

BMJ Open Are joint replacement registries associated with burden of revision changes? A real-world panel data regression analysis

Charles Ebuka Okafor ,¹ Son Nghiem ,² Joshua Byrnes¹

To cite: Okafor CE, Nghiem S, Byrnes J. Are joint replacement registries associated with burden of revision changes? A real-world panel data regression analysis. *BMJ Open* 2023;**13**:e063472. doi:10.1136/bmjopen-2022-063472

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (<http://dx.doi.org/10.1136/bmjopen-2022-063472>).

Received 01 April 2022

Accepted 06 January 2023



© Author(s) (or their employer(s)) 2023. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

¹Centre for Applied Health Economics, School of Medicine and Dentistry, Griffith University, Nathan, Queensland, Australia

²Department of Health Services, Research and Policy, Australian National University, Canberra, Australian Capital Territory, Australia

Correspondence to

Charles Ebuka Okafor;
charles.okafor@griffithuni.edu.au

ABSTRACT

Objectives The association of joint replacement registries with outcomes such as revision burden is uncertain. This study aimed to evaluate whether joint replacement registries are associated with the burden of revision changes while controlling for confounders that could affect the association.

Design A longitudinal study involving a combination of cross-sectional and time series data from 1980 to 2018. The study was a panel regression analysis using the difference-in-difference method.

Setting Data from countries with joint replacement registries and countries without joint replacement registries were used. Registry data were obtained from joint replacement registries' annual reports, while non-registry data were obtained from each included country's pooled hospitals' annual revision burden reported in the literature.

Outcome measures Changes in revision burden from 1980 to 2018 was the outcome measure. The revision burden in the registry periods of registry countries was compared with the non-registry periods of registry and non-registry countries.

Results Data were obtained from 12 registry periods and 8 non-registry periods. The average difference in revision burden in the registry periods of registry countries relative to the non-registry periods of registry and non-registry countries was statistically significant for hip, -3.80 (95% CI -2.50 to -5.10); $p < 0.001$ percentage points and knee, -1.63 (95% CI -1.00 to -2.30); $p < 0.001$ percentage points. This translates to a 19.30%, and 21.85% reduction in revision burden for hip and knee registries, for the whole sampling period.

Conclusion Joint replacement registries are associated with a significant reduction in the burden of revision. Although revision burden reduces over time even without the registries, the establishment of joint replacement registries is associated with an increased reduction. The establishment of joint replacement registries in non-registry countries would be a worthwhile decision as it will further improve the outcomes of arthroplasty surgeries.

INTRODUCTION

The purpose of joint replacement registries (JRR) is to define, improve and maintain the quality of care for patients who undergo

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ This is the first study assess the association of joint replacement registries with burden of revision changes, while controlling for spillover and technological progress effect.
- ⇒ The study was a multicountry analysis, which provides a robust evidence.
- ⇒ The evidence provided in this study can support health policies across countries.
- ⇒ Cumulative revision rate or Kaplan-Meier survival is more reliable measures compared with revision burden.
- ⇒ Revision burden may not be the only yardstick to measure the performance of a registry.

arthroplasty.¹ It aims to establish a voluntary observational data repository for public health safety and monitor device performance.¹ Achieving the purpose of JRR could be associated with a reduction in revision burden. As used in this study, revision is a subsequent operation due to surgical failure of the primary replaced joint, where some or all the original prosthesis components are removed and or replaced, or new components added,¹ while revision burden is the number of revision arthroplasties performed in 1 year divided by the total number of revisions plus primary arthroplasties during the same year.² Since the establishment of the Swedish knee and hip JRR in 1975 and 1979, respectively, over 23 countries have established national or regional JRR, with more countries planning to establish registries.^{3 4}

The association of JRR with outcomes such as revision burden is uncertain. While some countries with JRR have recorded reductions in revision burden,^{1 5-8} other countries without JRR have also reported similar reductions.⁹⁻¹¹ Additionally, in many countries with JRR, the revision burden trend is relatively similar to the period before (preregistry) their JRR establishment.^{2 12 13} Plausible

reasons for the obscured association of JRR with revision burden are the focus of most previous studies on country-level analysis (eg, comparing the preregistry and registry period of a particular registry country), and not controlling for potential confounding factors (eg, technological progress and spillover effect) that could affect revision burden. Given that most registry data of a particular registry country are accessible by surgeons in other countries, there is possibility of knowledge spillover and thus, a country-level analysis may provide bias results of the association of JRR with revision burden. Also, technological progress can lead to improved surgical techniques or improved prostheses design, which can affect revision burden. It could cause non-registry countries to have similar revision burden with registry countries, which could undermine the observed association of JRR with revision burden. It could also cause the registry period of registry countries to have lower revision burden compared with their preregistry period. It is, therefore, pertinent to evaluate the level of association of JRR with revision burden changes in countries with JRR by multi-country comparison using registry and non-registry data while controlling for confounding factors that could affect the association. This study will address the research question: Are JRRs associated with burden of revision changes?

Although crude, and influenced by several factors, revision burden can be used across registries as a simple unit of measure for comparison and quality improvement measure.² Unlike cumulative revision rates for a specific prosthetic cohort, revision burden is a feasible and available measure in the non-registry periods, which can enable registry and non-registry periods comparison within and between countries.²

This study, therefore, aimed to evaluate whether JRR are associated with revision burden changes or not by comparing the revision burden in the registry periods of registry countries to the non-registry periods of registry and non-registry countries using a difference-in-difference approach. The difference-in-difference method was employed because it has the capacity to compare the preperiods and postperiods observations, and control for the confounders.

METHODS

Design, data sources, inclusion and exclusion criteria

The study was a longitudinal study involving a combination of cross-sectional and time series data. The burden of revision data for hip and knee were searched from the year 1980 to 2018. Registry periods data (for registry countries) were collected from each included country's JRR annual reports. Non-registry periods data (for registry and non-registry countries) were obtained from each included country's pooled hospitals annual revision burden reported in the literature. A detailed description of 'registry periods' and 'non-registry periods' is provided in the 'Data categorisation' section. The assessment

focused on hip and knee replacements as it is the most common types of joint replacement procedures.^{1 5}

For non-registry periods data, a country-based study that reported revision burden from pooled hospitals datasets were included. Studies were included if they reported revision burden or the number of primary and the number of revision cases for hip or knee. Reoperations without revision were excluded, and reports for primary knee replacements without revisions were also excluded. The same criteria above were applied for registry periods data collection. The inclusion of registry and non-registry countries in the analysis was based on the number of available observations in the time series (1980–2018) for each country. The observations for each country refer to the revision burden each year from 1980 to 2018. Thus, the maximum expected observation per country was 39. Countries with less than 13 observations in the time series were excluded from the analysis to maintain reasonable df. A description of the search strategy for non-registry periods data is available in online supplemental table 1.

Patients and public involvement

No patient involved.

Data categorisation

Included data were broadly classified either as registry country or non-registry country data. Data for each registry country were further subclassified into a preregistry period and registry period data. For each non-registry country, data were further subclassified into 'corresponding preregistry period' and 'corresponding registry period' data, hereinafter referred to as preregistry and registry period data, respectively. The preregistry period of a registry country refers to the period before their JRR establishment, while the registry period refers to the period after their JRR establishment. For a non-registry country, the preregistry period and registry period, respectively correspond with the preregistry period and registry period, respectively, of a registry country. As different registry countries have different preregistry and registry periods, there is no specific preregistry and registry period for a non-registry country unless when compared with a specific registry country. To enable multicountry comparison, which is an objective of this study, the median registry year (1999) was chosen to define the preregistry period and the registry period for non-registry countries as 1980–1998 and 1999–2018, respectively (see figure 1). The preregistry and registry periods for non-registry countries and the preregistry periods for registry countries are collectively referred to as the non-registry periods (ie, data categories A, C and D in figure 1).

Validation of non-registry data

There was variation in the data sources between the registry periods and non-registry periods, as published data were the most comprehensive data available for the non-registry periods. This underscores the need for

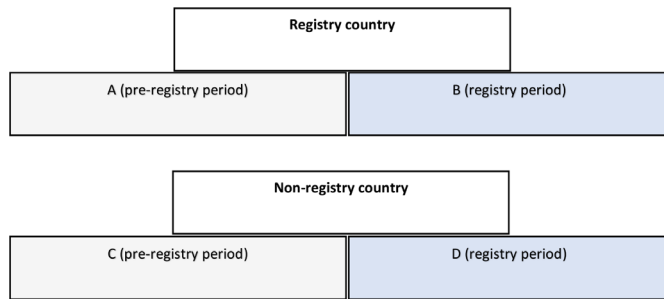


Figure 1 Schematic description of the analysis using the data categories.

non-registry data validation. The non-registry data were validated as follows: First, we ascertained that the data sources were from validated national hospital databases of the included countries. Next, the data were compared and matched to available arthroplasty data, reports and publications from the national hospital databases using the 9th and 10th International Classification of Disease (ICD) codes and the primary diagnosis codes that apply to primary and revision arthroplasties.^{14–17} Non-registry data were also available in some registry reports like the Italian registry, so the registry information was used to compare and match the data used.¹⁸ Data custodians were also contacted for verification and data matching. Data that could not be directly matched were compared and matched using proxied data from the databases such as hospital admission with the following ICD-10 codes: T845, T846, T847, T840, T841, T842, T843, T844, M23, M86, S72, etc.

Analytical approach

A pragmatic approach that compares the revision burden in the registry periods of registry countries to the non-registry periods of registry and non-registry countries from 1980 to 2018 was employed. It was performed by difference-in-difference approach using a panel regression model. Technological progress and spillover effect which could obscure the effect of JRR on revision burden was controlled by a linear trend variable in the model. The linear trend which represents the underlying common technologies and spillover effect that make non-registry and registry countries have similar characteristics regardless of a JRR was estimated in the model by computing the annual revision burden for both country categories and then generating common annual revision burden for both country categories in a straight-line curve. Data curation was performed using a moving average. It involves the estimation of missing data where applicable and the correction of some outliers or acute fluctuations in the time series. The data entry and curation were performed using Microsoft Excel 365 (Microsoft, Seattle, USA), while the data analysis was performed using STATA V.14 (StataCorp). For sensitivity check, the registry period for non-registry countries was defined as 1994–2018; 2003–2018; 2006–2018 and 2012–2018. Estimated parameters with $p < 0.05$ were considered statistically significant. All

analyses were performed separately for hip and knee, respectively.

Model specification

The association of JRR with revision burden changes is specified as:

$$Y_{it} = \beta_0 + \beta_1 R_{it} + \beta_2 P_{it} + \beta_3 T + \beta_4 R_{it} P_{it} + (\alpha_i + \varepsilon_{it})$$

where Y_{it} =revision burden of country i in year t ; R =Registry country; p =Registry period; T =linear trend, due to confounding factors; the asterisk symbol (*) represents the interaction between the variables; α_i represents unobserved time-invariant characteristics of countries that may affect the outcome and ε_{it} is the random noise. The five beta-s, $s=0, 1, 2, 3$ and 4 are the parameters to be estimated, where β_0 is the intercept; β_1 represents the average difference in revision burden between registry countries and non-registry countries; β_2 represents the average difference in revision burden between the preregistry periods of both country categories and the registry periods of both country categories; β_3 represents the annual change in revision burden in the whole sampling period due to the confounders; β_4 (difference-in-difference) represents the average difference in revision burden in the registry periods of registry countries relative to all non-registry periods. Thus, β_4 measures the level association of JRR with revision burden changes.

The estimation was performed using the random-effects and fixed-effects panel-data regression models. The choice of appropriate estimator was determined using the Hausman test. The null hypothesis of the Hausman test assumes no correlation between the regressors and the error terms (residuals). If the null hypothesis is rejected, the fixed-effect estimators will be preferred, as it is more consistent. Otherwise, the random effects estimator will be preferred.

RESULTS

Characteristics of included registry and non-registry periods data

A total of 28 reports for non-registry period data were identified. After screening, only 15 reported revision burden of joint replacements for hip or knee or both from pooled hospitals dataset. Of these, seven data reports were excluded due to lack of observations and non-specificity for hip or knee. So, eight non-registry period data reports (from five registry countries and three non-registry countries) were included. Registry periods revision burden data were obtained from 19 countries, but only 12 countries had sufficient observations for inclusion. Online supplemental figure 1 illustrates the selection process. Online supplemental tables 2 and 3 describe the excluded registry and non-registry periods reports.^{3,9,10,19–29} Tables 1 and 2 present the included non-registry and registry periods data, respectively, after eligibility check. Table 1 describes the characteristics of the data in the non-registry periods, while table 2 describes

**Table 1** Characteristics of data in the non-registry periods

	Period reported	Reported data	Other details	Source
Included reports				
New Zealand	1980–1991	Hip	Preregistry data	34
Iceland	1982–1996	Hip	Country without joint registry	35
USA	1990–2002	Hip and knee	Preregistry data	36
USA	2005–2011	Hip and knee	Preregistry data	21
England/Wales	1991–2000	Hip and knee	Preregistry data	12
Italy	2001–2005	Hip and knee	Preregistry data	13
Spain	1997–2011	Knee	Country without joint registry	11
Taiwan	1998–2009	Hip and knee	Country without joint registry	37

the characteristics of data in the registry periods for registry countries.

Hip and knee registries association with revision burden

The Hausman test failed to reject the null hypothesis of no correlation between the regressors and the residuals for hip ($p=0.41$) and knee ($p=0.33$), respectively. Thus, the random effect estimator is preferred. Coefficients with negative signs indicate a reduction in revision burden, while positive signs indicate an increase (tables 3 and 4).

From 1980 to 2018, the average difference (β_1) in revision burden between registry countries (regardless of when their JRRs were established) compared with non-registry countries was statistically significant for hip -4.57 (95% CI $(-2.34$ to $-6.80)$; $p=0.04$) percentage points, but not for knee -0.05 (95% CI $(1.50$ to $-1.60)$; $p=0.98$) percentage points. On average, registry countries had 4.57 and 0.05 percentage points reduction in revision burden for hip and knee, respectively, relative to non-registry countries for the whole sampling period (tables 3 and 4).

From 1980 to 2018, the average difference (β_2) in revision burden between the preregistry periods (of both country categories) and the registry periods (of both country categories) was statistically significant for hip 2.46 (95% CI $(1.85$ to $3.07)$; $p<0.001$) percentage points, and knee 1.82 (95% CI $(1.52$ to $2.12)$; $p<0.001$) percentage points. On average, the revision burden in the pooled registry periods of both country groups were higher by 2.46 (for hip) and 1.83 (for knee) percentage points relative to the pooled preregistry periods of both country groups for the whole sampling period (tables 3 and 4).

From 1980 to 2018, there was a statistically significant annual decrease (β_3) in revision burden common across both country categories due to the effect of the confounding factors, which was -0.08 (95% CI $(-0.06$ to $-1.00)$; $p<0.001$) percentage points for hip, and -0.03 (95% CI $(-0.02$ to $-0.04)$; $p<0.001$) percentage points for knee. Annually, both registry and non-registry countries experienced a common reduction of 0.08 and 0.03 percentage points for hip and knee revision burden, respectively, due to the confounders (tables 3 and 4, figure 2A,B).

Finally, the association of JRR with revision burden changes which was measured as the average difference in revision burden (β_4) in the registry periods of registry countries relative to all non-registry periods was statistically significant for hip -3.80 (95% CI $(-2.50$ to $-5.10)$; $p<0.001$) percentage points and knee -1.63 (95% CI $(-1.00$ to $-2.30)$; $p<0.001$) percentage points. This translates to a 19.30% and 21.85% reduction in revision burden for hip and knee registries, respectively, for the whole sampling period, when the reduction was compared with the revision burden at the starting time, t_0 (represented by the value of the intercept, β_0). Tables 3 and 4 provide details of the hip and knee registries association with revision burden, while figure 2A,B presents the association in predictive linear trends. Online supplemental figures 2 and 3 present the mean annual burden of hip and knee revisions for registry versus non-registry countries. Further information on the data used for analysis and the results (from the model) is available in online supplemental file 2.

From the sensitivity test, changes in the median registry year of non-registry countries from 1994 to 2012 had no statistically significant effect on hip and knee registries association with revision burden (represented by β_4). For hip registries, the reduction in revision burden as percentage points changed from -4.70 (95% CI $(-3.40$ to $-6.00)$; $p<0.001$) in 1994 to -2.35 (95% CI $(-0.70$ to $-4.00)$; $p=0.004$) in 2012. Whereas for knee registries, the reduction in revision burden changed from -1.23 (95% CI $(-0.60$ to $-1.90)$; $p<0.001$) in 1994 to -2.04 (95% CI $(-1.30$ to $-2.80)$; $p<0.001$) in 2012.

DISCUSSION

This study used existing data on the revision burden for hip and knee replacement to evaluate whether JRR are associated with the burden of revision changes or not from the global perspective from 1980 to 2018. The association of JRR with revision burden changes was measured by comparing the registry periods for registry countries to all non-registry periods (preregistry periods for registry countries and the preregistry and registry periods for

Table 2 Characteristics of data in the registry periods for registry countries

Country	Year registry established	Surgeries reported	Management and participation	Validation and completeness	Reporting style	Source
Included registries						
Sweden	Knee: 1975 Hip: 1979	Hip and knee replacements; knee osteotomy.	MGT: medical society. Both registries managed separately. Participation: voluntary	Validation: yes and continuous. Completeness: primary, 97%; revision, 92%. PROM: 82%	Annual; all-electronic online statistics for knee available; periodic update online.	^{5 30}
Finland	1980	Hip and knee replacements.	MGT: managed by the government since 1993. Participation: mandatory	Validation: yes and continuous. Completeness: primary, 95%; revision, 82%.	Updated daily; all-electronic online report available.	³⁸
Norway	Hip: 1987. Other joints started in 1994. Cruciate ligament: 2004 Hip fracture: 2005 Paediatric hip: 2010	Four-in-one register: joint replacements; hip fracture; cruciate ligament; and paediatric hip	MGT: Norwegian orthopaedic association. Participation: voluntary	Validation: yes and continuous. Completeness: hip: 93% knee: 91% PROM data collection recently initiated.	Annual; updated periodically. Electronic recording surgeon form recently developed for Cruciate ligament registry; also, electronic recording of other procedures available.	³⁹
Denmark	Hip: 1995 Knee: 1997	Hip and knee replacements.	MGT: orthopaedic society. Participation: voluntary	Validation: yes and continuous. Completeness: 94%	Annual; updated periodically; annual report in Danish	^{40 41}
Australia	1999	Hip, knee and shoulder replacements.	MGT: orthopaedic society. Funded by the government. Participation: voluntary	Validation: yes and continuous. Completeness: 97.8% PROM data collection ongoing.	Annual; periodic reporting; online data collection forms.	¹
New Zealand	1999	Hip, knee, shoulder, ankle, elbow, lumbar and cervical disc replacements	MGT: orthopaedic society. Participation: voluntary	Validation: yes and continuous. Completeness: >90% PROM data collection: 70%	Annual; periodic reporting; online data collection forms.	⁸
England/Wales	2003	Hip, knee, shoulder, ankle and elbow replacements.	MGT: government Participation: voluntary	Validation: yes and continuous. Completeness: 96% PROM data: 94%	Annual; periodic update of the registry online. Statistics of procedures updated online	⁷
Romania	2001	Hip and knee replacements; spine and cruciate ligament surgery.	MGT: government Participation: mandatory	Validation: yes and continuous. Completeness: >99%	Annual; monthly update online; statistics updated online	⁶
Slovakia	Hip: 2003 Knee: 2006	Hip and knee replacements.	MGT: government Participation: voluntary	Validation: yes and continuous. Completeness: 100%	Annual; periodic update of the registry online. Statistics of procedures updated online	⁴²

Continued

**Table 2** Continued

Country	Year registry established	Surgeries reported	Management and participation	Validation and completeness	Reporting style	Source
Italy	2006	Hip, knee and shoulder replacements	MGT: government Participation: voluntary. Legal process ongoing to make participation mandatory	Validation: yes and continuous. Completeness: 66%	Annual reporting	¹⁸
France	2006	Hip replacement	MGT: SOFCOT Participation: voluntary	Validation: yes and continuous.	Biennial reporting	⁴³
USA	2012	Hip and knee replacements.	MGT: orthopaedic society. Participation: voluntary	Validation: yes and continuous. Completeness: 86% PROM data collection: 20% and ongoing	Annual	²

MGT, management; PROM, patient-reported outcome measure; SOFCOT, French Society of Orthopaedics and Traumatology.

non-registry countries). The results showed that regardless of when JRRs were established, there was a significant difference in revision burden between the registry countries and non-registry countries for hip, but not for knee (see β_1 in tables 3 and 4) when compared for the whole sampling period (1980–2018). Registry countries, however, had a statistically significant reduction in revision burden when their registry periods were compared with all non-registry periods for both hip and knee (β_4 in tables 3 and 4), which infers that JRR are associated with revision burden changes.

Several factors could be responsible for the significant association of JRR with revision burden reduction. Most JRR monitor the performances of implants and devices and surgical techniques outcomes.^{1 5 7 8 30} This has led to the identification of optimal surgical techniques and prostheses with a low risk of revision. The identification of prostheses with a higher than anticipated risk of revision by countries with JRR leads to an early cessation in the use of these prostheses and the subsequent withdrawal from the countries' market before other countries without JRR. Registries have also supported decision making for the right patient selection. Analysis of data from regional registries of Swiss and Scottish orthopaedic hospitals have shown the effect of cross-cultural variations in arthroplasty outcomes.³¹ Also, most JRRs provide feedbacks to registry participants who are outliers. These feedbacks enable the registry participants to improve on their arthroplasty outcomes especially when the possible causes of their treatment failures are identified from evidence provided by registry data.

Similar to the knee results (for β_1 in tables 3 and 4), an international survey showed that the revision burden in the registry and the non-registry countries were similar.³² Different from our results, a study showed that

revision rates of all clinical studies for specific implants do not differ significantly from revision rates for the same implants from registry data³³ (see β_4 in tables 3 and 4). Although the study³³ did not control for confounding factors, a sound reason for the results difference was that the data we used were not cumulative revision rates for specific implants. Naïve analyses comparing registry countries to non-registry countries only,³² or comparing the preregistry to the registry revision burden of a specific country only¹³ are biased in that the systematic difference between the two country groups,^{32 33} the spillover and technological progress effect,^{13 32 33} and the systematic change in the registry period of both country categories were not assessed.^{32 33}

This study has some limitations. First, the comparison of registry data to non-registry data are a limitation given that the data collection protocol and processes may differ between the preregistry and the registry periods. The effect of this limitation was controlled by non-registry data validation. Performing the analysis using registry data only or the preregistry and registry data from registry countries only would make the study trivial, yield a biased result and nullify the study objective. The use of cumulative revision rate data or Kaplan-Meier survival for a specific prosthetic cohort would have been a better measure for the two periods because it better links the revision arthroplasties to the primary arthroplasties, but this would be impossible due to the lack of cumulative revision rate data or data for a specific prosthetic cohort during the preregistry periods. Hence, we used the burden of revision data which is an available and feasible measure common in the two periods regardless of a registry.² Second, the availability of limited non-registry periods data led to assessment with a few non-registry countries. The effect of this limitation was minimised

Table 3 Hip registries association with revision burden

	Main model				Sensitivity test				
	Registry period for non-registry countries								
	1999–2018		2003–2018		2006–2018		2012–2018		
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	
Intercept (β_0)	0.1917***	0.0206	0.1835***	0.0206	0.1959***	0.0205	0.1978***	0.0205	0.1983***
Registry country (β_1)	-0.0457**	0.0223	-0.0367	0.0224	-0.0512**	0.0223	-0.0541**	0.0223	-0.0548**
Registry periods (β_2)	0.0246***	0.0061	0.0353***	0.0062	0.0143**	0.0063	0.0065	0.0064	0.0053
Trend (β_3)	-0.0008***	0.0002	-0.0009***	0.0001	-0.0006***	0.0002	-0.0005***	0.0002	-0.0005***
Registry period of registry countries (β_4)	-0.0380***	0.0067	-0.0470***	0.0068	-0.0301***	0.0069	-0.0236***	0.0071	-0.0235***
Hausman test									
Test statistics	1.77		1.65		1.93		2.07		2.10
Hausman test p value	0.41		0.44		0.38		0.36		0.35
Two-tailed p values: ***p<0.01, **p<0.05, *p<0.1.									

Table 4 Knee registries association with revision burden

	Main model				Sensitivity test				
	Registry period for non-registry countries								
	1999–2018		2003–2018		2006–2018		2012–2018		
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	
Intercept (β_0)	0.0746***	0.0142	0.0741***	0.0142	0.0756***	0.0142	0.0766***	0.0142	0.0787***
Registry country (β_1)	-0.0005	0.0155	-0.0080	0.0155	-0.0010	0.0154	-0.0021	0.0154	-0.0053
Registry periods (β_2)	0.0182***	0.0030	0.0127***	0.0032	0.0226***	0.0030	0.0245***	0.0030	0.0210***
Trend (β_3)	-0.0003***	0.0001	-0.0002***	0.0001	-0.0003***	0.0001	-0.0003***	0.0001	-0.0002***
Registry period of registry countries (β_4)	-0.0163***	0.0033	-0.0123***	0.0034	-0.0198***	0.0032	-0.0217***	0.0033	-0.0204***
Hausman test									
Test statistics	2.20		2.38		0.68		2.11		2.36
Hausman test p value	0.33		0.30		0.41		0.35		0.31
Two-tailed p values: ***p<0.01, **p<0.05, *p<0.1.									

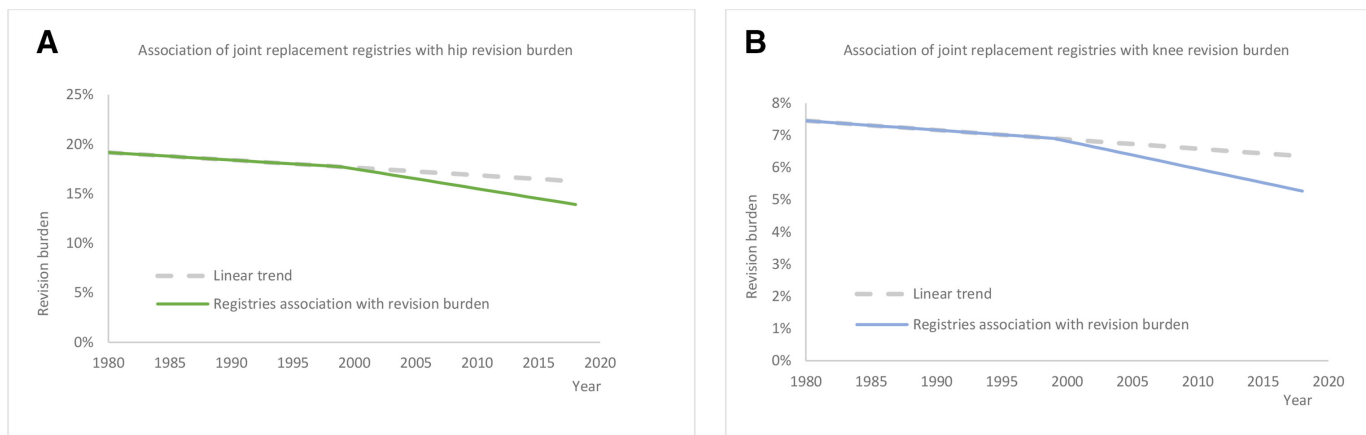


Figure 2 (A) Predictive trend of joint replacement registries association with hip revision burden from 1980 to 2018. (B) Predictive trend of joint replacement registries association with knee revision burden from 1980 to 2018.

by the availability and inclusion of non-registry period data for some registry countries. Third, the analysis did not explore the possible lag and diminishing effect and did not control for the Hawthorne effect of JRR on the burden of revision. After a registry is established, there is an initial period (lag period) of data collection, then analysis and then information dissemination which needs to occur before there is behaviour change among arthroplasty surgeons, regulators and prosthesis suppliers. This period was not considered in order to measure revision burden changes. Also, the assumption that the JRR effect on revision burden may have diminishing returns in the future was not tested. Similarly, the Hawthorne effect on surgeons' behaviour which could affect revision burden in JRR would have been controlled for by discarding the early observation period data. Although the effect of the Hawthorne and lag effect was minimised by the linear trend variable in the model, a much longer registry time horizon would be required to better control for the lag and Hawthorne effect.

CONCLUSION

JRRs are associated with a significant reduction in revision burden. Sustaining the management system of JRR is important to support clinical decision making on arthroplasties which will maintain positive outcomes. While some countries without JRR have also experienced a reduction in revision burden, their establishment of JRR would be a worthwhile decision as it will further improve arthroplasties' outcomes.

Acknowledgements The authors are grateful to the data custodians of registries and non-registry databases for their information and data provided.

Contributors CEO, SN and JB were responsible for conceptualisation. CEO and SN developed the study design and model, inclusion and exclusion. CEO did the literature search and data extraction. JB and SN reviewed the search and data collected. CEO, JB and SN contributed to the synthesis and data analyses. CEO wrote the first draft of the manuscript. JB and SN revised the manuscript. All authors reviewed the final manuscript. CEO is responsible for the overall content as the guarantor.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as online supplemental information.

Supplemental material This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

ORCID iDs

Charles Ebuka Okafor <http://orcid.org/0000-0002-7048-910X>

Son Nghiem <http://orcid.org/0000-0002-2451-5290>

REFERENCES

- 1 Australian Orthopaedic Association. Joint replacement annual report, 2020. Available: <https://aoanjrr.sahmri.com/annual-reports-2020> [Accessed 15 Apr 2021].
- 2 American Academy of Orthopaedic Surgeons. American joint replacement Registry-2019 report, 2019. Available: <http://connect.ajrr.net/2019-ajrr-annual-report> [Accessed 20 Jun 2020].
- 3 Ceyhan E, Gursoy S, Akkaya M, et al. Toward the Turkish national registry system: a prevalence study of total knee arthroplasty in turkey. *J Arthroplasty* 2016;31:1878–84.
- 4 ISAR. International Society of arthroplasty registries, 2021. Available: <https://www.isarhome.org/> [Accessed 8 Jan 2021].
- 5 Lund University. The Swedish Knee Arthroplasty Register - Annual report, 2020. Available: <https://stat.myknee.se/?lang=en> [Accessed 15 May 2020].
- 6 Romanian Ministry of Health. Romanian arthroplasty register, 2020. Available: <https://www.rne.ro/rne/informatii/> [Accessed 15 Jun 2020].

- 7 The National Joint Registry Steering Committee. National joint Registry for England, Wales, Northern Ireland and the Isle of Man, 2019. Available: <https://reports.njrcentre.org.uk/> [Accessed 10 Jun 2020].
- 8 New Zealand Orthopaedic Association. Joint Registry report, 2020. Available: <https://nzoa.org.nz/nzoa-joint-registry> [Accessed 15 Jun 2020].
- 9 Koh IJ, Kim TK, Chang CB, *et al.* Trends in use of total knee arthroplasty in Korea from 2001 to 2010. *Clin Orthop Relat Res* 2013;471:1441–50.
- 10 Leitner L, Türk S, Heidinger M, *et al.* Trends and economic impact of hip and knee arthroplasty in central Europe: findings from the Austrian national database. *Sci Rep* 2018;8:6–10.
- 11 Guerrero-Ludueña RE, Comas M, Espallargues M, *et al.* Predicting the burden of revision knee arthroplasty: simulation of a 20-year horizon. *Value Health* 2016;19:680–7.
- 12 Dixon T, Shaw M, Ebrahim S, *et al.* Trends in hip and knee joint replacement: socioeconomic inequalities and projections of need. *Ann Rheum Dis* 2004;63:825–30.
- 13 Torre M, Romanini E, Zanoli G, *et al.* Monitoring outcome of joint arthroplasty in Italy: implementation of the National registry. *Joints* 2017;05:070–8.
- 14 National Center for Health Statistics. National hospital discharge survey, 2021. Available: https://www.cdc.gov/nchs/nhds/nhds_publications.htm [Accessed 10 Apr 2021].
- 15 NHS Digital. Hospital episode statistics, 2021. Available: <https://digital.nhs.uk/data-and-information/data-tools-and-services/data-services/hospital-episode-statistics> [Accessed 6 Mar 2021].
- 16 Ministerio de Sanidad. Hospital discharge record in the National health system, 2021. Available: <https://www.sanidad.gob.es/en/estadEstudios/estadisticas/cmbdhome.htm> [Accessed 15 Mar 2021].
- 17 Ministry of Health and Welfare Taiwan. National health insurance research database, 2014. Available: <https://nhird.nhri.org.tw/en/> [Accessed 8 Mar 2021].
- 18 Italian National Institute of Health. Italian arthroplasty registry, 2018. Available: <http://riap.iss.it/riap/en/> [Accessed 17 Jun 2020].
- 19 Villanueva-Martinez M, Hernandez-Barrera V, Chana-Rodríguez F, *et al.* Trends in incidence and outcomes of revision total hip arthroplasty in Spain: a population based study. *BMC Musculoskelet Disord* 2012;13:37.
- 20 Yoon PW, Lee Y-K, Ahn J, *et al.* Epidemiology of hip replacements in Korea from 2007 to 2011. *J Korean Med Sci* 2014;29:852–8.
- 21 Wengler A, Nimptsch U, Mansky T. Hip and knee replacement in Germany and the USA: analysis of individual inpatient data from German and US hospitals for the years 2005 to 2011. *Dtsch Arztebl Int* 2014;111:407–16.
- 22 De Carvalho RT, Canté JCL, Lima JHS, *et al.* Prevalência de artroplastia de joelho no estado de São Paulo entre 2003 E 2010. *Sao Paulo Med J* 2016;134:417–22.
- 23 Canadian Institute for Health Information. Canadian joint replacement registry, 2018. Available: <https://www.cihi.ca/en/canadian-joint-replacement-registry-cjrr> [Accessed 21 Jun 2020].
- 24 EPRD. German arthroplasty registry, 2020. Available: <https://www.eprd.de/en/> [Accessed 19 Jun 2020].
- 25 Orthopride. Belgian hip and knee arthroplasty registry, 2015. Available: <https://www.ehealth.fgov.be/file/view/5fca367bad5fd36bf017d1363087849a> [Accessed 15 Oct 2021].
- 26 Netherlands Orthopaedic Association. Dutch arthroplasty register, 2020. Available: <https://www.lroi-report.nl/> [Accessed 10 Sep 2021].
- 27 Pakistan Arthroplasty Society. Pakistan arthroplasty register, 2020. Available: <https://www.arthroplasty.org.pk/> [Accessed 13 Oct 2021].
- 28 Portuguese Society of Orthopaedics and Traumatology. Portuguese arthroplasty register. Available: <http://www.rpa.spot.pt/Quick-Links/Home.aspx?lang=en-GB> [Accessed 12 Sep 2021].
- 29 SIRIS. The Swiss national joint registry, 2020. Available: <https://www.siris-implant.ch/en/home> [Accessed 9 Sep 2021].
- 30 Department of Orthopaedics Sahlgrenska University Hospital. The Swedish national hip arthroplasty register: annual report, 2018. Available: <https://shpr.registercentrum.se/in-english/annual-reports/p/rkeyyeElz> [Accessed 9 Jun 2020].
- 31 Giesinger JM, Giesinger K, Federico B, *et al.* Differences in case mix and outcomes between Swiss and Scottish total knee arthroplasty patients. *Knee Surg Sports Traumatol Arthrosc* 2020;28:1797–804.
- 32 Kurtz SM, Ong KL, Lau E, *et al.* International survey of primary and revision total knee replacement. *Int Orthop* 2011;35:1783–9.
- 33 Pabinger C, Berghold A, Boehler N, *et al.* Revision rates after knee replacement. Cumulative results from worldwide clinical studies versus joint registers. *Osteoarthritis Cartilage* 2013;21:263–8.
- 34 Poon PC, Rennie J, Gray DH. Review of total hip replacement. The Middlemore Hospital experience, 1980–1991. *N Z Med J* 2001;114:254–6.
- 35 Ingvarsson T, Hägglund G, Jónsson H, *et al.* Incidence of total hip replacement for primary osteoarthritis in Iceland 1982–1996. *Acta Orthop Scand* 1999;70:229–33.
- 36 Kurtz S, Mowat F, Ong K, *et al.* 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.
- 37 Kumar A, Tsai W-C, Tan T-S, *et al.* Temporal trends in primary and revision total knee and hip replacement in Taiwan. *J Chin Med Assoc* 2015;78:538–44.
- 38 National Institute of Health and Welfare. Finnish arthroplasty register online, 2018. Available: <https://www2.thl.fi/endo/report/#html/welcome> [Accessed 9 Jun 2020].
- 39 Norwegian National Advisory Unit on Arthroplasty and Hip Fractures. Annual report, 2019. Available: <http://nrlweb.ihelse.net/eng/> [Accessed 10 Apr 2021].
- 40 Regionernes Kliniske KvalitetsudviklingsProgram. Danish knee arthroplasty register, 2018. Available: <https://www.sundhed.dk/sundhedsfaglig/kvalitet/kliniske-kvalitetsdatabaser/planlagt-kirurgi/knaealloplastikregister/> [Accessed 18 Jun 2020].
- 41 Aarhus University. The Danish hip arthroplasty register, 2019. Available: <http://danskhoftalloplastikregister.dk/en/publications/annual-reports/> [Accessed 18 Jun 2020].
- 42 Slovak Ministry of Health. The Slovak arthroplasty register, 2019. Available: <https://sar.mfn.sk/pracoviska> [Accessed 10 Jun 2020].
- 43 SOFCOT. Total hip arthroplasty register, 2021. Available: https://www.swissrdl.unibe.ch/registries/french_hip_arthroplasty_sofcot/index_eng.html [Accessed 16 Feb 2022].