UNIVERSITAT DE BARCELONA

Data Driven Approach to Enhancing Efficiency and Value in Healthcare

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Appendix B

Supplementary Materials. Predicting the burden of revision knee arthroplasty: simulation of a 20-year horizon

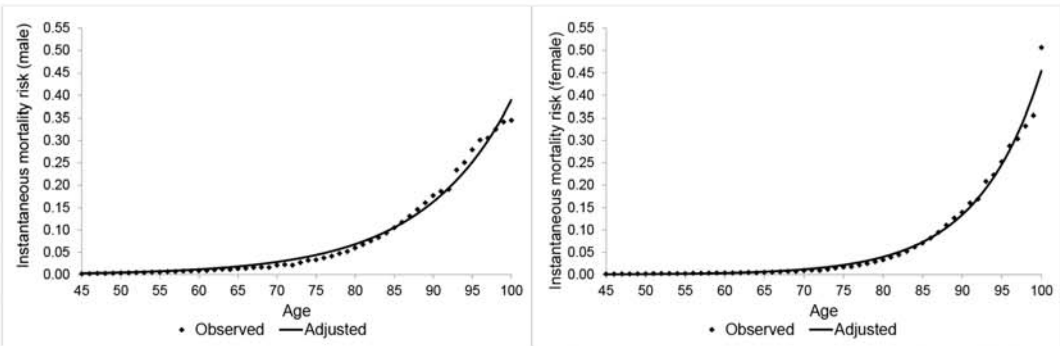
Predicting the burden of revision knee arthroplasty: simulation of a 20-year horizon

APPENDIX

Lifetime distribution

The time until death was assigned when a new patient was created, that is, at the time of undergoing a primary KA, according to the patient's simulated sex and age values. To calculate the instantaneous mortality risk, the number of inhabitants and the number of deaths by age (yearly) and sex in Spain in 2011 were used.[1] Gompertz models for men and women were adjusted[2] and the distribution of time until death conditioned on current age was obtained. Figure A1 shows the goodness-of-fit of the models for men and women.

Figure A1: Observed and estimated instantaneous risk of death by age and sex. Data on Spanish population and deaths, 2011.

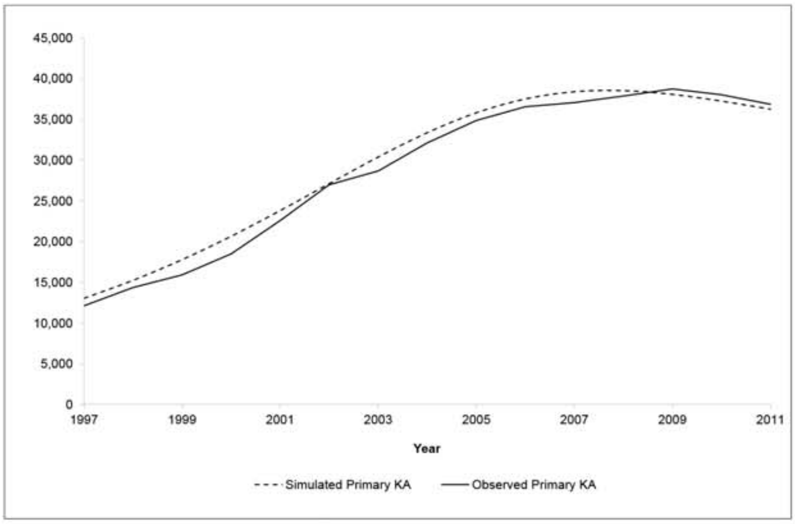


Utilization of Knee Arthroplasty

Data on utilization of knee arthroplasty were obtained from the hospital discharge minimum data set of the Spanish health system.[3] The number of surgeries was available per year from 1997 to 2011, by gender and age group (45-64 years, 65-74 years, and 74 years or older). The age group of less than 45 years was excluded from the study because the incidence of KA was considered as irrelevant. The ICD-9-MC code 81.54 (total knee replacement) was used to identify primary total KA utilization, and codes 81.55 (revision of knee replacement, not otherwise specified), and 00.8x codes (00.81: revision of knee replacement, tibial component; 00.82: revision knee replacement, femoral component; 00.83: revision of knee replacement, patellar component; and 00.84: revision of knee replacement, tibial insert) were used to identify revision KA.

In a discrete event simulation model, new entities enter the model following a distribution of time between arrivals. In our model, new entities represented patients undergoing primary KA. To reproduce the historical figures of the number of primary KA from 1997 to 2011, the best fitting option for the time between primary KAs was a cubic regression model. The estimated cubic model was -1.57*10(-13)*t^3+2.53*10(-9)*t^2-1.28*10(-5)*t+3.02*10(-2), where t is calendar time. Figure A2 shows the evolution of real data and the estimation used within the simulation model in terms of the number of primary KA observed and simulated through time.

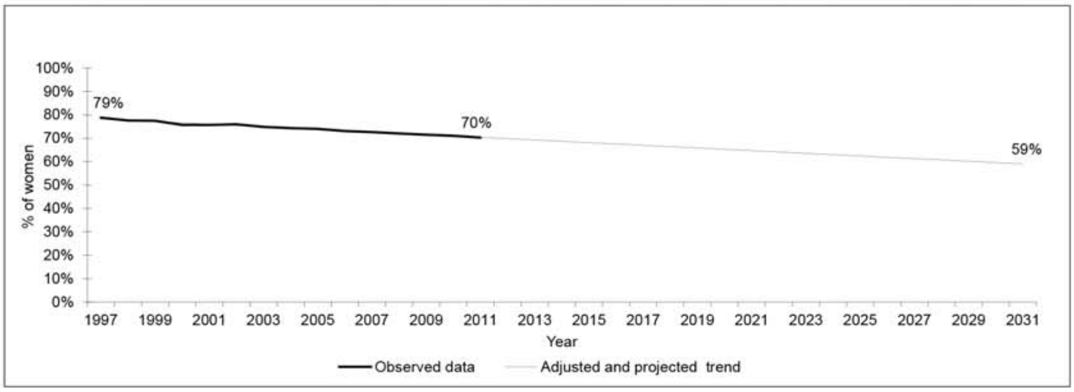
Figure A2: Data on primary KA in Spain from 1997 to 2011. Comparison with primary KA utilization introduced in the simulation model (Pearson correlation of 0.996).



Sex distribution

The analysis of the sex distribution of primary KA from 1997 to 2011 demonstrated a significant tendency towards a decrease in the proportion of primary KA among women. Given the different outcomes between sexes, it was considered important to include this tendency in the model. A linear adjustment proved the best fit and the projection within the simulation horizon showed a projected proportion reaching 59% of primary KA in women in 2031. This percentage was considered as valid because it was similar to the rate observed in other countries (range 52% to 67%).[4–9] Figure A3 shows the fit of the linear model to observed data and the 20-year projection.

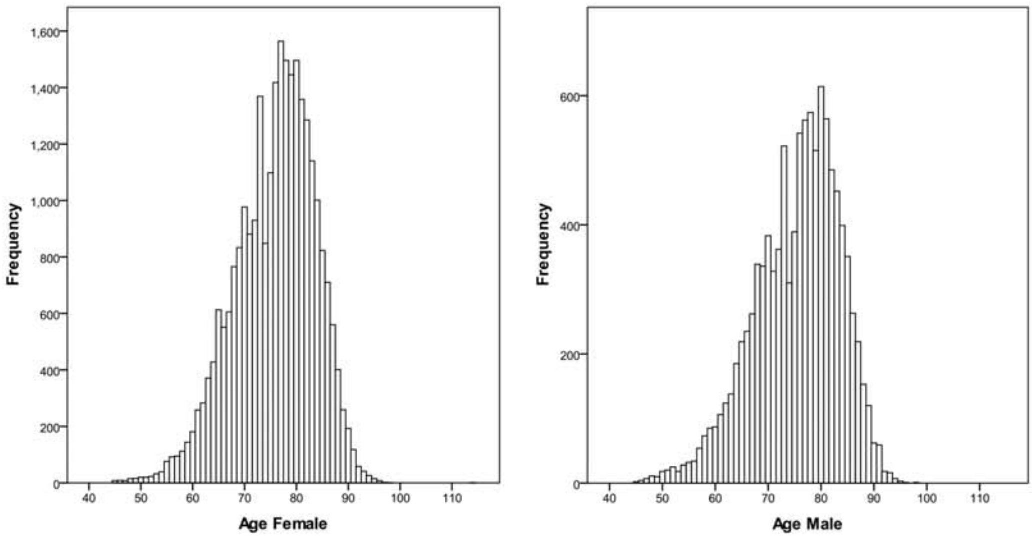
Figure A3: Proportion of primary KA in women. Observed data from 1997 to 2011 and linear model from 1997 to 2031.



Age distribution

The age distribution of primary arthroplasty by sex was estimated using individual-level data from the Catalan Arthroplasty Registry (RACat) between 2005 and 2011[10,11] and is shown in Figure A4. The distributions were introduced in the model as empirical distributions. Data corresponded to 27,120 primary knee arthroplasties in women, with a mean age of 75.8 years (standard deviation of 7.7 years), and 10,726 primary arthroplasties in men, with a mean age of 75.5 years (standard deviation of 8.1 years).

Figure A4: Empirical distribution of age at primary KA, by sex. Data from RACat (2005-2011).



Simulation scenarios for primary KA utilization

<u>Scenario 1: low primary KA utilization rate</u>

This scenario assumes that economic restrictions will continue and that resources for KA surgery will not increase or decrease through the simulation horizon. The number of surgeries per year was unchanged during the period and was equal to the number of primary KA in 2011.

<u>Scenario 2: moderate primary KA utilization rate</u>

To maintain the coverage of population needs, this scenario assumes that the rate of primary KA surgery will not increase or decrease through the simulation horizon. Thus, the number of surgeries was projected for 2012 to 2031, considering that age- and sex-specific KA rates for 2011 applied to the projections of the Spanish population.[1]

<u>Scenario 3: high primary KA utilization rate</u>

To simulate a scenario without economic restrictions, this scenario was based on the assumption that the number of inhabitants of a population group is correlated with the number of primary KA and that this relationship can be used to predict the total number of primary KA to be undertaken in the future, following the methodology described by Bashinskaya et al.[12]

To validate the hypothesis of a correlation between population number and number of primary KA in Spain, 4 age groups were created (45-64 years, 65-74 years, older than 74 years and overall population). A linear relationship between these two variables was assumed, based on visual assessment of the scatter plots between the population and the number of primary KA. Pearson correlation coefficients were calculated to determine the strength of the association (see Table A1), the highest being that for the group aged 75 years or more.

Table A1: Pearson correlation coefficients between population number and number of primary KA.

Age group	Pearson correlation
45-64 years	0.899
65-74 years	0.194
>75 years	**0.948**
Overall	0.932

Thus, the projection for the number of primary KA between 2012 and 2031 used the population number older than74 years as an explanatory variable with the following estimated equation:

Number of primary KA (year) = -33,811.4 + 0.01901* population >75 years (year)

Simulation scenarios for prostheses survival

Scenario B: Better survival (RACat)

RACat is the Arthroplasty Register of Catalonia, created in 2005, in which all publicly funded hospitals submit data on hip and knee arthroplasties. Prostheses survival was calculated as the time between the primary KA and the first revision registered in RACat between 2005 and 2011 (n=44,557). Analysis of survival data showed that there were statistically significant differences in the survival curves according to sex, age and arthroplasty type. Thus, Cox proportional hazards models were adjusted by age group (55-64 years, 65-74 years, ≥75 years) and arthroplasty type (unicompartimental and patellofemoral, posterior cruciate ligament-retaining [CR] and posterior-stabilized [PS], or others) for men and women separately, as their survival curves were not proportional. To introduce these parameters in the simulation model, a Weibull distribution with parameters α_0 and β_0 was adjusted for the survival time of the most frequent group (age ≥ 75 years and CR-PS, Table 1) for men and women, which was the group used as the baseline group for the Cox models. The parameters of the Weibull distribution were adjusted through a nonlinear regression model with the form:

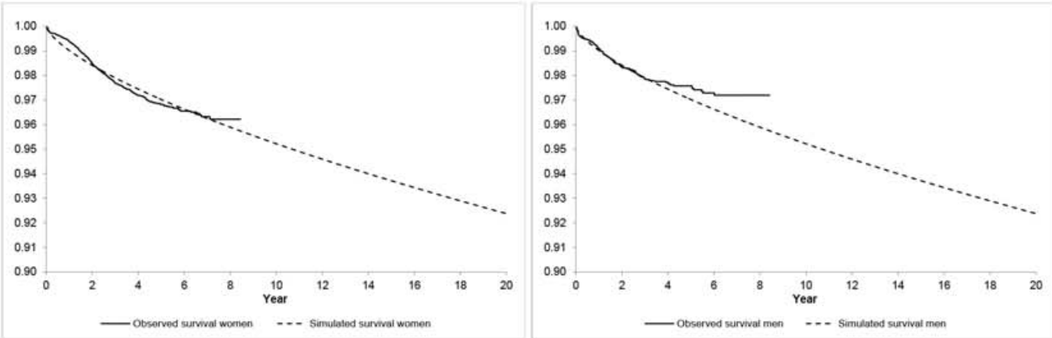
$$\boldsymbol{S(t) = e^{-\beta_0 t^{\alpha_0}}}$$

The hazard ratios estimated for the other categories (HR_i) were applied to the parameters of the distribution according to each patient's characteristics using the following equation, where u is a value sampled from a Uniform distribution between 0 and 1.

$$\boldsymbol{t = \left(-\frac{ln(1-u)}{{\beta_0}^{\alpha_0} \prod HR_i}\right)^{\frac{1}{\alpha_0}}}$$

Table 1 includes the parameters and hazard ratios for age and type of prosthesis. As there is no statistical test for the goodness-of-fit of nonlinear models, the visual goodness-of-fit of the Weibull distribution is shown in Figure A5.

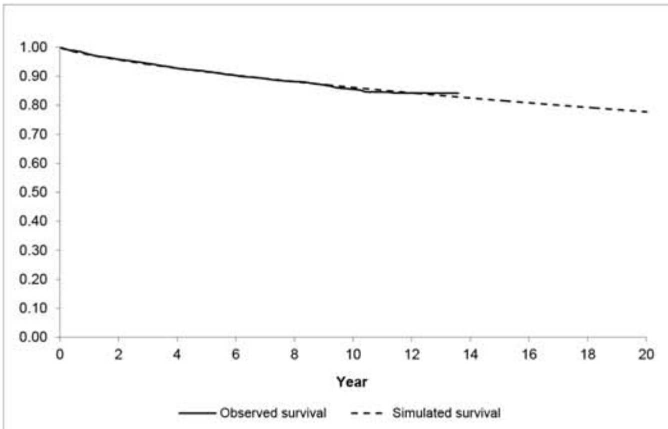
Figure A5: Visual goodness-of-fit of the Weibull distribution to the survival of the most frequent group (age ≥ 75 years and CR-PS), by sex.



Scenario W: Worse survival (AIAQS)

The other survival function was estimated using a retrospective cohort study on KA in eight hospitals in Spain between 1995 and 2000 (n=2,000).[13] Survival time was also modelled with a Weibull distribution (Table 1). Figure A6 shows the goodness of fit of the estimated distribution.

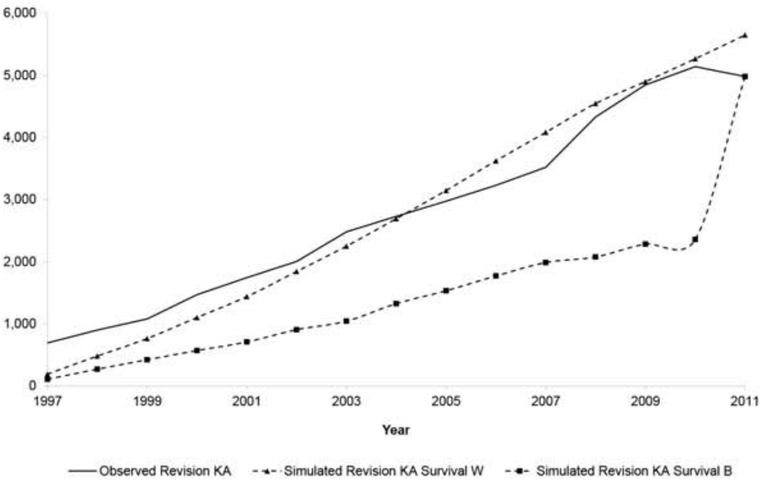
Figure A6: Goodness-of-fit of the Weibull distribution.



Calibration of number of revision KA

The two survival functions used represent the available data on prostheses survival in Spain, but were estimated in different time periods. Survival W was obtained from surgeries between 1995 and 2000, while survival B was obtained from surgeries between 2005 and 2011 and represents a substantial improvement in survival (from 91.5% to 96.5% 5-year survival, see Figure 2). The first analysis of the simulation results showed that, with survival W, the predicted number of revisions fitted the observed data. However, when survival B was applied, the number of revisions at year 2011 was lower. Thus, to take into account in results of the models with survival B that former survival was worse, the number of revisions at year 2011 was recalibrated to meet the observed number of revisions. See Figure A7.

Figure A7: Number of revision KA. Observed values and simulated values under survival function B and W.



Analysis of results based on operating room time

Operating room time was defined as the time that an operating room was occupied to perform one intervention. It included anesthesia, surgery and cleaning time. The orthopedic surgeons of the research team agreed to assign values of 2 and 3 hours for primary and revision surgery, respectively. The demand for operating room time was calculated by multiplying the number of procedures by the corresponding operating room time (primary and revision KA), per year. The percentage of change in resource demand from 2011 was calculated.

Validation of the results

Inputs and outputs of the model were validated in several meetings of the whole research team (orthopedic surgeons, epidemiologists, and statisticians). Inputs were refined when needed and when data was available and scenarios were agreed among all members of the team. Outputs were validated using the face validity approach, by showing scenario results to the research team. Results were discussed and compared to those published in the literature. Definitive results were those considered as valid, credible, and useful for the study objectives.

Currently, data on years 2012 and 2013 are available from the hospital discharge minimum data set of the Spanish Health System.[3] Figure A8 overlaps the updated data on the 3 simulation scenarios for primary KA utilization showing that real trends are closer to scenario 3 (high utilization rate). Figure A9 shows that, after a decrease in 2012, the real number of revision KA in Spain in 2013 was similar to the model's predictions using survival function B.

Figure A8: Number of primary KA. Observed values and simulated values according to scenarios of primary KA utilization.

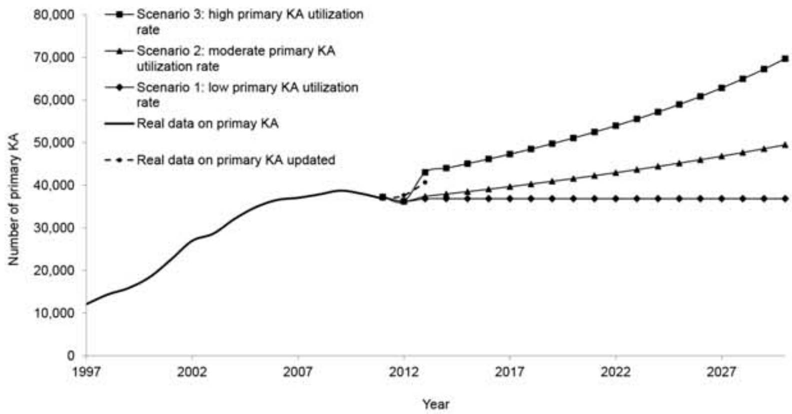
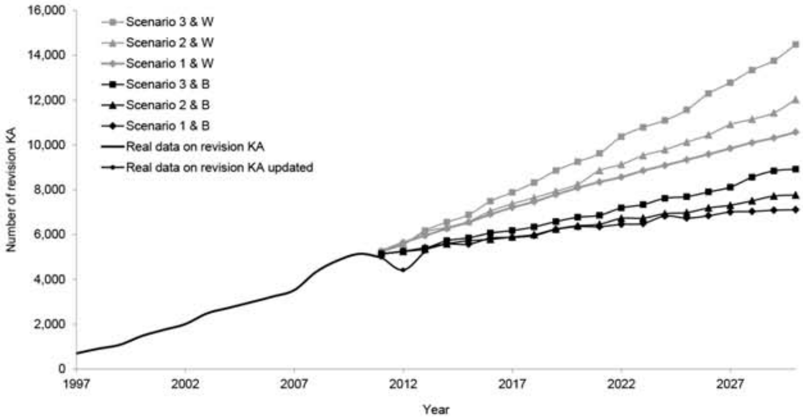


Figure A9: Number of revision KA. Observed values and simulated values according to scenarios of primary KA utilization and prostheses survival.



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