Projections of Primary and Revision Hip and Knee Arthroplasty in the United States from 2005 to 2030

By Steven Kurtz, PhD, Kevin Ong, PhD, Edmund Lau, MS, Fionna Mowat, PhD, and Michael Halpern, MPH, MD, PhD

Investigation performed at Exponent Inc., Philadelphia, Pennsylvania

Background: Over the past decade, there has been an increase in the number of revision total hip and knee arthroplasties performed in the United States. The purpose of this study was to formulate projections for the number of primary and revision total hip and knee arthroplasties that will be performed in the United States through 2030.

Methods: The Nationwide Inpatient Sample (1990 to 2003) was used in conjunction with United States Census Bureau data to quantify primary and revision arthroplasty rates as a function of age, gender, race and/or ethnicity, and census region. Projections were performed with use of Poisson regression on historical procedure rates in combination with population projections from 2005 to 2030.

Results: By 2030, the demand for primary total hip arthroplasties is estimated to grow by 174% to 572,000. The demand for primary total knee arthroplasties is projected to grow by 673% to 3.48 million procedures. The demand for hip revision procedures is projected to double by the year 2026, while the demand for knee revisions is expected to double by 2015. Although hip revisions are currently more frequently performed than knee revisions, the demand for knee revisions is expected to surpass the demand for hip revisions after 2007. Overall, total hip and total knee revisions are projected to grow by 137% and 601%, respectively, between 2005 and 2030.

Conclusions: These large projected increases in demand for total hip and knee arthroplasties provide a quantitative basis for future policy decisions related to the numbers of orthopaedic surgeons needed to perform these procedures and the deployment of appropriate resources to serve this need.

Over the past thirteen years, there has been an increase in the number of revision total hip arthroplasties and total knee arthroplasties performed in the United States[1], while the revision burden—defined as the ratio of revision arthroplasties to the total number of arthroplasties—has remained relatively constant. Previous analyses of nationwide data on the procedures have indicated that the revision burden for total hip arthroplasty was approximately 17.5% between 1990 and 2002, whereas the revision burden for total knee arthroplasty was approximately 8.2%[1]. In economic terms, revision total hip arthroplasty is estimated to have consumed 19% of the Medicare hip replacement expenditures between 1997 to 2003, whereas total knee arthroplasty revisions consumed only 8% of the total annual Medicare expenditures for knee replacement[2].

In Scandinavia, England, Australia, and Canada, the numbers of these procedures that have been performed are readily obtainable from national arthroplasty registries[3-6]. However, in the United States, the American Academy of Orthopaedic Surgeons (AAOS)[7] and other investigators have had to rely on representative surveys of hospital discharge records to provide estimates of the prevalence of primary and revision arthroplasties[1,8].

Given the many years required for the training of surgeons and the equally complex task of planning for hospital capacity, reliable projections regarding the demand for arthroplasties are crucial for policy makers in government, education, and industry. Importantly, reliable projections of revision arthroplasties would be particularly useful, as they consume greater economic resources than do primary procedures[9].

Disclosure: The authors did not receive any outside funding or grants in support of their research for or preparation of this work. Neither they nor a member of their immediate families received payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity. No commercial entity paid or directed, or agreed to pay or direct, any benefits to any research fund, foundation, division, center, clinical practice, or other charitable or nonprofit organization with which the authors, or a member of their immediate families, are affiliated or associated.

For this study, we hypothesized that the demand for total hip and total knee arthroplasties in the United States will increase substantially over the next twenty-five years. To test this hypothesis, we performed statistical projections of the number of primary and revision total hip and total knee arthroplasties between 2005 and 2030 on the basis of the available historical Nationwide Inpatient Sample (NIS) data from 1990 to 2003[10], compared with projections assuming a constant prevalence.

Materials and Methods

Data Sources

The National Hospital Discharge Survey (NHDS) and the NIS are national (United States) sample surveys of hospital discharge records. Comparisons of the two surveys conducted by the Agency for Healthcare Research and Quality have found that, on a year-by-year basis, the numbers of surgical procedures estimated to have been performed from the NIS and the NHDS are similar, differing by approximately 10%[11]. However, the NIS collects a substantially larger number of discharge records than does the NHDS and is therefore better suited to accurately quantify the prevalence of inpatient arthroplasty procedures in the United States. Consequently, we relied on the NIS data from 1990 to 2003 for our projections for the current study. The NIS is a federal-state cooperative database designed to compile annually a representative sample of hospital discharge records in the United States. In 2003, the NIS had a sample size of about eight million discharge records from approximately 1000 hospitals, which represent approximately 20% of all United States community hospitals. All of the discharge records from 1990 to 2003 were examined for this study.

We obtained demographic data on the patients (e.g., age, gender, and race and/or ethnicity) from the NIS. Disease diagnoses and surgical procedures performed (if any) were recorded for the NIS with use of the Ninth Revision of the International Classification of Diseases (ICD-9-CM). Specifically, primary hip and knee arthroplasty are identified by the ICD-9-CM codes 81.51 and 81.54, respectively. For revisions, the corresponding codes are 81.53 and 81.55. From 1990 to 2003, the ICD-9-CM codes for these procedures were consistent, thereby allowing the determination of longitudinal trends in the prevalence of both primary and revision joint arthroplasty. We also used projected population statistics for the nation and for individual states by age, gender, and race and/or ethnicity through 2025 that were published by the Census Bureau in 1997[12].

Projection Methodology and Statistical Analyses

The annual prevalence of arthroplasty surgery was modeled with use of a Poisson regression with age, gender, race and/or ethnicity, census region, and calendar year as covariates to account for differences in prevalence among population subgroups as well as changes over time. Age was categorized into eight subgroups (less than forty-five, forty-five to fifty-four, fifty-five to sixty-four, sixty-five to sixty-nine, seventy to seventy-four, seventy-five to seventy-nine, eighty to eighty-four, and eighty-five or more years old), while race and/or ethnicity was grouped into five categories (white, black, Asian, Hispanic, and Native American). "Hispanic" included all patients of Hispanic origin, regardless of race. Four census regions (Northeast, South, Midwest, and West) and the two genders were also categorical covariates in the analysis. Two-way interactions between age, gender, race, census region, and calendar year were included in the regression model. Surgery prevalence was calculated by dividing the number of procedures estimated from the NIS for each population subgroup by the corresponding population from the Census Bureau. The projected number of procedures was estimated by applying the surgery prevalence estimated from the regression model to the projected population data for each subgroup. The projected national total is the sum of the projected number of procedures from each subpopulation. Independent models were used for each type of primary and revision hip and knee arthroplasty.

To evaluate the methodological sensitivity of our results, we compared our primary projections obtained from the NIS (in which the prevalence of surgery is allowed to vary over time on the basis of the actual data) with projections in which the prevalence of each population subgroup was held constant on the basis of the 1990 to 2003 averages. Deviance and Pearson chi-square values were determined to describe the goodness of fit for the Poisson regression model for the various arthroplasty data. Additional detailed descriptions of the statistical analyses are presented in the Appendix.

Results

In 2003, the most recent year for which national inpatient procedure data are currently available from NIS, a total of 202,500 primary total hip arthroplasties and 402,100 primary total knee arthroplasties were performed nationally in the United States. During the same year, a total of 36,000 revision total hip arthroplasties and 32,700 revision total knee arthroplasties were performed.

Sensitivity of Projection Methodology

Between 1990 and 2003, the prevalence of primary and revision total hip and knee arthroplasties all increased substantially over time. The overall goodness of fit of the regression models, represented by the value of the scaled Pearson chi square (a measure of the lack of fit between model and data), averaged 1.11 (range, 1.03 for primary total knee replacement to 1.26 for revision total knee replacement procedures) (see Appendix). When the year of surgery was excluded from the Poisson regression model to simulate a constant prevalence over time, the models fitted with the remaining covariates all showed a substantial increase in the deviance value (i.e., poorer fit), especially for knee arthroplasty.

The projections of primary and revision total joint replacement were found to be highly sensitive to assumptions regarding trends in the prevalence of surgery. If the trends

TABLE I Summary of Sensitivity Analysis of the Projected Number of Hip and Knee Arthroplasties with Use of Models Comparing Variable Prevalence (Baseline) with Constant Prevalence

	Annual Number of Procedures (in Thousands)†			
Type of Procedure*	2005	2010	2020	2030
Primary total hip arthroplasty				
Variable	209 (193-225)	253 (232-276)	384 (339-435)	572 (481-681)
Constant	179 (156-202)	194 (169-219)	236 (205-268)	277 (240-315)
Primary total knee arthroplasty				
Variable	450 (425-477)	663 (618-711)	1520 (1362-1700)	3481 (2948-4136)
Constant	301 (265-337)	329 (289-370)	415 (364-467)	488 (425-550)
Revision total hip arthroplasty				
Variable	40.8 (34.9-47.0)	47.8 (40.3-56.1)	67.6 (54.0-83.9)	96.7 (72.1-130.0)
Constant	36.0 (29.5-42.6)	38.9 (31.8-46.0)	47.2 (38.3-56.0)	56.6 (45.8-67.5)
Revision total knee arthroplasty				
Variable	38.3 (32.6-44.3)	55.3 (46.5-65.1)	121 (95.9-153)	268 (193-381)
Constant	25.9 (21.3-30.5)	28.1 (23.0-33.3)	35.1 (28.6-41.7)	41.7 (33.6-49.9)

*The variable prevalence (baseline) and the constant prevalence are based on 1990 to 2003 data from the Nationwide Inpatient Sample.
†The values are given as the projected value with the 95% prediction interval in parentheses.

(i.e., increases in the prevalence of surgery) observed from 1990 to 2003 were to continue, by 2030 the projections with use of the NIS data could range from two to five times greater than the projections assuming a constant surgery prevalence over time (Table I). The projections for primary and revision total knee surgery were more sensitive to modeling assumptions than those for primary or revision total hip arthroplasty because of the steep increase in the number of knee procedures from 1990 to 2003.

Projected Primary and Revision Arthroplasty Procedures with Use of the Nationwide Inpatient Sample Baseline Model

Our projection model predicted substantial increases in the numbers of hip and knee replacement procedures (Figs. 1 and 2). On the basis of the NIS model, the demand for primary total hip arthroplasty was estimated to grow by 174%, from 208,600 (95% prediction interval, 193,300 to 224,600) in 2005 to 572,000 (95% prediction interval, 481,000 to 681,000) by 2030 (Fig. 1). If the number of total knee arthroplasties performed continues at the current rate, the demand for primary total knee arthroplasty is projected to grow by 673%, from 450,000 (95% prediction interval, 425,000 to 477,000) in 2005 to 3.48 million procedures (95% prediction interval, 2.95 to 4.14 million) by 2030.

Overall, the total number of revision arthroplasty procedures performed in 2005 is expected to double by the year 2026 for revision total hip arthroplasty and by 2015 for revision total knee arthroplasty. Although more revision total hip arthroplasties than revision total knee arthroplasties are currently performed, the number of revision total knee arthroplasties performed were predicted to outnumber total hip arthroplasty revisions after 2007 (Fig. 2). Total hip arthroplasty revisions were projected to grow from 40,800 (95% prediction interval, 34,900 to 47,000) in 2005 to 96,700 (95% prediction interval, 72,100 to 130,000) in 2030 (an increase of 137%). If the trend observed from 1990 to 2003 were to continue, total knee arthroplasty revisions were projected to grow from 38,300 (95% prediction interval, 32,600 to 44,300) in 2005 to 268,200 (95% prediction interval, 192,700 to 381,400) in 2030 (an increase of 601%).

On the basis of these estimates, the revision burden for total hip replacements was projected to be 16.3% in 2005 and 14.5% in 2030. The corresponding revision burden for total knee replacements was projected to be 7.8% in 2005 and 7.2% in 2030.

Discussion

In this study, arthroplasty projections were derived by considering temporal changes in arthroplasty rates, as well as in population subgroups. As the official demographer of the United States, the Census Bureau has devoted considerable effort to developing reliable projections of the future United States population. In contrast, little information is available to quantify the expected number of hip and knee revision arthroplasties in the future. For example, the projection recently developed by the AAOS[7] was limited to primary hip and knee replacements. The AAOS projections were found to have underpredicted the expected utilization of primary joint replacement surgery[1] because they were based on the NHDS survey, which has a much lower sample size than the NIS. Additionally, the AAOS estimates assumed a constant prevalence of surgery over time. In contrast, our results underscore the importance of accounting for changes in the rate of surgery

for future projections because the prevalence of surgery is changing rapidly over time.

The present study provides, for the first time to our knowledge, quantification of the demand for primary and revision hip and knee arthroplasties in the United States through 2030. We project a massive increase in demand for primary and revision total joint procedures over the next two decades—a demand that, to be met, will need to be addressed with a combination of increased economic resources, operative efficiency, technical capacity (i.e., additional surgeons), and implant longevity.

The projections in this study are limited on the basis of an extrapolation of historical procedural data. As demonstrated in this study, the uncertainties inherent in such an extrapolation can be minimized by choosing a suitably large set of historical data (e.g., NIS instead of NHDS), and by incorporating as many covariates as possible into the model. Nevertheless, these projections are limited by the quantity

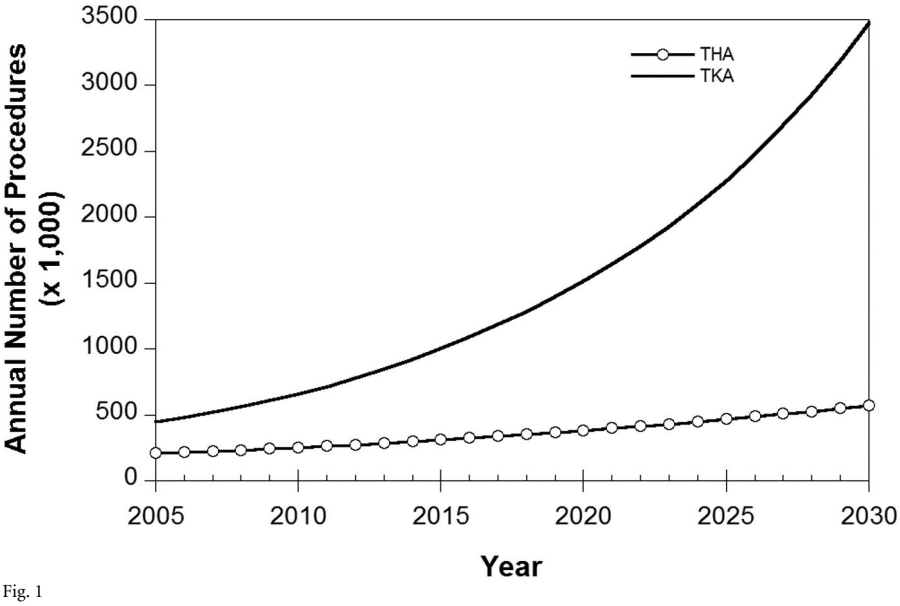

Fig. 1

The projected number of primary total hip arthroplasty (THA) and total knee arthroplasty (TKA) procedures in the United States from 2005 to 2030.

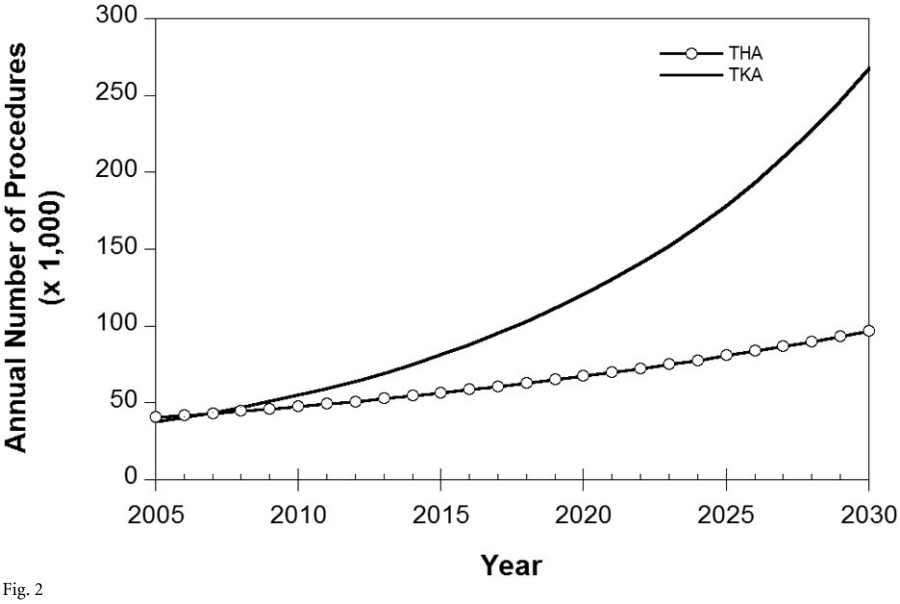

Fig. 2

The projected number of revision total hip arthroplasty (THA) and total knee arthroplasty (TKA) procedures in the United States from 2005 to 2030.

and quality of available data. The trends established by historical data, even if accurate, may not persist in the future because of improvements in implant technology, such as advanced bearing materials or designs. Furthermore, it is impossible to anticipate, at present, whether future orthopaedic treatment technologies or newer pharmaceutical nonoperative interventions will lead to a reduced demand for primary total joint replacements by 2030. Our model also does not incorporate unforeseen changes in economic factors associated with these arthroplasties. It is uncertain, for example, to what extent the United States health-care system will be able to finance the future demand for arthroplasties anticipated by the present study.

We selected a twenty-five-year time frame for the study, extending to 2030, purely to facilitate comparisons with previous AAOS projections, which employed an identical time frame. Intuitively, we appreciate that long-term projections will be more prone to unexpected disruptions than those spanning a near-term horizon. Nevertheless, such uncertainties in no way diminish the value and necessity of conducting projections for the purpose of long-range planning and policy-making.

Consequently, it is inevitable that the projections performed in the present study will be superseded in the future as new years of procedure data become available. Other methodological approaches to the prediction problem, such as age-period-cohort models or generalized additive models, should also be attempted to further validate the reliability of the projections established by the present approach. It is relatively straightforward to update the projections reported in this study with use of the present methodology, but continued monitoring and updating will need to occur.

In addition, it is clear from the different trends observed that the sensitivity of the projections appears to be procedure-dependent. For example, because of the substantially higher rate of increase in knee arthroplasty between 1990 and 2003, the models simulating a constant prevalence over time produced a considerably poorer fit. Consequently, the specific findings for total hip and knee replacement should not be generalized to other orthopaedic procedures, which may exhibit entirely different historical growth histories. However, this study establishes a methodology whereby an investigator can systematically evaluate orthopaedic surgery projections in a generalized statistically based framework. Although the data and projected number of procedures can be updated regularly, the methodology we have developed is expected to remain relevant for years to come.

The projections for revision procedures in this study were limited by the generality of the ICD-9-CM codes in the existing data, which currently do not yet discriminate between partial or total revision of an artificial joint. As of October 2005, new ICD-9-CM codes had been introduced by the Center for Medicare and Medicaid Services (CMS) for revision hip and knee arthroplasties. New ICD-9-CM codes also had been introduced to track the type of bearing (ceramic, metal, or polyethylene) used for total hip replacements. However, 2006 will provide the first full year of data incorporating this new coding scheme, and there is a two and a half-year lag between the end of the calendar year and the production of the corresponding NIS dataset. Furthermore, at least four years of data would be necessary to perform even the most rudimentary projection. Consequently, it will be well into the second decade of this century that sufficient years of information will be available for mathematically sound projections with use of the recently introduced ICD-9-CM procedure codes.

We modeled revision hip and knee replacement as independent orthopaedic procedures for this study, although it is feasible to construct a predictive model for future revisions on the basis of the number of primary procedures performed and an assumed Kaplan-Meier-type survivorship model for the different population subgroups. However, the necessary survival data for such a model can only be derived from a longitudinal database, such as a national implant registry, which does not yet exist in the United States. The only rationale for developing such a complex model would be historical evidence that the revision burden was changing over time, as has been documented in Sweden. However, available data in the United States between 1990 and 2003 do not support such a hypothesis; indeed, the revision burden has remained essentially unchanged in this country for over a decade[1]. Between 1990 and 2002, the national revision burden for total hip arthroplasty ranged between 15.2% and 20.5% (average, 17.5%); for total knee arthroplasty, the revision burden varied between 7.3% and 9.7% (average, 8.2%)[1]. Without compelling evidence that either implant technology or surgical technique have improved the survival of primary replacements at a national level, it is difficult to say whether a more sophisticated projection method for revisions than the one we employed in the present study would be of use. The revision projections in the current study may be interpreted as a conservative upper bound for what awaits the orthopaedic community if improvements in primary implant survival cannot be achieved at a national level.

The recent ICD-9-CM coding changes for hip and knee revisions in the United States were accompanied by 26.5% increases in reimbursement by the CMS and the formation of separate diagnosis-related group codes for primary and revision procedures (544 and 545, respectively)[13]. The changes in coding and reimbursement reflect heightened awareness and acceptance by CMS of the greater burden that revisions place on patients, surgeons, and hospitals. The revision projections in the current study provide the necessary foundation for future cost-benefit analyses at a national level, to quantify the increasing societal impact of revision arthroplasty in the United States.

Appendix

eA A table showing the summary of multivariate Poisson regression analysis results and a detailed description of the projection methodology and statistical analysis are available with the electronic versions of this article, on our web site at jbjs.org (go to the article citation and click on "Sup-

plementary Material") and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM). ■

Steven Kurtz, PhD
Kevin Ong, PhD
Exponent Inc., 3401 Market Street, Suite 300, Philadelphia, PA 19104.

E-mail address for K. Ong: kong@exponent.com

Edmund Lau, MS
Fionna Mowat, PhD
Exponent Inc., 149 Commonwealth Drive, Menlo Park, CA 94025

Michael Halpern, MPH, MD, PhD
Exponent Inc., 1800 Diagonal Road, Suite 355, Alexandria, VA 22314

References

1. Kurtz S, Mowat F, Ong K, Chan N, Lau E, Halpern M. Prevalence of primary and revision total hip and knee arthroplasty in the United States from 1990 through 2002. J Bone Joint Surg Am. 2005;87:1487-97.

2. Ong KL, Mowat FS, Chan N, Lau E, Halpern MT, Kurtz SM. Economic burden of revision hip and knee arthroplasty in Medicare enrollees. Clin Orthop Relat Res. 2006;446:22-8.

3. National Joint Registry. National Joint Registry for England and Wales. 2nd Annual Report. 2005.

4. Malchau H, Herberts P, Eisler T, Garellick G, Soderman P. The Swedish Total Hip Replacement Register. J Bone Joint Surg Am. 2002;84 Suppl 2:2-20. Erratum in: J Bone Joint Surg Am. 2004;86:363.

5. Canadian Institute for Health Information, Canadian Joint Replacement Registry (CJRR). 2004 report: total hip and total knee replacements in Canada. 2004.

6. Australian Orthopaedic Association. National Joint Replacement Registry annual report 2005. 2005.

7. Frankowski JJ, Watkins-Castillo S. Primary total knee and hip arthroplasty projections for the U.S. population to the year 2030. 2002. http://www.aaos.org/wordhtml/research/stats/TJR_projections.pdf. Accessed 2004 Feb 20.

8. Mahomed NN, Barrett JA, Katz JN, Phillips CB, Losina E, Lew RA, Guadagnoli E, Harris WH, Poss R, Baron JA. Rates and outcomes of primary and revision total hip replacement in the United States medicare population. J Bone Joint Surg Am. 2003;85:27-32.

9. Bozic KJ, Katz P, Cisternas M, Ono L, Ries MD, Showstack J. Hospital resource utilization for primary and revision total hip arthroplasty. J Bone Joint Surg Am. 2005;87:570-6.

10. Agency for Healthcare Research and Quality. NIS technical documentation. Rockville, MD: Agency for Healthcare Research and Quality; June 2003. http://www.hcup-us.ahrq.gov/db/nation/nis/nisdbdocumentation.jsp.

11. Agency for Healthcare Research and Quality. Comparative analysis of HCUP and NHDS inpatient discharge data: technical Supplement 13. 1996. http://www.ahrq.gov/data/hcup/nhds/comptb9.htm. Accessed 2005 Oct 8.

12. National Center for Health Statistics. State Population Projections. 1997. http://www.census.gov/population/www/projections/stproj.html. Accessed 2005 Jan 5.

13. Center for Medicare and Medicaid Services. Changes to the hospital inpatient prospective payment systems and fiscal year 2006 rates. Federal Register. 2005;70:47278. http://www.cms.hhs.gov/QuarterlyProviderUpdates/downloads/cms1500f.pdf. Accessed 2005 Oct 2.