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Projected increase in total knee arthroplasty in the United States – an alternative projection model

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SUMMARY

Objective: The purpose of our study was to estimate the future incidence rate (IR) and volume of primary total knee arthroplasty (TKA) in the United States from 2015 to 2050 using a conservative projection model that assumes a maximum IR of procedures. Furthermore, our study compared these projections to a model assuming exponential growth, as done in previous studies, for illustrative purposes.
Methods: A population based epidemiological study was conducted using data from US National Inpatient Sample (NIS) and Census Bureau. Primary TKA procedures performed between 1993 and 2012 were identified. The IR, 95% confidence intervals (CI), or prediction intervals (PI) of TKA per 100,000 US citizens over the age of 40 years were calculated. The estimated IR was used as the outcome of a regression modelling with a logistic regression (i.e., conservative model) and Poisson regression equation (i.e., exponential growth model).
Results: Logistic regression modelling suggests the IR of TKA is expected to increase 69% by 2050 compared to 2012, from 429 (95%CI 374–453) procedures/100,000 in 2012 to 725 (95%PI 121–1041) in 2050. This translates into a 143% projected increase in TKA volume. Using the Poisson model, the IR in 2050 was projected to increase 565%, to 2854 (95%CI 2278–4004) procedures/100,000 IR, which is an 855% projected increase in volume compared to 2012.
Conclusions: Even after using a conservative projection approach, the number of TKAs in the US, which already has the highest IR of knee arthroplasty in the world, is expected to increase 143% by 2050.

Introduction

The United States has the highest incidence rate (IR) of knee arthroplasty worldwide, with 235 procedures/100,000 habitants[1]. In 2012 alone, the number of knee arthroplasties performed in the United States was over 700,000, which was 9% of the eight million non-maternal and non-neonatal inpatient hospital stays where a procedures was performed[2]. Because of the high incidence of knee arthroplasty and its historical increase[3–7], understanding the future healthcare demands of these procedures is important. Reliable projections of future surgery demand can assist healthcare providers, leaders, and services in preparing, through capacity building, staff training, financial commitment, and other important resource building strategies.

Three separate projections studies of future demand for knee arthroplasty in the US have been published[3–5]. In 2007, Kurtz *et al.*, estimated that from 2005 to 2030 a 673% increase in the number of procedures would be observed, with an expected volume of 3.5 million procedures being performed yearly by 2030[3]. In 2014, Kurtz *et al.* revaluated their original models and new estimates were proposed, which were slightly lower for 2020, however, no figures could be extrapolated from their published graphs[4]. A third study,

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by Bashnskaya *et al.*, in 2012, proposed that a similar increase in volume as proposed by Kurtz *et al.*[3] was expected for 2030, and projected that three million procedures would occur annually by then[5]. While these three studies have arrived at similarly high estimates of future demand they have used different modelling approaches. The first study used a Poisson regression model, which assumed an exponential growth in the incidence of knee arthroplasty. The second and third studies used linear regression models, which also assumed a continuous increase in demand[4,5]. Both models make projections that are not biologically plausible, or consistent with what we know about what drives the incidence of these procedures. To illustrate this point, the estimated prevalence of knee osteoarthritis according to the Global Burden of Disease 2010 study puts the global age-standardised prevalence of symptomatic radiographically confirmed knee osteoarthritis around 3.8%[8], while the prevalence of knee osteoarthritis is estimated to be 10–13% among Americans[8,9]. This relatively low number of people with osteoarthritis, the already high incidence of knee arthroplasty in the US, and the fact that it is estimated that only about 50% of those with symptomatic osteoarthritis have surgery in the United States[10] suggest that there will be a finite number of future patients undergoing surgery and not a continuous projected growth as proposed by other authors.

There is no way to test which methodology is best suited for joint arthroplasty projections, but biological plausibility and constraints to the healthcare system have prompted researchers to explore alternative projection models for this patient population[11–13]. Furthermore, inaccurate growth projection can lead to wasted or misplaced resources when overestimated and lack of preparedness when underestimated. Evaluating alternative projection models will increase our understanding of the modelling limitations and eventually reproducibility of findings will increase our confidence in projected estimates. In this study we used the more conservative projection model proposed by Nemes *et al.* in Sweden to estimate the future demand of knee arthroplasty in the US[11,12] because there is an upper limit to total knee arthroplasty (TKA) incidence that prior projections have not considered. Failure of considering this upper limit, or asymptote, will ultimately lead to biased projected rates[14]. The model is a logistic model, which has more parameters than the models used by the other US projection studies. The parameter of most interest in this model is the asymptote, which in this case is the estimated maximum incidence of knee arthroplasty. This parameter has units that correspond to the outcome. The existence of such a maximum incidence is a strong assumption and an untestable one; however, employing such assumption is unlikely to attain numbers high enough to sustain the yearly growth in knee arthroplasty proposed by the models in the current published projection studies.

The purpose of our study was to estimate the future IR and volume of primary TKA in the United States from 2015 to 2050 using an alternative projection model that assumes a maximum IR. Furthermore, our study compared these projections to a model assuming exponential growth for illustrative purposes.

Methods

A population based epidemiological study was conducted using data from US National (previously Nationwide) Inpatient Sample (NIS)[15] and US Census Bureau[16]. The NIS was developed by the Healthcare Cost and Utilisation Project (HCUP), which is sponsored by the Agency for Healthcare Research and Quality (AHQR). This ~20% stratified sample of patients who were discharged from 1000 hospital in 44 states in the US has been shown to be 95% representative of the US population.[15]

Primary TKA procedures performed between 1993 and 2012 (most recent year available) were identified in the NIS using International Classification of Disease, ninth revision, Clinical Modification (ICD-9-CM) code 81.54. The new trend weights released with the 2012 NIS data were used to estimate procedure yearly volumes.[17]

The US Census historical population estimates for 1993–2012 were obtained from the intercensal estimates of the resident population by age[18] and projected population estimates for 2015 to 2050 were obtained from the projections of the population for the US.[19]

Historical changes in the total number of TKA per year were modelled with piecewise-linear regression splines. Piecewise-linear regression splines fit multiple regression lines to the data connected by a change-point. Model fitting and change-point estimation followed the algorithms outlined by Mueggo[20]. The number of change points were selected by minimizing the Akaike Information Criterion, with the restriction that change-points cannot be placed at the extremes of the data. The IR and 95% confidence intervals (CI) or prediction intervals (PI) of TKA per 100,000 US citizens over the age of 40 years were calculated. Historical data was summarized as IRs and associated 95%CI, while projections were presented with 95%PI. The incidence in the population 40 years or older was chosen because the number of patients with joint arthroplasty younger than 40 is minimal (0.7% of TKAs). The estimated IR was used as the outcome of a regression modelling with logistic regression and Poisson regression equation. Logistic regression is a conservative projection model that assumes a maximum incidence level exists and changes in estimates grow exponentially from the beginning to the half-way point of the maximum incidence and then decrease until maximum incidence is reached. This model is based on the logistic growth model and assumes a S-shape growth curve. The model parameters have clear meanings. According to this model the incidence in a time point is directly dependent on the incidence a time-unit before and can be modelled as

$$\frac{dy'}{dt} = \beta y\left(1 - \frac{y}{A}\right)$$

where y observed incidence, A the asymptote that has units equal to incidence and β the growth rate with units equal to t (years in our case). As one can see if the observed incidence is far from the asymptote the growth is accentuated. However, as the observed incidence y approaches the asymptote A the growth slows down. The model parameters are estimated using its integrated form and routine optimization methods. We used the following reparametrised form

$$\frac{A}{1 + e^{(\gamma - t)/\xi}}$$

where the parameters of interest are A the asymptote that has units equal to incidence and γ a numeric parameter representing the year value at the inflection point of the curve.

By comparison, Poisson regression assumes exponential growth through the whole time period. We used grid-search to estimate the parameters of the logistic regression equation. Grid search is an exploratory Monte Carlo optimization method[21,22]. Parameters of the Poisson regression were estimated using maximum likelihood method. 95%PIs were constructed with Monte Carlo simulation for the logistic regression and with bootstrapping for Poisson regression. 95%PIs for IRs were calculated with the Wilson method[23]. All analyses were conducted using R 3.3.1.

This study uses publicly available de-identified data so review by an Institutional Review Board was not required.