) | 337 (0.7) | 374 (0.8) | 447 (1.0) | <0.0001 |
| Sepsis *(no. [%])* | 293 (0.6) | 333 (0.6) | 394 (0.7) | 461 (0.7) | 582 (1.0) | 849 (1.5) | <0.0001 |
| | 164 (0.4) | 208 (0.5) | 231 (0.5) | 255 (0.5) | 324 (0.7) | 461 (1.1) | <0.0001 |
| Composite adverse outcome *(no. [%])* | 3407 (7.0) | 3941 (7.3) | 4717 (8.1) | 5302 (8.5) | 5358 (9.3) | 6249 (10.9) | <0.0001 |
| | 2069 (5.4) | 2468 (5.7) | 2917 (6.3) | 3124 (6.3) | 3091 (7.0) | 3514 (8.2) | <0.0001 |
| All-cause readmission rate *(no. [%])* | 7223 (14.9) | 7801 (14.6) | 8308 (14.4) | 8772 (14.0) | 8733 (15.1) | 11,454 (20.0) | <0.0001 |
| | 5213 (13.7) | 5807 (13.5) | 6018 (12.9) | 6209 (12.5) | 5994 (13.5) | 7540 (17.6) | <0.0001 |

*Gray shading indicates values for the elective cohort (i.e., excluding patients admitted through the emergency room or transferred in from another hospital). †The values are given as the median, with the interquartile range in parentheses.

Examination of individual complications after primary total hip arthroplasty revealed a number of interesting trends. Mortality within ninety days after primary total hip arthroplasty declined in both unadjusted analyses (Table III) and adjusted analyses that accounted for trends in patient complexity (see Appendix). The rates of other adverse outcomes demonstrated trends that ranged from increases to decreases over time (see Appendix). For example, postoperative infection decreased significantly over time, as did the occurrence of deep venous thrombosis (see Appendix). However, the rate of postoperative hemorrhage demonstrated an increasing trend, as did myocardial infarction (Table III and Appendix). Lastly, sepsis remained relatively constant until a late increase from 2003 to 2008.

For revision total hip arthroplasty, unadjusted outcomes are reported for the entire revision total hip arthroplasty cohort and also for revision total hip arthroplasties that would be considered elective (Table IV). The composite rate of adverse outcomes increased from 7.0% in 1991-1993 to 10.9% in 2006-2008 (Table IV); the results were similar in analyses that accounted for the increase in patient complexity over time (see Appendix). Ninety-day postoperative mortality increased slightly from 4.2% in 1991-1993 to 5.0% in 2006-2008 (Table IV), but this increase was largely attenuated when adjusted for patient complexity, suggesting that the increased patient mortality that was observed was largely related to an increase in the risk profile of the revision total hip arthroplasty population over time. As with primary total hip arthroplasty, the rates of the individual adverse outcomes after revision total hip arthroplasty varied over time, with increasing, decreasing, and static rate trends for individual outcomes (Table IV and Appendix). Ninety-day rates of myocardial infarction, hemorrhage, and postoperative infection demonstrated consistent increases over the course of the study period (Table IV). The incidences of pulmonary embolism and deep venous thrombosis fluctuated over the study period. Sepsis remained relatively static until a significant rise at the end of the study period. Rates of adverse outcomes were lower when patients admitted through the emergency room or through transfer were excluded (Table IV).

Finally, all-cause readmission rates declined modestly for both primary and revision total hip arthroplasty between 1991 and 2003 before demonstrating a marked increase for both procedures at the end of the study period, when rates actually exceeded those in 1991 (see Appendix). In sensitivity analyses, results were similar when the excluded populations were added back into the study populations.

## Discussion

In a longitudinal analysis of Medicare administrative data, we identified a number of important trends in primary and revision hip arthroplasty outcomes. This is especially pertinent information given that primary and revision total hip arthroplasty were ranked third and fourth among the orthopaedic procedures that accounted for the majority of adverse events and excess hospital days[29]. We observed a steady decline in the rates of most adverse outcomes after primary total hip arthroplasty, especially in adjusted analyses that took into account the effect of increasing patient complexity. The opposite effect, an increase in the rates of many adverse outcomes, was observed in the revision total hip arthroplasty population even after accounting for patient complexity. Finally, we found that the declining length of hospital stay after total hip arthroplasty may be coming at the expense of rising readmissions.

The mean age of patients undergoing both primary and revision total hip arthroplasty increased slightly over time and the burden of comorbid illness increased significantly, suggesting that total hip arthroplasty is being performed on an older and sicker population than ever before. Longitudinal data on patient complexity are limited, but prior studies have demonstrated similar longitudinal trends of increasing comorbidity burden and patient complexity in hip[12] and knee arthroplasty[2,30-32] as well as in cardiovascular procedures[33-35].

Our data demonstrated that the rates of most adverse outcomes after primary total hip arthroplasty declined over the majority of the study period, despite increased patient complexity, before again increasing during the last three years. The overall decline in the composite score over the study period was fostered by progressive declines in most of the individual outcomes that were studied, including postoperative mortality, infection, and deep venous thrombosis. The observed reduction in these complications is plausible in light of the greater attention given to preoperative antibiotics and postoperative venous thromboembolism prophylaxis by surgical teams.

A gradual but definite increase in the composite rate of adverse outcomes after revision total hip arthroplasty throughout the study period was observed. This increase persisted after adjustment for changing patient demographics, clinical characteristics, and hospital clustering, which suggests that worsening outcomes were not entirely due to the aging population. It is likely that the worsening outcomes observed reflect not only the increasing comorbidity burden of the revision total hip arthroplasty population but also the increasing technical complexity of total hip arthroplasty revisions over time.

Gradual decreases in the length of hospital stay were observed for both primary and revision total hip arthroplasty patients. The time spent in the hospital decreased by >50% for both procedures during the study period. An overall increasing trend was also observed in all-cause readmission rates after primary total hip arthroplasty. The trend for all-cause readmission after revision total hip arthroplasty was similar to that after primary total hip arthroplasty, with a slow, gradual decline between 1992 and 2003 followed by an abrupt increase. By the end of the study period, >20% of revision total hip arthroplasty patients required readmission within ninety days after the end of the index admission. Small but definite increases in the rates of postoperative infection, hemorrhage, myocardial infarction, and sepsis after revision total hip arthroplasty were noted during the later portion of the study period, and these were likely associated with the increase in readmissions.

The remarkably high readmission rate should serve to further highlight the complexity and risk associated with revision procedures. Likewise, the rising readmission rate highlights the inherent conflict that surgeons face in managing the length of hospital stay in tandem with hospital administrators; keeping a patient in the hospital for an extra day or two may be best for the patient but financially detrimental to the hospital. Our findings may also have important future implications regarding reimbursement. Until recently, readmissions were not costly for hospitals, as the hospitals were reimbursed piecemeal for each readmission. However, in the future there may be financial disincentives for potentially avoidable hospital readmissions related to quality of care.

Two temporal elements within the orthopaedic arthroplasty field may also have had direct influence on the outcomes reflected in our data. The increase in the rate of postoperative hemorrhage may be related to the increasingly widespread adoption of more aggressive pharmacologic prophylaxis against venous thromboembolism. In addition, there are potential technique-related orthopaedic factors to be considered. The utilization of minimal-incision arthroplasty became popular during the latter years of our study period. Some reports have identified minimal-incision arthroplasty as being a risk factor for early failure of total hip arthroplasty and as being correlated with increased surgery-related complications[36-38].

The results of the current study can be compared with the existing literature. Using one year (1995-1996) of Medicare claims data, Phillips et al. found the rate of pulmonary embolism to be 0.9% within six months after primary total hip arthroplasty and 0.8% after revision total hip arthroplasty. The rate of deep infection during this time period was 0.2% after primary procedures and 1.1% after revision procedures[39]. These complication rates are higher than our results, possibly reflecting the longer postoperative inclusion period. Using the same 1995 to

1996 data, Mahomed et al. found a 4.6% rate of readmission rate within ninety days after primary total hip arthroplasty and a 10.0% rate after revision total hip arthroplasty[40]. Ninety-day mortality was 1.1% after primary total hip arthroplasty and 2.6% after revision total hip arthroplasty in that study. Using 2003 hospital discharge data for approximately 230,000 primary and revision total hip arthroplasties, Zhan et al. demonstrated ninety-day readmission rates of 8.9% and 15.7% after primary and revision procedures[41]. Ninety-day mortality rates were 0.33% and 0.84% in that study, which were both markedly lower than our results and those of Mahomed et al. Lastly, using fifteen years of National Hospital Discharge Survey data, Memtsoudis et al. and Liu et al. reported infection rates of 0.47% and 0.48% after primary and revision total hip arthroplasty, a pulmonary embolism rate of 0.33% after primary procedures, and mortality rates of 0.33% and 1% after primary and revision procedures[12,13].

There are a number of limitations to the present study that are inherent in any analysis of large claims databases. There is a potential for bias resulting from underreporting of outcomes that could be considered complications[42] or undercoding of patient comorbidities[42,43]. Underreporting of complications can possibly artificially inflate risk-adjusted outcomes. Coding of comorbidities and outcomes in claims databases requires a clinical suspicion, confirmation of that comorbidity or outcome (often with a test), and finally documentation of the result. Extensive medical record reviews have demonstrated that models based on claims data produce risk estimates that are good surrogates for the actual occurrence of major procedures and complications[44,45]. However, studies have also shown that the completeness of Medicare data is more limited for complications such as surgical site skin infections or deep venous thromboses that are of a more minor nature[46-48]. Lastly, we attempted to risk-adjust the populations being analyzed with use of coded comorbidity data, but our adjustment may not have been perfect.

Although a small number of attempts to validate such administrative data have been published[21], much work needs to be done. Recently, an analysis was performed to assess the sensitivity and positive predictive value of administrative data regarding surgical adverse events; the calculated sensitivities ranged from 29% to 63% and the positive predictive values ranged from 22% to 89%[49]. In addition, it is possible that a portion of the changes in outcome over time that we observed reflect an increase in the aggressiveness of coding practices in recent years[50]. Nevertheless, we are unaware of any systematic changes in the coding of primary or revision total hip arthroplasty that would have substantially impacted our findings. Despite these inherent limitations in using claims-based databases, such data will continue to be used in the future in the United States by the Centers for Medicare & Medicaid Services for assessing hospital outcomes.

It is very important to emphasize that our study was limited to fee-for-service Medicare beneficiaries, and thus extrapolation to other populations should be done with caution. Medicare Part A data lack clinical information such as the implants utilized, anesthesia-related variables, and functional outcome measures. Our data represent Medicare claims data and not a registry. Such administrative data cannot capture many key orthopaedic outcomes such as quality of life and functional status. However, in the absence of national registries of arthroplasty patients that capture patient comorbidity, surgical complications, and postoperative functional status, such data sets remain an essential part of research.

In conclusion, the complexity of patients undergoing primary and revision total hip arthroplasty has increased. Despite this increasing complexity, patient outcomes after primary total hip arthroplasty improved markedly before stabilizing or slightly worsening in recent years. However, patient outcomes after revision total hip arthroplasty have gradually worsened, likely reflecting the increase in medical comorbidities and surgical complexity of these patients.

## Appendix

eA A list of the ICD-9-CM codes used to identify the primary outcomes in this study and figures showing mean length of hospital stay, rates of adverse outcomes, and readmission rates within ninety days after primary and revision total hip arthroplasty are available with the online version of this article as a data supplement at jbjs.org. ■

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