International Orthopaedics (2019) 43:133–138
https://doi.org/10.1007/s00264-018-4165-7

ORIGINAL PAPER

Total knee arthroplasty in Italy: reflections from the last fifteen years and projections for the next thirty

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Received: 31 August 2018 / Accepted: 14 September 2018 / Published online: 6 October 2018

Abstract

Purpose Annual rates of knee arthroplasty are increasing in all developed countries, imposing a significant economic and organizational burden; it is crucial to forecast the future need for knee arthroplasty, to assist stakeholders in planning strategies and investments, especially in a country like Italy, with the largest proportion of elderly citizens in Europe. Few epidemiological studies have been performed worldwide to estimate the demand for future knee replacement, and a variety of methods have been proposed.
Methods We investigated the epidemiology of knee arthroplasty performed in Italy in the last 15 years and projected incidence rates up to the year 2050, utilizing, comparing, and adapting the available methodologies.
Results From 2001 to 2016, 812,639 primary TKA were performed in Italy on patients over 40. The total number of surgeries increased by 262% with an average annual growth rate of 6.6%.
Conclusions Adopting the best fitting projection method, an increase of 45% in incidence rate is expected for 2050.

Keywords Total knee arthroplasty · Epidemiology · Projections · Hospital discharge data

Introduction

Knee osteoarthritis has doubled in prevalence since the mid-twentieth century [1] and keeps growing [2], mostly due to aging and obesity. Physicians, supported by constant improvements in techniques and long-term patient-oriented outcomes [3, 4], are currently offering total knee arthroplasty (TKA) to younger and more demanding individuals affected by knee osteoarthritis [5]. As a result, annual rates of knee arthroplasty have progressively increased in all developed countries and they are projected to keep rising, imposing a significant economic and organizational burden [6, 7]. Therefore, it is crucial to forecast the future need for knee arthroplasty on a local basis, to assist stakeholders to plan strategies and investments, especially in a country like Italy, with the largest proportion of elderly citizens (aged ≥ 65) in Europe of 21.4% [8].

Few epidemiological studies have been performed worldwide to estimate the demand for future knee replacement, and a variety of methods have been proposed; lately, the statistical approach has been refined, especially in order to prevent overestimation of projections [9, 10].

In the present study, we investigated the epidemiology of knee arthroplasty performed in Italy between 2001 and 2016 and projected patient numbers up to the year 2050, utilizing and adapting the available methodologies. No study, to our knowledge, analyzed past and future TKA trends in Italy in detail.

Methods

Data

The National Hospital Discharge Data database (HDD) and the Italian population data were used for this population-based study. Every year, the Italian National Institute of Health

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receives from the Ministry of Health the whole HDD to conduct epidemiological studies in public health; orthopedic implant data are analyzed within the framework of the Italian National Arthroplasty Registry [11]. HDD was browsed and all the primary TKA procedures performed in the period 2001–2016 (ICD9-CM code 81.54), as either principal or secondary procedures, were extracted.

Population data, distinct by age and sex both for resident citizens in the 2001–2017 period and projections to 2065, are available from the Italian National Institute of Statistics (ISTAT, www.istat.it/en/), a public research organization. ISTAT is the main producer of official statistics in the service of citizens and policy-makers and operates in complete independence and continuous interaction with the academic and scientific communities.

According to previous published studies [9, 10], only data of patients aged 40 years or older were considered in the analyses because the number of patients younger than 40 undergoing primary TKA is minimal (0.8% of TKAs in our data).

Statistics

Four alternative projection models were applied to evaluate TKA projections in Italy: logistic regression, Poisson regression, logarithmic regression, inverse/power regression. They are described by the following formulas where y is the TKA volume, and t is the year:

1. logistic regression: $y(t) = \frac{A}{\left(1+e^{\frac{\alpha-t}{\beta}}\right)}$
2. Poisson regression: $y(t) = e^{\alpha + \beta t}$
3. logarithmic regression: $y(t) = \alpha + \beta \ln(t)$
4. inverse/power regression: $y(t) = \alpha + \frac{\beta}{t^{\gamma}}$.

Predictions for volume TKA were made for 2017, then each five years from 2020 to 2050.

In addition, predictions for the incidence rate (IR) were computed. IR is defined as: $IR = \frac{VolumeTKA_{over40}}{Pop_{over40}} \times 100,000$, where $VolumeTKA_{over40}$ is the number of primary TKA performed in patients aged 40 years or older in a specific year and Pop_{over40} is the population over 40.

All analyses were conducted using R-3.5.1.

Results

Historical data

From 2001 to 2016, 818,835 primary TKA were performed in Italy, 812,639 of them on patients aged 40 or older. The total number of surgeries increased by 262% with an average annual growth rate of 6.6%. Historically, the highest average yearly increase in surgical volume was registered in the period 2001–2007 (+ 11.7%), then it slowed down from 2008 to 2013 (+ 2.1%) to accelerate again in the last period (+ 5.6%) (Fig. 1).

Projections

The logistic regression model (Fig. 2a), converges rapidly to its asymptote, to remain steady thereafter (Adj. R-square = 0.9759). Using this model, the incidence rate of TKA is expected to increase only 1% by 2050 compared to 2017.

The Poisson regression model (Fig.2b) delivers projections that quickly diverge to infinite (Adj. R-square = 0.9068). It forecasted, among all the performed models, the highest increase of the incidence rate, 411% by 2050 compared to 2017.

The logarithmic regression model (Fig.2c) shows a better fit than the Poisson and slow-growing predictions (Adj. R-square = 0.9553), with an increase of the incidence rate of 21% by 2050 compared to 2017.

The inverse/power regression model (Fig.2d) delivers the best fit to the data (Adj. R-square = 0.9853) and shows slowly-growing predictions similar to the logarithmic ones with an increase of the incidence rate of 45% by 2050 compared to 2017.

The characteristics of the models are shown in Table 1.

A comparison of the predictions for IR is shown in Table 2 and Fig.3.

Discussion

Reflections on the 2001–2016 historical data

In the 1970s and 1980s, TKA was widely considered a poor operation, leading physicians and patients to choose it only when absolutely necessary [12, 13]. The explosion for TKA happened at least a decade after hip joint in the USA, and other more conservative countries adopted the procedure later. The constant evolution in prostheses designs, surgical techniques [14–17], make TKA today a quality of life changing procedure worldwide, resulting in a rapid annual increase in the late adopting countries: historical data of primary TKA in Italy show that IR doubled in the last 15 years. In 2006, TKAs outperformed total hip arthroplasty (THA) volume for the first time [18]. Present data on TKA adoption in Italy are becoming consistent with the prevalence of osteoarthritis in the population (knee 3.8%, hip 0.85%) [19] and IR registered in other countries (USA, Switzerland, Germany, Australia) [6, 20].

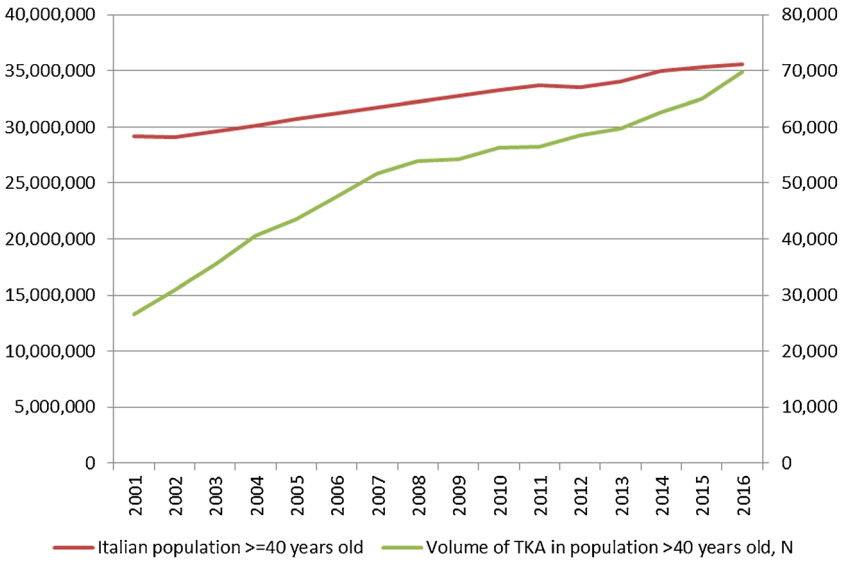

Fig. 1 Italian population aged 40 years or older and primary TKA procedures on patient 40 years and older, 2001–2016

Projections for the next 30 years

The ability to predict future demand of knee arthroplasty is crucial for planning adequate resources and professional workforce.

The growing but still limited literature on the subject has been initially flawed by the use of models that provided unlikely projections [21]. Kurtz et al. updated their previous projections of demand for joint replacement in the United States and found reasonable agreement with the previous

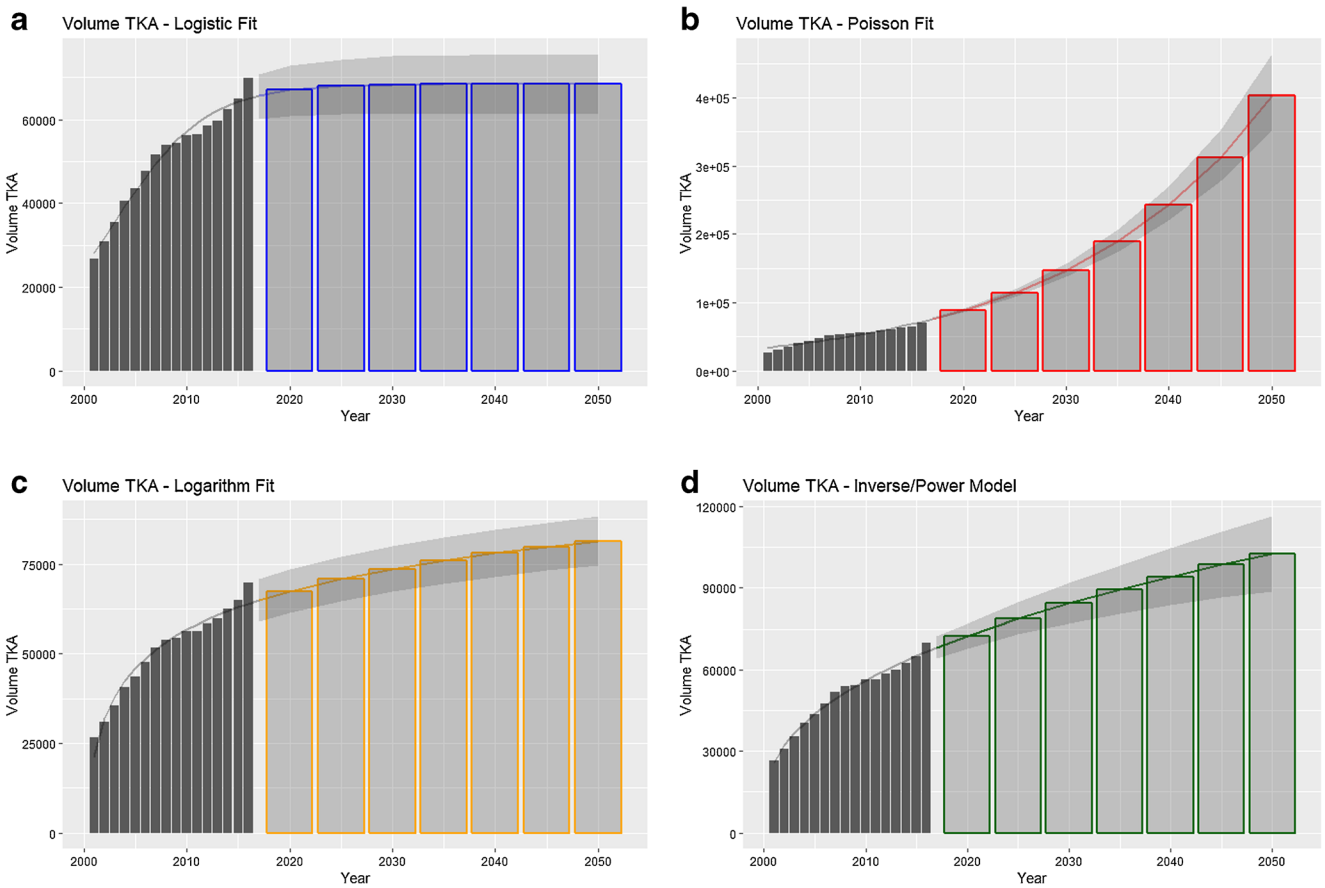

Fig. 2 Historical (2001–2016) and projected (2017–2050) volume and 95% prediction intervals of primary TKA procedures in citizens 40 years and older: **a** logistic model, **b** Poisson regression model, **c** logarithmic regression model, and **d** inverse/power regression model

Table 1 Models characteristics

	Logistic	Poisson	Logarithmic	Inverse/power
Fit type	a/(1+exp.(−(x-b)/c))	exp(a+b∗x)	a+b∗log(x)	a+b/x^c
SSE	5.5756E+07	2.1526E+08	9.3948E+07	3.4018E+07
R-square	0.9759	0.9068	0.9593	0.9853
DFE	13	14	14	13
Adjusted R-square	0.9721	0.9002	0.9564	0.9830

projections, which were based on a more limited dataset [22]. Different methods were then tested by other researchers to generate more biologically plausible predictions [9, 10, 23, 24].

In this study, a comparison of four alternative regression models (logistic regression, Poisson regression, logarithmic regression, inverse/power regression) was performed to evaluate TKA projections in Italy for a population aged 40 years or older.

On the Italian data, logistic regression showed discrete fit. However, differently from previously published data [9], the obtained predictions are unrealistic, since the curve converged rapidly to its asymptote, to remain steady. In the process of data analysis, some adjustments in the estimation procedure were applied to cope with this asymptotic behavior problem, in particular by working on the R functions *SSlogis* and *nls* involved in the model. The first function provides an algorithm to find adequate starting values for the logistic curve, while the second function estimates model parameters with the non-linear least square (nls) algorithm, that iterates to find solutions to minimize the sum of squared residuals and stops when a certain "convergence tolerance" (a very small $\frac{S_k - S_{k+1}}{S_k} < \varepsilon$, where S is the sum of squared residuals) is reached (Gauss-Newton algorithm). Attempts were made to evaluate the estimates' stability to alternative approaches by: (i) reducing the "convergence tolerance" by forcing more algorithm iterations; (ii) using OLS to manually estimate plausible starting values for the algorithm; and (iii) using a different algorithm (Levenberg-Marquardt). However, all these solutions led to similar results, anyhow different from those showed by Inacio et al. [9]. This difference might be explained by the different trends of the historical data. In fact, US data suggest a logistic inflection point around the years 2003–2004 (after this point the growth slows down, while before it was exponential-like), while Italian data do not (and they do not even show initial exponential growth). So, apparently, only the part of the logistic curve after the inflection point is estimated resulting in a steady projection. Poisson regression, which equals assuming infinite resources and constant exponential growth, resulted in unrealistic projection, not dissimilarly from Inacio et al. [9].

The logarithmic regression model shows a better fit than both the logistic and the Poisson, and also more plausible predictions. Finally, the inverse/power, like the logarithmic model, showed more plausible predictions than the logistic and Poisson models. Moreover, it delivered the best fit to the data among the four.

Limitations

This area of research does inevitably present some limitations.

A potential issue arises from the data source used to perform projections. For some papers data are taken from registries, which are certainly a more accurate source [10, 25], while the most part of the studies, including the OECD analyses, used so-called "secondary data", which are potentially less reliable [7, 26].

Our projections are also implicitly limited by the model adopted, which only accounts for past incidence of TKA.

Table 2 Projected annual incidence rate (95%PI) per 100,000 citizens aged 40 years or older, 2017–2050

Year	Logistic		Poisson		Logarithmic		Inverse/Power	
	Projected TKA IR (95% PI)		Projected TKA IR (95% PI)		Projected TKA IR (95% PI)		Projected TKA IR (95% PI)	
2017	183	(168–197)	212	(208–218)	181	(164–198)	190	(179–202)
2020	184	(167–199)	242	(236–251)	185	(168–201)	199	(186–212)
2025	183	(165–200)	307	(293–323)	191	(174–208)	213	(197–228)
2030	183	(164–201)	391	(367–419)	197	(180–214)	226	(206–245)
2035	182	(163–200)	501	(462–546)	202	(185–219)	238	(214–261)
2040	182	(163–200)	644	(584–716)	207	(190–225)	250	(222–278)
2045	182	(163–201)	832	(740–941)	213	(195–231)	262	(230–295)
2050	184	(165–202)	1.078	(942–1,242)	219	(200–237)	275	(238–312)

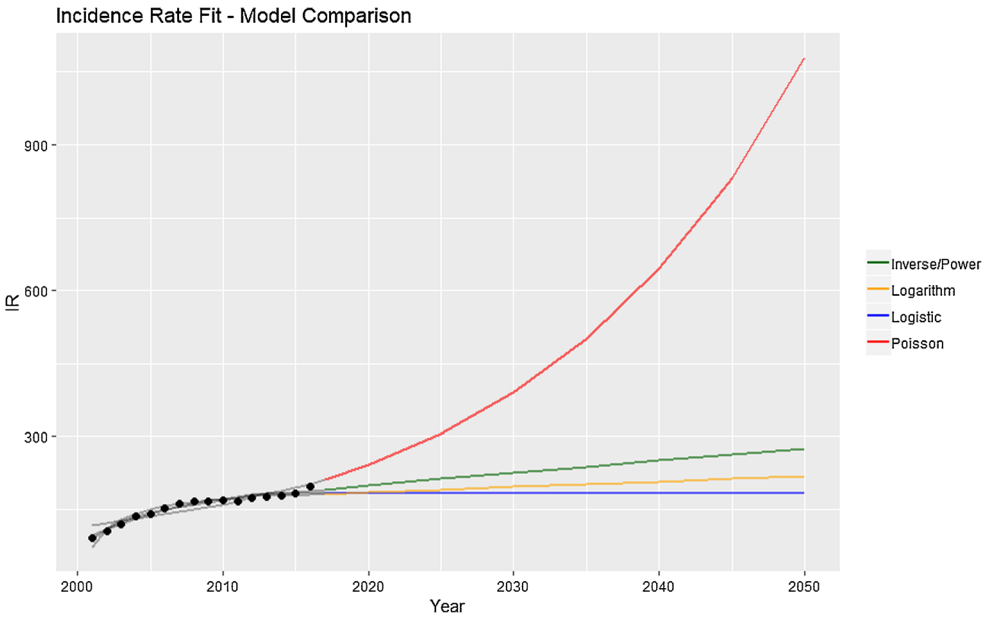

Fig. 3 Historical (2001–2016) and projected (2017–2050) incidence rate (per 100,000) of primary TKA in citizens 40 years and older for all the tested models

Moreover, the accuracy of projection studies is potentially influenced by a number of other factors, only partially known at present. European countries are observing a growing immigration occurrence that might change the expected rates of interventions with the changing population pattern. Indications to surgery also might change, with a broader age spectrum of patients. The known influence of obesity on knee pain and its wide increase in population is alarming, though prevalence is lower in Italy than in other European countries [27, 28]. Finally, joint replacement is presently the treatment of choice for end-stage joint disease; however, research on regenerative strategies might change the horizon in the next future as well as initiatives aimed at teaching OA prevention strategies might reduce the future demand for TKA.

Conclusion

This study supports previous findings that the demand for TKA will keep increasing in the next decades worldwide, Italy included, the major cause being the aging population.

Changes in lifestyle and the availability of new therapeutic approaches to joint pathologies hopefully might slow the process down, reducing the burden on the healthcare system.

The accuracy of projections is potentially weakened by a number of unpredictable factors, therefore a short-term monitoring of the forecast might help confirm the usefulness and the reliability of this kind of analysis.

Acknowledgments The authors wish to thank Mascia Masciocchi and Stefania Ceccarelli.

Authors' contributions Conception and design (ER, MT), acquisition of data (MT, IL, PL), statistical analysis (FD, EC), drafting of the article (ER, MT, FD, GZ, MV). All authors interpreted results, revised critically, and approved the final version of the manuscript.

Funding Francesco Decarolis thankfully acknowledges financial support from the European Research Council (ERC Starting Grant 679217).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent The design of this study did not require any informed consent.

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