International Outcomes of Total Hip Arthroplasty

Influence of Patient, Implant, and Surgical factors on Total Hip Arthroplasty Survivorship in Australia, Sweden, and the US

Elizabeth Walton-Paxton

UNIVERSITY OF GOTHENBURG

Department of Orthopedics
Institute of Clinical Sciences
at Sahlgrenska Academy
University of Gothenburg
Sweden

2019

International Outcomes of Total Hip Arthroplasty

Liz.W.Paxton@gmail.com

Typeset by Team Media Sweden AB
Cover illustration by Pontus Andersson, Pontus Art Production
Printed in Gothenburg, Sweden 2019
BrandFactory AB

ISBN: 978-91-7833-478-0 (PRINT)
ISBN: 978-91-7833-479-7 (PDF)
http://hdl.handle.net/2077/59553

Contents

"Find a group of people
who challenge and inspire you,
spend a lot of time with them,
and it will change your life."

Amy Poehle

Dedicated to my son Brett, my Dad and Elecia,
and my wonderful husband Stephen who continually
support and love, inspire and challenge me
to achieve and succeed in life

List of papers

This thesis includes the following papers:

I. **Meta-analysis of individual registry results enhances international registry collaboration.**
Paxton EW, Mohaddes M, Laaksonen I, Lorimer M, Graves SE, Malchau H, Namba RS, Kärrholm J, Rolfson O, Cafri G.
Acta Orthop. 2018 Aug;89(4):369–373.

II. **An international comparison of THA patients, implants, techniques, and survivorship in Sweden, Australia, and the United States.**
Paxton EW, Cafri G, Nemes S, Lorimer M, Kärrholm J, Malchau H, Graves SE, Namba RS, Rolfson O.
Acta Orthop. 2019 Apr;90(2):148–152.

III. **Do implants matter? An international comparison of Exeter and Summit THA survivorship in Sweden, Australia, and the US.**
Paxton EW, Cafri G, Lorimer M, Kärrholm J, Malchau H, Graves SE, Namba RS, Rolfson O.
In Manuscript

IV. **Predictors of total hip arthroplasty revision in the US, Australia, and Sweden.**
Paxton EW, Cafri G, Bülow E, Lorimer M, Kärrholm J, Graves SE, Malchau H, Namba RS, Rolfson O.
In Manuscript

V. **Patient risk factors of total hip arthroplasty revision in patients with osteoarthritis.**
Paxton EW, Cafri G, Kärrholm J, Malchau H, Namba RS, Rolfson O.
In Manuscript

Abbreviations

Abbreviation	*Definition*
AOANJRR	Australian Orthopaedic Association National Total Joint Registry
ASA Class	American Association of Anesthesiologist Physical Status Classification System
BMI	Body Mass Index
EHR	Electronic Health Record
ICD-9-CM	International Classification of Diseases, 9th revision, Clinical Modification
ICOR	International Consortium of Orthopaedic Registries
KP	Kaiser Permanente
NOV	Nederlandse Orthopaedische Vereniging Classification of Orthopaedic Implants (Netherlands)
OA	Osteoarthritis
ODEP	Orthopaedic Device Evaluation Panel (UK)
PLAC	The Prostheses List Advisory Committee (Australia)
PROMs	Patient Reported Outcomes Measures
RCT	Randomized Clinical Trial
SHAR	Swedish Hip Arthroplasty Register
THA	Total Hip Arthroplasty

Abstract

Background

Hip osteoarthritis (OA) is debilitating disease resulting in pain, stiffness, and reduced physical function. Although total hip arthroplasty (THA) is a successful treatment for OA, some THAs require revision surgery due to infection, dislocation, aseptic loosening, fracture and other reasons. Numerous factors influence the success of THA including patient, surgical, hospital and implant factors. Understanding the influence of these factors on THA risk of revision is critical for prevention of revision surgery.

Internationally, arthroplasty registries play a critical role in identifying patient and clinical practices at higher risk for THA revision surgery. Several national and regional arthroplasty registries exist worldwide. Collaborations of these registries provide an opportunity to evaluate differences in patients, clinical practices, risk factors, and outcomes between countries.

Objective

The purpose of this thesis was to examine variation in patient, surgical, implant characteristics, and THA outcomes in Sweden, US and Australia to identify THA risk factors and clinical best practices. The five studies in this thesis investigated:

1. Meta-analysis as an alternative to individual patient data analysis by comparing the risk of revision of porous tantalum cups versus other uncemented cups in primary total hip arthroplasties from Sweden, Australia, and a US cohort.
2. Variation in patient characteristics and co-morbidities, surgical approach, implant characteristics, hospital settings and THA revision rates between Sweden, Australia, and the US to identify differences in practices and opportunities for improving THA outcomes internationally.
3. Implant-specific sources of variation in THA implant survival across the US, Sweden, and Australia by examining implant survival of Exeter and Summit THAs.
4. Patient, implant, clinical practices and hospital predictors of THA revision in Sweden, Australia, and the US.
5. The influence of more granular patient-related factors (i.e., age, gender, body mass Index, and comorbidities) on THA risk of revision in a US healthcare setting

Patients and methods

Primary THAs with an OA diagnosis were identified using the Swedish, Australian, and Kaiser Permanente registries. The study time period was 2003–2015 for studies I, II, and III. Study IV's timeframe was 2001–2016 and study V's time period was 2008–2016. Kaplan Meier statistics were used to assess time to revision with censoring for death and loss to follow-up. Multivariable cox regression models were used to identify patient, implant, surgical, and hospital factors associated with revision surgery.

Results

Patient-level data analysis and meta-analytic approaches yielded the same results with the porous tantalum cups having a higher risk of revision than other uncemented cups. Patients, implants and surgical practices differed between the countries. Sweden's 5- and 7-year THA survival was higher than Australia and the US. However, when patient characteristics, fixation and implants were controlled for THA survival was similar between countries. Predictors of THA revision also differed by country. In the US cohort, increased number of comorbidities and certain comorbidities had higher risk of all cause, revision due to dislocation, and septic revision.

Conclusion

Meta-analysis is a viable method for enhancing international registry collaboration. In comparing THA survival across countries, implant selection plays a critical role. Predictors of THA revision differ between countries most likely due to variation in clinical practices and implant selection. The number of patient co-morbidities and higher risk comorbidities should be considered by surgeons and patients prior to THA surgery.

Key words: Total Hip Arthroplasty Survival, Revision Risk Factors, Meta-analysis, Arthroplasty Registries, Variation in International Practices

Background and introduction

Osteoarthritis (OA) is a leading cause of disability worldwide (Cross et al., 2014, Johnson and Hunter 2014, Palazzo et al. 2016). OA occurs when cartilage in the joint degrades resulting in pain, stiffness, and reduced physical functioning. While early stages of hip OA can be treated with non-surgical treatment such as physical therapy, anti-inflammatory and pain medicine, total hip arthroplasty (THA) is a successful treatment for advanced stage OA. Specifically, patients with OA who undergo THA report reduction in pain and stiffness and improvement in physical function (Bachmeier et al. 2001, Rolfson et al. 2011). The procedure also has good long-term success with approximately 85% of THA procedures lasting for 20 years (Berry et al. 2002, SHAR 2014, Kawamura et al. 2016, Petheram et al. 2016). Despite this longevity, some patients require revision surgery due to dislocation, infection, fracture, aseptic loosening, and other problems (Garellick et al. 2014, Garellick et al. 2016, Malchau et al. 2018). Not only is revision surgery associated with increased risk of complications such as infection, venous thromboembolism and mortality (Mahomed et al. 2003, Khatod et al. 2006, Badarudeen et al. 2017), complex THA revision procedures are costly and the demand for revision surgery is projected to increase significantly over the next decade (Kurtz et al. 2009, Nemes et al. 2014). In order to manage this increased demand and reduce complications and mortality associated with revision surgery, identification of patients, implants, surgical techniques, and hospital settings associated with increased risk of THA revision is critical for prevention of THA revision surgery.

Patient factors

Parallel with the increased volume of THA surgery, the prevalence of obesity and multiple comorbidities in THA patients has increased dramatically (Cram et al. 2011, Kirksey et al. 2012, Singh and Lewallen 2014, Cnudde et al. 2018). As the numbers of THA patients with multiple comorbidities increases, it is necessary to understand the risk of revision for these patients.

Numerous studies have examined patient factors and comorbidities associated with risk of THA revision. Prior studies have evaluated gender, body mass index (BMI), age, socio-economic factors, race and a wide range of co-morbidities as predictors of THA revision (Santaguida et al. 2008, Prokopetz et al. 2012, Wright et al. 2012, Bozic et al. 2014, Dy et al. 2014). However, findings from these studies are inconsistent and limited due to methodological issues such as dependency on administrative and claims-based data, coding inaccuracies, lack of validated outcomes, inclusion of Medicare patients only, and use of different measures and definitions of comorbidity.

Co-morbidity indexes such as Anesthesia Society Association (ASA) physical status classification system (Doyle and Garmon 2019), Charlson comorbidity index (Charlson et al. 1987) and Elixhauser comorbidity index (Elixhauser et al. 1998) have also been used to evaluate the relationship between co-morbidities and THA outcomes. These studies report conflicting results most likely related to assessment of different endpoints and use of differ indexes and definitions of co-morbidity (Gordon et al. 2013, Jamsen et al. 2013, Khatod et al. 2014). In evaluating the effect of age and gender on risk of THA revision, many studies suggest younger age and male gender are associated with increased risk of revision (Liu et al. 2015, Wagner et al. 2016, Hanna et al. 2017, Jeschke et al. 2018) suggesting these are also critical patient factors to consider in evaluating risk of THA revision.

Comparisons of patient risk factors have not been fully examined across countries. Further evaluation of such risk factors across countries is important to identify those that are potentially modifiable with aim to reduce number of future revisions.

Surgical and implant characteristics

In addition to patient characteristics, surgical approach has been reported as a risk factor for THA dislocation and revision. While approach may have more of an influence on dislocation, the influence on THA revision requires further evaluation (Sheth et al. 2015). THA cement fixation is another area that requires additional assessment. While some studies report increased risk of uncemented implants, others report increased risk of cemented fixation (Morshed et al. 2007, Corbett et al. 2010, Prokopetz et al. 2012).

Implant characteristics such as implant material and femoral head size have also been identified as influencing THA revision. For example, highly crosslinked polyethylene THA liners have been reported as having improved longevity compared to conventional polyethylene (Paxton et al. 2014, Paxton et al. 2015, de Steiger et al. 2018). Femoral head size is another important factor in revision with larger head size reported as having lower risk of revision due to dislocation (Sheth et al. 2015). The influence of these implant characteristics and others on THA dislocation and revision needs to be examined in the context of patient, surgical and hospital characteristics..

Hospital settings and annual THA volume

Similarly, health care settings appear to play a role in THA outcomes with lower hospital volume, rural hospitals, and health insurance status associated with increased risk of complications and revision (Dy et al. 2014). Understanding the types of healthcare settings and factors associated with THA revision allows identification of potentially modifiable risk factors.

New technology adoption across countries

While patient, implant, surgical and hospital setting have been examined in relationship to THA, the broader context of medical device regulation and technology adoption has not been thoroughly investigated. New technology is constantly introduced into the market with little evidence of clinical effectiveness. Early on, Sweden streamlined the number of THA devices used in the country. In addition, the Australian Registry reported no improvement and even higher risk of revision with new technology (Anand et al. 2011). The variation in new technology adoption and subsequent impact on THA outcomes is of interest for all stakeholders.

While variation in THA devices utilization is limited in Sweden, there has been wider adoption of new technology in the United States and Australia. Understanding the impact of new technology adoption in these different countries and the impact on THA revision will provide additional opportunities to enhance THA outcomes.

Arthroplasty registries

Patient registries are defined as "an organized system that uses observational study methods to collect uniform data (clinical and other) to evaluate specified outcomes for a population defined by a particular disease, condition, or exposure, and that serves one or more predetermined scientific, clinical, or policy purposes" (Gliklich et al. 2010). Registries provide a mechanism to evaluate patient, implant, surgical, hospital and country factors associated with THA outcomes. Although randomized clinical trials are recognized as a higher level of scientific evidence, observational studies such as those using patient registries provide real-world evidence based on a wide range of patients, procedures, implants, surgeons and hospitals settings without the strict inclusion and exclusion criteria typically associated with Randomized Clinical Trials (RTCs). Registries also provide an opportunity to monitor longitudinal outcomes which often is not feasible with clinical trials. In addition, registries based on large populations have the statistical power to detect differences in low adverse events unlike smaller clinical trials. Finally, registries offer an opportunity to study clinical questions when randomized trials are not practical, cost prohibitive or unethical (Inacio et al. 2016). In addition to identifying variation, registries provide an important role in quality assurance. Arthroplasty registries have a long history of improving quality of care in orthopedics. Sweden was the first country to establish national knee and hip arthroplasty registers to monitor arthroplasty outcomes and provide feedback on techniques and implants. The continuous feedback provided by SHAR has resulted in changes in clinical practices such as cement techniques, and low revisions rates providing a model for other countries (Herberts and Malchau 1999, Herberts and Malchau 2000)

Based on Sweden's success, national arthroplasty registries have developed in other countries. Australia's large national total joint registry has played a key role in identifying implants at higher risk for revision thus affected quality of care internationally (Graves 2010). Regional registries such as the Kaiser Permanente National total joint registry in the US have also been modeled after the SHAR for quality improvement in an integrated healthcare system (Paxton et al. 2012). The Swedish, Australian, and Kaiser Permanente Registries are full members of the International Society of Arthroplasty Registries and meet the standards of a quality making them ideal for evaluating the impact of patient, implant, surgical, hospital characteristics, and regulatory settings on THA outcomes.

International collaborations of registries with high quality data provide an opportunity to identify THA variation in patients, implants, techniques, and outcomes across countries potentially leading to identification of clinical best practices and enhancement of THA quality of care worldwide. Despite the potential benefits of international collaborations, comparisons across countries has been limited due to concerns about sharing data, privacy issues, data ownership concerns, regulatory issues, lack of standardized definitions and variables, and methodological differences between registries.

The Nordic Arthroplasty Register Association (NARA) is one of the few examples of international comparisons of registry practices and outcomes. Through the development of a minimum common dataset, NARA compared patient, practices and THA outcomes of Norway, Sweden, Denmark and Finland. NARA identified variation among these countries in patient demographics, surgical approaches, cement fixation, and implants (Havelin et al. 2011). International Consortium of Orthopaedic Registries (ICOR) an FDA initiative, did utilize data across 6 international registries to examine bearing types (Paxton et al. 2014). However, ICOR did not conduct comparisons across countries' risk factors and outcomes, which is necessary to identify clinical best practices and opportunities for improving care worldwide. Expansion of comparisons across additional countries could further identify clinical practices and risk factors associated with THA revision.

Aims

The purpose of this thesis was to examine the variation in patient, surgical, implant characteristics, and THA outcomes in Sweden, US and Australia to identify best practices for enhancing THA outcomes. The specific aims included

- The investigation of meta-analysis as an alternative to individual patient data analysis by comparing the risk of revision of porous tantalum cups versus other uncemented cups in primary total hip arthroplasties from Sweden, Australia, and a US cohort. This study provides the methodological foundation for the other collaborative studies.
- Assessing variation in patient characteristics and co-morbidities, surgical approach, implant characteristics, hospital settings and THA revision rates between Sweden, Australia, and the US to identify differences in clinical practices and opportunities for optimizing THA outcomes.
- Identifying implant-specific sources of variation in THA survival comparing Sweden, Australia, and the US.
- Comparing patient, implant, surgical, and hospital predictors of THA revision in Sweden, Australia and the US.
- Examining the influence of patient-related factors such as age, gender, obesity and co-morbidities on THA risk of revision in a US health care setting.

Patients and methods

Patients with primary THA were identified using the Swedish (SHAR 2017), Australian (AOANJRR 2017), and Kaiser Permanente Registries (Paxton et al., 2012).

The Swedish Hip Arthroplasty Register (SHAR)

The SHAR was developed in 1979 and registers over 17 thousand new procedures each year. The SHAR collects data on patients, techniques, revision and re-operation rates as well as patient reported outcomes. Most of data are collected through a web-based system. Completeness of the SHAR is evaluated through linkage to the Patient Register at the National Board of Health and Welfare. All registered reoperations are checked by the SHAR register coordinators who document reoperations based on admission and discharge and surgical reports. The registry has high quality data based on complete coverage and completeness of about 98% (SHAR 2017).

Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR)

The AOANJRR was established in 1999 and tracks over 1.4 million arthroplasty procedures. This registry captures data using a paper-based system and validates capture of procedures through cross referencing of other national databases. The AOANJRR captures similar data as the SHAR including patient information, implant details, surgical techniques, revision and reasons for revision. The AOANJRR also has complete coverage of the country, minimal loss to follow-up and minimal missing data (AOANJRR 2017).

Kaiser Permanente (KP) National Total Joint Replacement Registry

The Kaiser Permanente total joint registry was established in 2001 and monitors arthroplasty procedures for the 12 million members of this US integrated healthcare system in 8 regions of the United States. The registry was developed as a quality assurance mechanism to track total joint procedures, identify patients at risk for complications and revisions, assess implant performance and identify clinical best practices (Paxton et al. 2012). The KP registry currently tracks over 400,000 total joint replacement procedures to date. This registry uses standardized Electronic Health Record (EHR) documentation at the point of care to capture patient, surgical techniques, implant characteristics and outcomes. The healthcare system's integrated EHR allows linkage of the registry variables and chart review validation of all registry THA outcomes including complications, mortality, and revision THA. The registry has over 95% capture of the patients in the healthcare system, less than 8% loss to follow-up over 17 years, and minimal missing data (Paxton et al. 2012).

Registry variables and definitions were standardized across the three registries (**Table 1**). Patients were identified using the three registries.

Research protocols with inclusion and exclusion criteria were developed for each study based on input from registry collaborators.

A distributed data approach in which SAS programs were developed at Kaiser Permanente and distributed to the other registries to apply to their own data was used. The other registries then provided aggregate level data including descriptive statistics, survival probabilities to Kaiser Permanente for analyses (**Figure 1**).

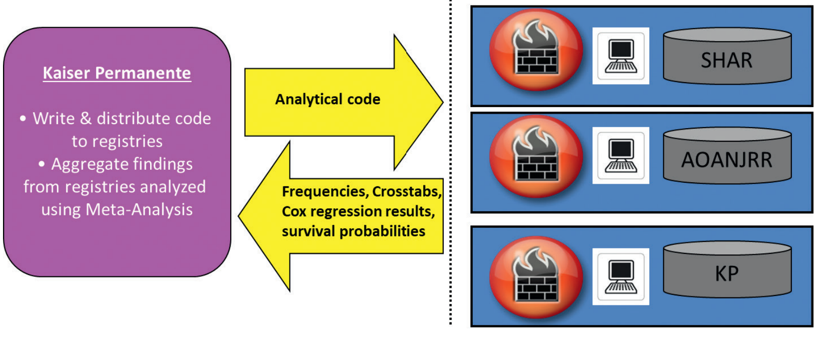

Figure 1. Distributed data network approach

Table 1. Standardized patient, surgical, implant, hospital and outcome variables

Patient factors	**KP**	**AU**	**Sweden**
Age at primary THA	X	X	X
Date of procedure	X	X	X
Diagnosis	X	X	X
Gender	X	X	X
BMI <30, 30–35 >35	X	X	X
Co-morbidities			
Elixhauser Index (1 year prior and during primary THA admission)	X		X*
ASA class			
1–5	X	X	X
Surgical factors			
Surgical approach Anterolateral Direct lateral Posterior Anterior Other	X	X	X
Hospital factors			
Annual hospital THA case volume	X	X	X
Implant factors			
Femoral head size	X	X	X
Fixation Cemented Uncemented Hybrid	X	X	X
Bearing surface (created) Metal on metal Metal on conventional Metal on highly crosslinked Ceramic on ceramic Ceramic on conventional Ceramic on highly crosslinked	X	X	X
Cup material, reference number, description, company, model name	X	X	X
Liner material, reference number, description, company, model name	X	X	X
Femoral head material, reference number, description, company, model name	X	X	X
Stem material, reference number, description, company, model name	X	X	X
Outcomes			
Death (yes/no)	X	X	X
Date of death	X	X	X
Revised (yes/no)	X	X	X
Date of revision	X	X	X
Reason Diagnosis All cause Instability Infection Aseptic loosening Periprosthetic fracture	X	X	X

** By linking to the Swedish national patient register*

Table 2. Study designs

Paper	n	Study period	Inclusion Criteria	Exposures	Covariates	Outcomes
I	Porous tantalum cups (n=23,201) Other uncemented cups (n=128,321)	2003–2015	Primary conventional THAs Metal on Highly cross-linked Polyethylene Uncemented cups	Meta analytic approach vs. Individual patient data TM versus other cups	Age, sex, diagnosis, head size, stem fixation	All cause revision
II	Sweden (n=159,695) Australia (n=279,693) KP (US) (n=69,641)	2003–2015	Primary conventional THAs due to OA	Country (Sweden, AU, US) comparisons	Unadjusted	All cause revision
III	Exeter Sweden (n=8,802) Australia (n=25,757) Summit KP (n=12,382) Australia (n=1,213)	2003–2015	Primary conventional THAs due to OA Patient age >55 Metal or ceramic on highly cross-linked bearing surfaces Femoral head size of 32mm and 36mm	Exeter: Sweden vs Australia Summit: KP vs Australia	N/A	All cause revision
IV	Sweden (n=181,732) Australia (n=309,671) KP (n=75,814)	2001–2016	Primary conventional THAs due to OA Metal-on- metal bearing surfaces excluded	Patient, hospital, surgical, implant characteristics	Year of primary THA	All cause revision
V	KP (n=51,012)	2008–2016	Primary conventional THAs due to OA Metal-on- metal bearing surfaces excluded	Patient characteristic Elixhauser co-morbidities	Bilateral procedures, operative side, annual THA hospital volume, surgical approach, operative side, femoral head size, bearing surface and year of operation Age, sex, BMI, bilateral procedures, operative side, annual THA hospital volume, surgical approach, operative side, femoral head size, bearing surface and year of operation	1. All cause revision 2. Revision due to infection 3. Revision due to dislocation

Paper I

Patients who had a primary THA between 2003 and 2015 were identified using the SHAR, AOANJRR, and KP registries. The study was restricted to metal-on highly crosslinked bearing surface and uncemented THA cups. There were 23,201 THAs with porous tantalum design and 128,321 other uncemented cups during the study period. Patient level data were combined from SHAR and AOANJRR into one database to conduct a comparison of individual patient level analysis with meta-analysis of summary level data. The KP registry provided summary level data for the metanalytic approach only due to restriction in sharing patient level data. Summary level data from the SHAR, AOANJRR and KP were used in the metanalytic approach comparing porous tantalum with other uncemented cups.

Paper II

Primary THAs with an OA diagnosis were identified using the SHAR (n=159,695), AOANJRR (n=279,693), and KP (n=69,641) registries between 2003 and 2015. Bilateral procures were included in the study. Patient with hip resurfacing were excluded. Each registry provided tables with summary level descriptive data on patient characteristics (i.e., age, sex, BMI, ASA class), surgical techniques (i.e., surgical approach, cement fixation), implant types (i.e., bearing surface, femoral head size), and 5- and 10-year THA implant survival to evaluate patient, implant, techniques and THA survivorship across the registries.

Paper III

Primary THAs due to OA (2003–2015) were identified using the SHAR, AOANJRR, and KP registries. Study inclusion criteria consisted of patient age > 55, conventional primary THA procedures, metal or ceramic on highly crosslinked polyethylene bearing surfaces, and femoral head size of 32mm and 36mm to control for potential confounders. Sweden (n=8,802) and Australian (n= 25,757) THA survival was evaluated for Exeter™ V40™ Primary Standard Stem (Stryker Howmedica, Mahwah, New Jersey, USA). Australia (n=1,213) and US (N=12,381) THA survival was evaluated for uncemented Summit® Stems (DePuy Synthes Co., Warsaw, IN, USA.) and Pinnacle ® Cups (DePuy Synthes Co., Warsaw, IN, USA). All cause revision was the outcome of interest. Patient and implant descriptive statistics were reported from the registries. Survival probabilities and standard errors were obtained from the registries at 1,3,5, and 7 years follow-up.

Paper IV

Primary THAs with a diagnosis of OA were identified in Sweden (n=181,732), Australian (n=309,671), and the US (n=75,814) using national and regional registries. Hip resurfacing and metal-on-metal bearing surfaces were excluded from the study. Descriptive statistics on age, gender, operative side, hospital volume, procedure volume, femoral head size, and bearing surface were reported. Multivariable cox regression evaluating time to all cause revision was reported from each registry.

Paper V

Primary THAs performed between 2008–2016 with an osteoarthritis diagnoses were identified using the KP integrated health system's registry (n=51,012) (**Figure 2**). Patient characteristics (i.e., age, gender, BMI, number of Elixhauser comorbidities, ASA) were obtained from the registry as well as THA revision, date and diagnosis. Bilateral procedures, annual THA hospital volume, surgical approach, operative side, implant characteristics (i.e., femoral head size, bearing surface) and year of operation were also obtained from the registry to include as study covariates. ICD-9-CM codes (International Classification of Diseases, Ninth Revision, Clinical Modification) from the US health systems Electronic Health record (EHR) were linked to the registry data to assess Elixhauser comorbidities and calculate the Elixhauser Index based on ICD-9 coding one year prior to and during primary THA admission

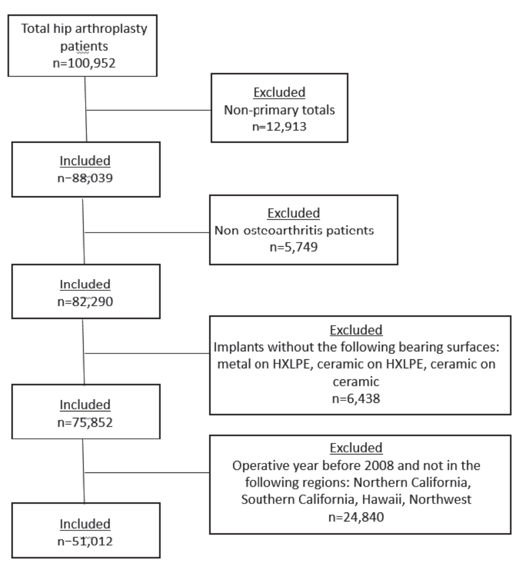

Figure 2. Selection criteria

Statistical methods

Paper I

Descriptive statistics including frequencies, percentages, means and standard deviations were used to describe the porous tantalum and other uncemented cup groups. For both individual patient data analysis and meta-analysis approaches a multivariable Cox proportional hazard model was fit for time to all cause revision comparing porous tantalum with other uncemented cups. Model covariates included age, sex, diagnosis, head size, and stem fixation. In the meta-analysis approach, treatment effect size (i.e., Cox proportional hazard ratio) was calculated within each registry and a weighted average for the individual registries' estimates was calculated. For the individual data approach analysis, we stratified on registry to allow for baseline hazards comparable estimates to the meta-analysis approach.

The average treatment effect for the metanalytic approach was calculated based on (Hedges and Olkin 1985). For each registry ($i = 1,2,\ldots,k$) we estimated a log hazard ratio from a Cox model, $LHR_i = \ln(HR_i)$. The variance of this estimate was denoted by $V(LHR_i)$ and a weight was calculated by taking the inverse of the variance, $W_i = 1 / V(LHR_i)$. The average treatment effect across registries was estimated using a weighted mean, $LHR = (\sum i{=}1 W_i\ LHR_i) / (\sum i{=}1 W_i)$ kk . The variance of this mean was calculated as k $V(LHR) = 1 / (\sum i{=}1 W_i)$ and the standard error was $SE(LHR) = \sqrt{V(LHR)}$. Normal theory confidence intervals (95%) were calculated: $LHR \pm 1.96 \times SE(LHR)$. Point estimates and interval endpoints were exponentiated (e.g., $HR = \exp(LHR)$). A 2-tailed p-value was calculated using $p = 2 \times [1 - (\Phi(|Z|))]$, with p as the standard normal cumulative distribution and $Z = (LHR) / SE(LHR)$.

Paper II

Descriptive statistics including frequency percentages, means and standard deviations were used to compare and contrast the patients, implants, and clinical practices in Sweden, Australia and the US. Kaplan Meier survival curves and 95% confidence intervals were used to assess THA survival in the different countries. Chi-square tests of survival probabilities were applied to evaluate differences in 5- and 10- year THA survival between the three countries.

Paper III

Descriptive statistics (i.e., frequencies, percentages, means and standard deviations) were used to compare patient, implants, and THA all cause revision in Sweden and Australia for the cemented Exeter THA and between Australia and the US for the Summit uncemented THA. Kaplan Meier survival curves were used to calculate survival probabilities and standard errors for the groups. 95% confidence intervals were calculated. Chi square tests were used to assess differences in survival estimates between countries for the Exeter and Summit THA comparisons.

Paper IV

Mean and standard deviations were used to describe study follow-up time for each registry. Frequencies and percentages described patient, implant, hospital, clinical practice and crude revision rates by country. Kaplan Meier survival curves were used to assess THA implant survival. Multivariable Cox proportional hazard ratios were used to evaluate patient, hospital, procedure and implant predictors of all cause revision in each country while adjusting for year of the primary THA.

Paper V

Frequency and percentages described the study patient characteristics including age, sex, BMI and co-morbidities. Multivariable Cox proportional hazard ratios were used to evaluate the effects of age, sex, BMI, ASA, and number of Elixhauser comorbidities on all cause, revision due to dislocation, and septic revision while adjusting for the following potential confounders: bilateral procedures, annual hospital volume, surgical approach, operative side, femoral head size, bearing surface, and year of operation. Cox proportional hazard models were used to evaluate the impact of individual Elixhauser comorbidities on risk of all cause revision, revision due to dislocation, and septic revision while adjusting for age, BMI, sex, bilateral procedures, annual hospital volume, surgical approach, operative side, femoral head size, bearing surface, and year of operation.

Results

Paper I

This study's demographic and Kaplan Meier results focus on the US cohort (**Table 1**). Patient-level data analysis and meta-analytic approaches yielded the same results with the porous tantalum cups having a higher risk of revision than other uncemented cups (HR, 95% CI=1.6 1.4–1.7) and HR, 95% CI=1.5, 1.4–1.7), respectively). Adding the US cohort to the meta-analysis led to greater generalizability, increased precision of the treatment effect, and similar findings (HR, 95% CI= 1.6,1.4–1.7) with increased risk of porous tantalum cups (**Table 2**).

Table 1. US cohort patient demographics.

	Porous Tantalum Cups		Other Uncemented Cups	
	#	%	#	%
Primary THAs	13088	23%	44725	77%
Revised THAs	374	3%	979	2%
Mean Age in Years (range)	66 (16–97)		67 (13–98)	
Male (%)	5447	42%	18369	41%
Right side (%)	7139	55%	24412	55%
OA Diagnosis	12000	92%	40987	92%
Years follow up, mean (range)	2.8 (0–14)		4.6 (0–15)	
Uncemented stem	12712	97%	41328	92%
Femoral head size				
28	430	3%	6186	14%
32	5403	41%	16190	36%
>32	7255	55%	22349	50%

Adapted from Paxton et al. 2018

Table 2. Comparison of traditional and meta-analytic approaches

	HR (95% CI)	SE	P
Sweden	1.452 (1.14, 1.85)	0.124	0.003
Australia	1.571 (1.38, 1.79)	0.066	<0.001
US Cohort	1.595 (1.41, 1.80)	0.063	<0.001
Individual Patient Data (Sweden and Australia combined	1.556 (1.39, 1.75)	0.059	<0.001
Meta-Analysis (Sweden and Australia)	1.544 (1.38, 1.73)	0.058	<0.001
Meta-Analysis (Sweden, Australia and US cohort)	1.568 (1.442, 1.704)	0.043	<0.001

Adapted from Paxton et al. 2018

Paper II

Comorbidity, according to the ASA classification, was lower in Sweden (84% ASA class<3) than in the US (65%) and Australia (67%). Cement fixation was used predominately in Sweden (73%) and cementless in the US (93%) and Australia (62%). The direct anterior approach was used in the US and Australia but not in Sweden. Smaller femoral head sizes (≤28mm) were used more often in Sweden (55%) than in the US (11%) and Australia (24%). Metal-on-highly cross-linked polyethylene was used more frequently in the US and Australia than in Sweden. Metal on conventional bearing surface was most common in Sweden but decreased over the study period (**Figure 1**). Sweden's 5- and 10-year survival estimates were higher than in the US and Australia (**Table 3**). Reasons for revision differed between the countries. Aseptic loosening was the most frequent cause for revision in Sweden and Australia whereas instability was the most common in the US cohort (**Figure 2**).

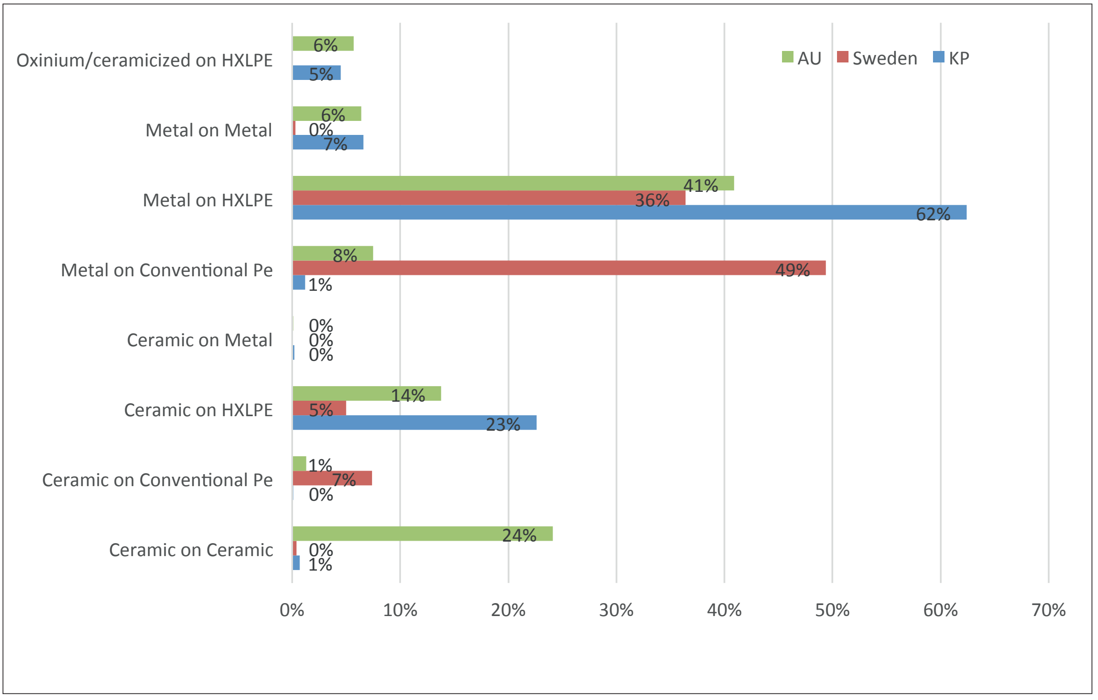

Figure 1. THA bearing surface use by country
Adapted from Paxton et al. 2019

Table 3. THA survival for all implants and all patients

	Sweden	Australia	Kaiser Permanente
Total primary procedures	159,695	279,693	69,641
Revised primaries (n, %)	4411 (2.7%)	10,832 (3.9%)	1938 (2.8%)
5-year survival rate (95% CI)	97.8 (97.8, 97.9)	96.3 (96.2, 96.4)	97.0 (96.7, 97.2)
10-year survival rate (95% CI)	95.8 (95.6, 95.9)	93.5 (93.4,93.7)	95.2 (94.7, 95.6)

Adapted from Paxton et al. 2019

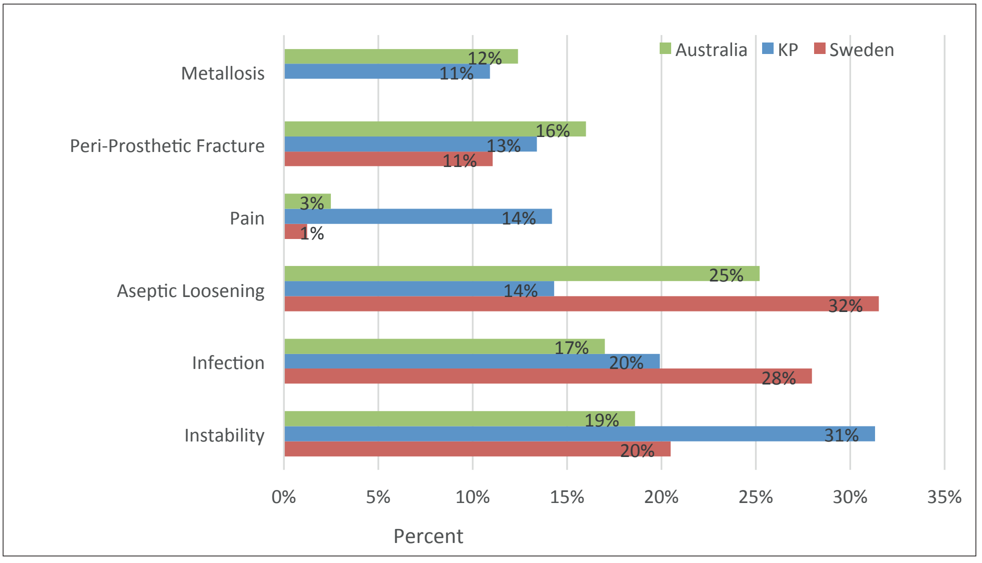

Figure 2. Most common THA revision diagnoses
Adapted from Paxton et al. 2019

Paper III

After restricting the sample to specific patient and implant characteristics, differences in Australia and Sweden Exeter bearing surfaces and femoral head sizes remained (**Table 4**). The Trident shell was used most frequently in Australia (82%) whereas Exeter X3 RimFit (59%) and Marathon cups (33%) dominated in Sweden. Exeter THA survival was similar in Australia and Sweden (**Table 5**). After patient and implant sample restriction, there were differences in Australia's and the US cohort's Summit bearing surface and head sizes (**Table 6**). Summit THA survival was similar in Australia and the US cohort (**Table 7**).

Table 4. Patient demographics and implant characteristics cemented Exeter stem

	Australia	Sweden
Years follow-up (Mean, Std Dev)	3.6 (2.7)	4.4 (1.8)
EXETER (n)	25,757	8803
Age (Mean, Std Dev)	73.6 (8.1)	73.4 (7.4)
Male (%)	43.6	38.5
Bearing Surface		
Metal on highly crosslinked polyethylene (%)	80.5	100.0
Ceramic on highly crosslinked polyethylene (%)	19.5	0.0
Femoral Head size		
32mm (%)	64.2	86.4
36mm (%)	35.8	13.6

Table 5. Exeter cemented THA survival probabilities

	Year 1	Year 3	Year 5	Year 7
Sweden	0.9876 (0.0012)	0.9844 (0.0014)	0.9822 (0.0016)	0.9805 (0.0020)
Australia	0.9899 (0.0006)	0.9850 (0.0008)	0.9801 (0.0011)	0.9769 (0.0013)
Difference	-0.002	-0.001	0.0021	0.004
Lower Bound	-0.005	-0.004	-0.0016	-0.001
Upper Bound	0.000	0.0025	0.0058	0.0083
p-value	0.084	0.687	0.263	0.128

Table 6. Patient demographics and Implant characteristics cemented Summit stem

	Australia	Sweden
Years follow-up (Mean, Std Dev)	4.5 (3.1)	3.7 (2.8)
SUMMIT (n)	1213	12,381
Age (Mean, Std Dev)	71 (8.2)	69.2 (7.9)
Male (%)	54.7	42.2
Bearing Surface		
Metal on highly crosslinked polyethylene (%)	61.5	78.1
Ceramic on highly crosslinked polyethylene (%)	38.4	21.9
Femoral Head size		
32mm (%)	55.2	35.7
36mm (%)	44.8	64.3

Table 7. Summit/Pinnacle uncemented THA survival probabilities

	Year 1	Year 3	Year 5	Year 7
Kaiser Permanente	0.9854 (0.001)	0.9815 (0.001)	0.9774 (0.001)	0.9735 (0.002)
Australia	0.985 (0.004)	0.9838 (0.004)	0.9805 (0.004)	0.9734 (0.006)
Difference	0.0004	0.0023	0.0031	0.0001
Lower Bound	-0.0068	-0.01	-0.0122	-0.0123
Upper Bound	0.008	0.0054	0.006	0.0125
p-value	0.9127	0.5799	0.5303	0.9874

Paper IV

Patients and clinical practices varied by country (**Table 8**). Crude revision rates for the US cohort, Sweden and Australia were 2.6%, 3.8% and 3.4%. Lower annual hospital volume (<50 THAs per year) was associated with risk of revision in the US and Sweden. In Australia, higher annual hospital volume (>200) was associated with lower revision risk. Same day bilateral surgeries had a higher risk in the US cohort but were protective in Australia and Sweden. In Australia and Sweden age < 55 and male gender were associated with higher risk of revision but not in the US cohort. Ceramic-on-ceramic was associated with higher risk of revision than metal on highly crosslinked in the US cohort. Metal-on-conventional polyethylene was associated with higher risk of revision than metal-on-highly- crosslinked in the US cohort and Australia but not in Sweden (**Table 9**).

Table 8. US, Swedish, and Australian descriptive statistics

	US		Sweden		Australia	
Bilateral	#	%	#	%	#	%
Bilateral Different Days	21,232	28	59,024	32.5	91,350	29.5
Same Day Bilateral	1266	1.7	2232	1.2	4402	1.4
Single Joint	53,316	70.3	120,476	66.3	213,919	69.1
Age Category	#	%	#	%	#	%
<55	8990	11.9	13,585	7.5	32,609	10.5
55–64	22,020	29	42,925	23.6	73,257	23.7
65–74	26,420	34.9	69,417	38.2	110,228	35.6
75–84	15,776	20.8	48,443	26.7	78,826	25.5
>=85	2576	3.4	7362	4.1	14,751	4.8
Gender	#	%	#	%	#	%
Male	31,199	41.2	77,446	42.6	141,172	45.6
Female	44,584	58.8	10,4286	57.4	168,499	54.4
Hospital Category	#	%	#	%	#	%
<=50	1241	1.6	4103	2.3	39,575	12.8
51–100	4484	5.9	23,344	12.8	66,616	21.5
101–200	26,075	34.4	71,707	39.5	85,596	27.6
>200	44,014	58.1	82,578	45.4	117,884	38.1
Head size	#	%	#	%	#	%
<32	8908	11.8	101443	55.8	82,520	26.7
32	27,324	36	71,966	39.6	115,725	37.4
>32	39,582	52.2	8323	4.6	111,426	36
Bearing Surface	#	%	#	%	#	%
Ceramic/Ceramic	506	0.7	622	0.3	78,326	25.3
Ceramic/HXLPE	24,628	32.5	10,467	5.8	67,761	21.9
Ceramic/Non HXLPE	0	0	13,581	7.5	0	0
Metal/Non HXLPE	1410	1.9	91,472	50.3	32,462	10.5
Metal/HXLPE	49,270	65	45,728	29.9	131,122	42.3

Table 9. Predictors of THA revision in US, Sweden and Australia

	US				Sweden				Australia			
	HR*	95%HR Confidence Limits		P Value	HR*	95%HR Confidence Limits		P Value	HR*	95%HR Confidence Limits		P Value
Single joint (Referent)												
Bilateral Different Days	0.917	0.82	1.024	0.1241	0.94	0.896	0.986	**.011**	0.892	0.851	0.935	**<.0001**
Same Day Bilateral	1.948	1.17	3.243	**0.0103**	0.757	0.596	0.961	**0.0022**	0.69	0.573	0.829	<.0001
Age 65–74 (Referent)												
Age <55	1.079	0.913	1.275	0.3712	1.512	1.317	1.736	**<.0001**	1.213	1.118	1.317	**<.0001**
Age 55–64	1.005	0.875	1.155	0.9456	1.27	1.185	1.36	**<.0001**	1.072	1.009	1.139	**0.0241**
Age 75–84	0.996	0.885	1.121	0.9484	0.984	0.901	1.075	0.722	1.008	0.948	1.071	0.808
Age >=85	1.073	0.816	1.41	0.6149	1.206	1.005	1.449	**0.045**	0.975	0.863	1.101	0.6776
Right Side (Referent)												
Left Side	1.052	0.963	1.149	0.259	1.025	0.978	1.075	0.3	0.981	0.942	1.022	0.3579
Female (Referent)												
Male	0.954	0.872	1.044	0.3074	1.352	1.279	1.429	**<.0001**	1.1	1.049	1.154	**<.0001**
Hospital volume 101–200 (Referent)												
Hospital volume <=50	1.537	1.051	2.247	**0.0265**	1.265	1.072	1.493	**0.005**	0.889	0.491	1.61	0.6974
Hospital volume 51–100	1.216	0.989	1.495	0.0634	1.09	0.978	1.216	0.12	0.766	0.441	1.332	0.3453
Hospital volume >200	1.191	1	1.417	0.05	1.021	0.897	1.161	0.753	0.761	0.589	0.984	**0.0375**
Head size >32 referent												
Head size <32	1.117	0.857	1.457	0.4131	0.936	0.737	1.188	0.586	1.045	0.946	1.154	0.3842
Head size 32	1.139	1.008	1.286	**0.0365**	0.968	0.783	1.197	0.763	0.962	0.879	1.053	0.4041
Metal/HXLPE (Referent)												
Ceramic/Ceramic	2.433	1.084	5.46	**0.0311**	0.804	0.429	1.506	0.495	1.051	0.943	1.171	0.3676
Ceramic/HXLPE	0.931	0.795	1.091	0.3779	0.918	0.718	1.173	0.493	0.946	0.851	1.052	0.3065
Ceramic/Conventional					0.744	0.618	0.897	0.002				
Metal/Conventional	2.192	1.587	3.029	**<.0001**	1.109	0.96	1.282	0.159	1.449	1.312	1.6	**<.0001**

**Model adjusted for year of primary THA operation*

Paper V

The majority of patients were male (58%) and 65 years of age or older (58%) (**Table 10**). At 7-years follow-up, THA survival for all cause, dislocation, and septic revision was 96.9% (95%CI 96.7–97.1%) 99.0% (95%CI 98.8–99.1%), and 99.3% (95%CI 99.2–99.4%) (**Figure 3**). Patients with 4 or more comorbidities had the highest risk for revision (**Figure 4**). Drug abuse, chronic blood loss anemia, weight loss, alcohol abuse, psychoses, other neurological disorders, depression, congestive heart failure, and chronic pulmonary disease were associated with increased risk for all cause revision (**Figure 5**). Drug abuse, psychoses, paralysis, depression, collagen/vascular disease, and valvular disease were associated with increased risk of revision for dislocation. Septic revisions were related to chronic blood loss anemia, weight loss, alcohol abuse, and congestive heart failure. Obesity was protective for revision due to dislocation but a risk factor for septic revision (**Figure 5**).

Table 10. Patient characteristics

	n	%
Primary THAs	51,012	100
Revised		
All cause	1182	2.3
Dislocation	399	.78
Septic	288	.56
Follow-up Mean, Std Dev	3.5	2.4
Age		
<55	6157	12.1
55–64	15,306	30.0
65–74	17,745	34.8
75–84	10,060	19.7
>=85	1744	3.4
Gender		
Male	29,800	58.4
Female	21,211	41.6
BMI		
<18.5	400	0.8
18.5–24.9	11,354	22.3
25–29.9	18,401	36.1
30–34.9	13,014	25.5
35–39.9	5888	11.5
>40.0	1930	3.8
ASA class		
1–2	33,041	64.8
>2	16,956	33.24
Number of Elixhauser comorbidities		
0	7024	13.8
1	11,159	21.9
2	11,160	21.9
3	7876	15.4
4	4356	8.5
5	2207	4.3
>5	1606	3.2

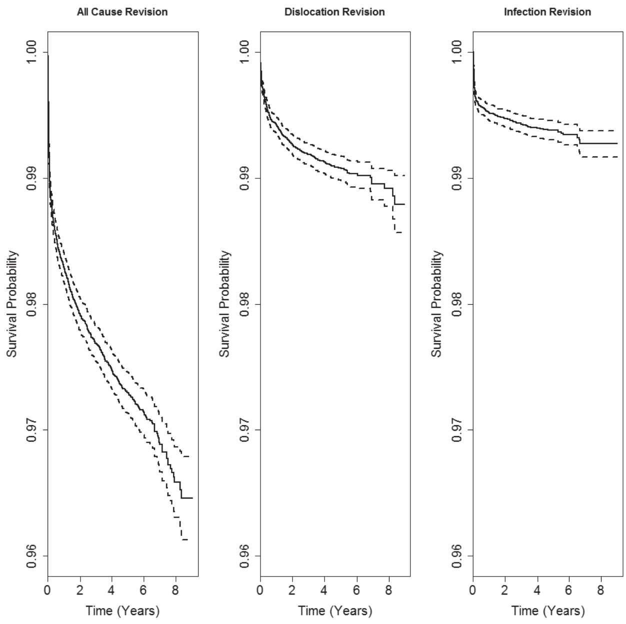

Figure 3. THA survival by revision diagnosis (unadjusted)

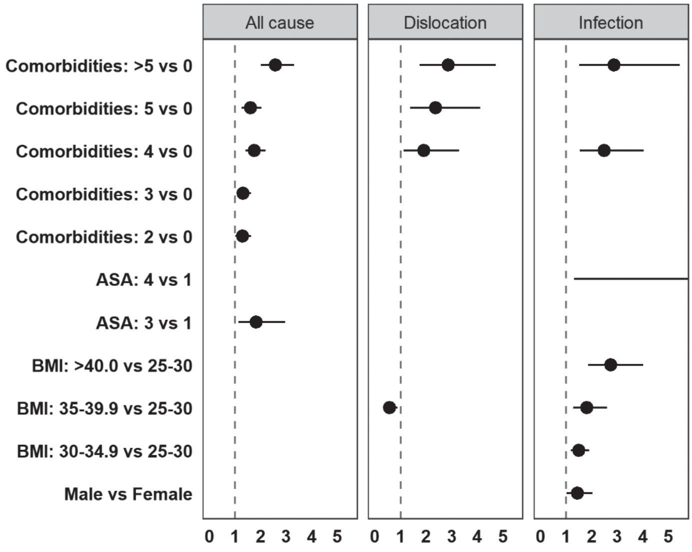

Figure 4. Patient characteristics associated with THA revision. Significant hazard ratios (p<.05) adjusted for age, bilateral procedures, annual THA hospital volume, operative side, surgical approach, operative side, femoral head size, bearing surface and year of operation

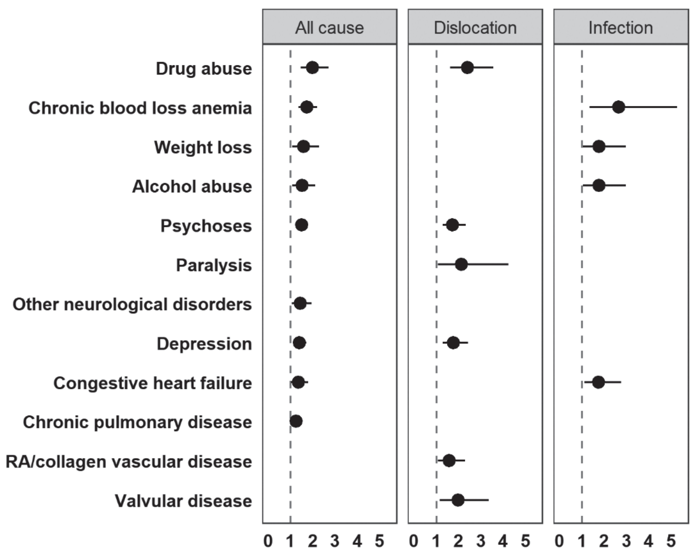

Figure 5. Elixhauser comorbidities associated with THA revision. Significant hazard ratios (p<.05) adjusted for age, gender, BMI, bilateral procedures, operative side, annual THA hospital volume, surgical approach, operative side, femoral head size, bearing surface and year of operation.

Strengths and limitations

Strengths

The main strength of the papers in this thesis is the high quality data from three internationally recognized arthroplasty registries. The registries all have high rates of coverage and completeness. In addition, all three registries are validated through independent, administrative data sources. The registries are representative of the patient and clinical practices of the regions and countries that they represent. The studies have high external validity and generalizability since they are based on registries which capture diverse patient populations, implants, and clinical practices from a variety of surgeons. The registries also provide longitudinal data with large sample sizes with sufficient statistical power to detect differences in low adverse event rates.

Limitations

The studies are observational in nature and therefore are limited by typical limitations of this type of study. RCTs are typically considered the gold standard for study designs. In an RCT, patients are randomized to treatments/exposures to eliminate confounding. In our studies, patients were not randomly assigned to the exposures of interest resulting in lower internal validity than an RCT. Only known and available confounders can be adjusted for in the analyses potentially resulting in residual confounding. Selection bias is also a concern in observational studies in that certain treatments may be selected for specific patient groups. We attempted to mitigate selection bias using multivariable analyses. In addition, a small percentage of missing values were present in the studies. However, missing values were less than 5% and were not systematically missing.

In all studies, a large integrated US health system represented US patients and clinical practices. The use of only one health system is a potential limitation in the studies. However, the health system is representative of the population in the regions it serves. (Karter et al. 2002, Koebnick et al. 2012). The health system does limit implants in a national contract and therefore does not have a wide range of implant manufacturers and designs but represents the largest US implant manufacturers.

Loss to follow-up is another limitation of the studies. Each registry has less than 8% loss to follow-up from 2001 to 2016. Patients who leave the country or health system may receive revision procedures elsewhere that are not captured in the registry studies. However, the loss to follow-up for all the registries is within acceptable standards.

The use of revision surgery as the only endpoint for the studies is an additional limitation. Some patients may have pain or other problems with their hip after surgery but may not have revision surgery due to a variety of factors including high risk for complications for some patient groups, fear of surgical procedures, lack of explanation for the pain or issue, and willingness to live with the THA outcome. Re-operations other than revision surgery were also not evaluated. Therefore, revision as the endpoint of THA may underrepresent failures. Patient reported outcomes, functional assessments, and radiographic measures may be more sensitive measures of failure than revision. However, revision is an objective endpoint in which both the patient and surgeon have decided that the joint replacement has failed.

Each study has specific limitations as well.

In Paper I, the use of multiple uncemented cup designs from different companies as a comparator to PT cups is a study limitation. Other design factors could potentially account for the differences in cup survival as a result. Ideally, one uncemented cup design from the same company should be compared to eliminate residual confounding effects. However, limiting the comparator cup would reduce generalizability of study findings. Selection bias may also be a limitation in that the trabecular metal cup design may have been used more often in more difficult THA primaries. However, this does not seem substantiated. First, we included only patients with an OA diagnosis to prevent potential complex cases. Second, we conducted a sensitivity analysis eliminating the trabecular metal cups from the study and our results were consistent with a higher risk of revision for the Porous tantalum design. Third, we also evaluated potential selection bias by assessing the percentage of use of the Continuum cup by surgeons. Surgeons who used the cup did so in most of their cases which suggests the cup is not being used selectively for certain cases. Another limitation of Paper I is the lack of investigation into the cup specific revisions. However, the frequency and percentage of cup and stem revisions were reported in the manuscript. Finally, this study only provides intermediate term follow-up emphasizing the need for longer evaluation of PT cups.

Paper II is a descriptive study in which confounders were not adjusted for and therefore is limited in the assessment of THA survival. However, this study was intentionally descriptive in nature to provide an overall description of patients and clinical practices in each country. Although Paper III attempted to adjust for patient and implant differences identified in Paper II between the countries using stratification, the comparison groups still differed in femoral head size and bearing surface. Therefore, this study could be improved with adjustment for these factors in a multivariable Cox proportional regression model. In addition, this study also included different cup designs and manufacturers in comparing Australia and Sweden's Exeter stems. Controlling for differences in cup designs and manufacturers could improve the study design as well.

Paper IV's main limitation is the lack of inclusion of specific comorbidities. All three registries did not have more detailed information on comorbidities therefore we focused only on ASA classification and BMI. Another limitation is the focus on revision for any reason. Predictors could differ by revision diagnosis.

Paper V attempted to improve upon Paper IV's limitations with the addition of the Elixhauser comorbidity index to the prediction models and assessment of revision due to dislocation as well as septic revision. Registry data was linked to the US health system's Electronic Health Record data to extract ICD-9 CM Elixhauser comorbidity codes. Although this process is fairly standard in assessment of comorbidities in administrative studies, coding inaccuracies are possible. Due to coding difference across countries, we did not include Swedish data, which appeared to underrepresent Elixhauser comorbidities.

Discussion

Although THA is an effective surgery for advanced stage osteoarthritis, some patients require revision surgery which has increased risk of complications and mortality. Understanding the patient, implant, surgical, and hospital factors associated with increased risk of THA revision is critical for identifying modifiable risk factors to improve THA care.

Arthroplasty registries real world data representing a variety of surgeons, patients, implants, and hospitals are an ideal mechanism for evaluating the impact of these factors on risk of THA revision. International collaborations of registries provide additional opportunities to identify best practices and optimize THA outcomes globally.

Although international registry collaborations are beneficial, strict regulations regarding individual patient level data can prevent registries from working together. Paper I presents an illustration of meta-analysis as an alternative to sharing patient level data. This study not only provides the framework for this body of work but offers a model for other international registry collaborations.

In applying the meta-analytic approach, we identified variation in patients, implants, surgical techniques, and outcomes across Sweden, Australia, and the US. Unadjusted 5- and 10-year THA survival was higher in Sweden than the US and Australia (Paper II). The US THA survival was higher than Australia. We hypothesized that the differences in THA outcomes between countries were related to variation in implants. As a result, we examined THA survival among specific patients and implants to determine if this accounted for the intra country variation. In evaluating specific models of implants by country, difference in outcomes between the countries disappeared highlighting the importance of implant selection on THA outcomes (Paper III). This finding also highlights the need for a more rigorous approach to introduction of THA implants with limited introduction and surveillance prior to more widespread adoption.

We also investigated revision risk factors between across the countries (Paper IV). Annual hospital THA volume was a consistent predictor of revision supporting the concept of centers of excellence with high THA volume. The US cohort and Sweden and Australia differed in gender and age as risk factors. This may be attributable to the practice of cemented THA use in the elderly in Australian and Sweden. Uncemented THAs used with younger patients are also associated with the use of conventional polyethylene which could account for the higher risk of revision for males in Australia. Differences in ceramic-on-ceramic as a risk factor may be related to the infrequent and older ceramic-on-ceramic material in the US cohort. Differences in bilateral surgery as a risk factor between countries most likely is due to patient selection practices. Identifying indications for bilateral surgery in Australia and Sweden could identify methods for improving patient selection internationally.

In evaluating patient co-morbidities and obesity, our results suggest increased ASA class and 4 or more comorbidities are associated with increased risk for revision THA. The Elixhauser comorbidity index demonstrated additive predictive value to ASA classification suggesting the Elixhauser should be included in THA predictive models when available. Our study also identified specific comorbidities with higher risk of THA revision. These findings are important for optimizing THA outcomes through pre-operative assessment and counseling of patients. Unlike other studies, obesity was not found to be associated with increased risk of all cause revision. BMI was however related to increased risk of septic revision suggesting that infection prevention protocols should be focused on within this patient population.

In order for international registry collaborations to occur, standardization of data elements and definitions is also necessary. The development of global common data elements and definitions could facilitate arthroplasty registry collaborations. One such area is global standardization of implant names and attributes which is currently underway in a collaboration with International Society of Arthroplasty Registers (ISAR) and Industry. The development of one accurate source of implant names and attributes will enhance international registries' abilities to compare implant survival and conduct international signal detection to improve patient safety and care worldwide.

Conclusions

1. Meta-analysis is a viable alternative to patient level data analysis and can be used to enhance international registry collaborations

2. Sweden, Australia and US differ in patients, clinical practices and outcomes. Cross country comparisons of outcomes need to take these differences into consideration

3. Variation in implants accounts for differences in THA survival between countries

4. Predictors of THA revision vary by country most likely accounted for by differences in patients, implant selection and clinical practices

5. The number and specific comorbidities predict risk of THA revision. Patients and surgeons should consider these revision risk factors prior to THA surgery.

Future projects

There are numerous potential future projects generated from this body of work.

International Signal Detection Networks

First, our work supports increased international collaborations between registries from different countries. Using the meta-analytic approach described in Paper I, registries from around the world can work together to identify the clinical best practices in THA without concerns about sharing patient level data and associated security and regulatory issues. With the limited number of overlapping implants used within our studies, expansion to other regional and national registries could enhance evaluation of implant performance on a global level. (Malchau et al. 2015). Such collaboration could enhance early signal detection of implants with poor performance to improve global public health and safety. Meta-analysis of THA survival of standardized registries studies evaluating implant performance could provide more relevant and real time data to key stakeholders including patients, surgeons, hospitals, manufacturers, payers, and regulatory bodies.

Global Benchmarking Standards

International benchmarking of implant performance is another future area of focus. Currently, there are several benchmarking systems internationally used such as the Orthopaedic Device Evaluation Panel (ODEP) (United Kingdom) (2017), The Prostheses List Advisory Committee (PLAC) (Australia) (2017), and the Nederlandse Orthopaedische Vereniging Classification of Orthopaedic Implants (NOV) (Nederland) (2019). Coordination of registries worldwide could assist in the development of international standards of implant performance based on real world data. A standardized benchmark of performance could benefit regulatory decision making, hospital purchasing, and clinical selection of implants that meet a minimum required global standard.

Coordinated International Clinical Trials Nested in Registries

The coordination of clinical trials nested in international registries provides another opportunity for future studies in orthopaedics. Malchau et al. (2015) specifically proposed a 4-level model for nesting registries in clinical trials including (1) reoperation data from multiple registries, (2) PROs from registries or for a specific study, (3) radiographic data and other parameters dependent upon specific clinical questions, and (4) the option for randomized studies. Pragmatic clinical trials where patients are randomized according to service delivery as opposed to individual patient randomization also could be considered in this model. Clinical trials nested in existing international registries' infrastructure could advance both pre and post market assessment of implant devices expediting enrollment of patients in trials at a reduced cost thereby facilitating more rapid introduction of new technology into the market with ongoing postmarket surveillance ensuring patient safety. This framework could also be used to assess key clinical questions surrounding thromboprophylaxis, cement fixation, and infection prophylaxis. In addition, changes in service delivery, impact of rehabilitation, and effects of care delivery pathways could also be evaluated in nested clinical trials models thus enhancing patient care and safety worldwide.

International Predictive Analytics

Additional international collaborations on predictors of THA outcomes is also a critical area for clinical intervention and decision making. Our studies were limited to revision as an endpoint. Future studies could evaluate PROMs, functional outcomes, complications, and mortality on a global level. Paper V emphasized the added predictive value with inclusion of the number of Elixhauser comorbidities. In order to accomplish this across countries, variations in coding practices must be examined and standardized. Advancements in statistical techniques such as random forests and neural networks could also be applied in assessing THA predictors of outcomes. Validation of statistical methods and prediction models across countries could play a key role in shaping data available for patient/surgeon shared decision making at the point of care.

Global Implant Retrieval Network

Another potential area for future studies is the linkage of registry data to implant retrieval analysis. Coordinating this on a global level may provide additional insight into the mechanisms of failure for specific devices helping advance development of improved THA implant designs.

Sammanfattning på svenska

Utfall efter total höftprotesoperation i ett internationellt perspektiv

Patientrelaterade, implantatrelaterade och kirurgiska faktorers betydelse för implantöverlevnad i Australien, Sverige och USA.

Höftartros är en ledsjukdom som ger i smärta, stelhet och nedsatt fysisk funktion. Även om total höftprotesoperation är en framgångsrik behandling för höftartros, kommer några drabbas av komplikationer såsom infektion, luxation, proteslossning, fraktur som kräver operation med byte av protesen, så kallad revision. Numerous factors influence the success of total hip replacement including patient, surg ical , hospital and implant factors.Ett flertal faktorer påverkar risken att drabbas revision: patient-, sjukhus- och implantatrelaterade samt kirurgiska faktorer. Understanding the influence of these factors on total hip replacement risk of revision is critical for prevention of revision surgery. Förståelsen av hur dessa faktorer påverkar risken för revision är viktig för att kunna förebygga av behovet av revision.

I ett internationellt perspektiv har kvalitetsregister varit viktiga för att identifiera patientgrupper och klinisk praxis som har högre risk för revision hos höftprotesopererade. Det finns många nationella och regionala protesregister över hela världen. Samarbete mellan register gör möjligt att utvärdera skillnader i patientegenskaper, klinisk praxis, riskfaktorer och utfall mellan länder.

Syftet med det här avhandlingsprojektet var att undersöka skillnader i patientrelaterade, implantatrelaterade samt kirurgiska faktorer och utfall efter total höftproteskirurgi i Australien, Sverige och USA för att identifiera riskfaktorer för revision och bästa kliniska praxis. De fem delarbetena i avhandlingen undersökte:Understanding the influence of these factors on total hip replacement risk of revision is critical for prevention of revision surgery.

1. Meta-analys som ett alternativ till att analysera individuella patientdata genom att jämföra risken för revision för tantalumcupar med andra ocementerade cupar vid total höftprotesoperation i Australien, Sverige och USA.
2. Variation i patientegenskaper och samsjuklighet, kirurgiskt snitt, implantategenskaper, sjukhusegenskaper och revisionsfrekvens mellan Australien, Sverige och Australien för att identifiera skillnader i praxis och möjliggöra internationella förbättringar inom höftproteskirurgi.
3. Implantatspecifika källor till variation i revisionsfrekvens vid total höftprotesoperation i Australien, Sverige och USA genom att undersöka de specifika höftprotesimplantaten Exeter och Summit.
4. Prediktiva faktorer för höftprotesrevision såsom faktorer som är relaterade till patientegenskaper, implantategenskaper, klinisk praxis och sjukhusegenskaper i Australien, Sverige och USA.
5. Hur patientrelaterade faktorer (såsom ålder, kön, BMI och samsjuklighet) påverkar risken för höftprotesrevision inom en stor sjukvårdsorganisation i USA

Patienter med total höftprotesoperation på grund av artros identifierades i höftprotesregister i Australien, Sverige och vid sjukvårdsorganisationen Kaiser Permanente. Kaplan–Meier överlevnadsstatistik med censurering för död och uppföljningsförlust. Multipel Cox regression användes för att identifiera patient-, implantat- och sjukhusrelaterade samt kirurgiska faktorer som var associerade med revisionskirurgi.

Analyser med data på patientnivå och meta-analys visade liknande resultat där tantalumcupar hade högre risk för revision än andra ocementerade cupar. Patientegenskaper, implantattyper och klinisk praxis skiljde sig mellan länderna. 5- och 7-års implantatöverlevnad i Sverige var högre än den i Australien och USA. Implantatöverlevnaden var dock lika mellan länderna när man justerade för patientegenskaper, fixationstyp och implantattyp. Faktorer som predicerar revision skiljde sig också mellan länderna. Patienter med flera sjukdomstillstånd och vissa specifika sjukdomstillstånd hade högre risk för revision oavsett orsak till revision och revision på grund av luxation och infektion.

Meta-analys är en genomförbar metod för att underlätta och förbättra internationellt registersamarbete. Vid jämförelse av protesöverlevnad efter total höftprotesoperation mellan länder är det viktigt att ta hänsyn till implantatval. Prediktorer för höftprotesrevision skiljer sig mellan länder, sannolikt på grund av variation i klinisk praxis och val av implantat. Förekomst av flera samtidiga sjukdomstillstånd och högrisk-tillstånd bör beaktas av ortopeder och patienter inför beslutet att genomgå total höftprotesoperation.

Project Collaborators

Supervisors

Ola Rolfson MD, PhD
Associate Professor, Orthopaedic Surgeon Department of Orthopaedics, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg and Director of the Swedish Hip Arthroplasty Register.

Henrik Malchau, MD, PhD
Professor, Harvard Medical School and Co-director Emeritus of the Harris Orthopaedic Laboratory at Massachusetts General Hospital, Boston, MA, USA, affiliated with the Swedish Hip Arthroplasty Register and Orthopaedic Surgeon with the Department of Orthopaedics, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg.

Johan Kärrholm, MD, PhD
Professor, Orthopaedic Surgeon the Department of Orthopaedics, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg and Director of the Swedish Hip Arthroplasty Register.

Collaborators/Co-Authors

Erik Bülow, PhD
Biostatistician Swedish Hip Arthroplasty Register, Gothenburg, Sweden

Guy Cafri, PhD
Research Scientist-Biostatistician Kaiser Permanente National Implant Registries, San Diego CA

Stephen Graves, MD
DPhil-Director of the Australia Orthopaedic Association National Joint Replacement Registry, Adelaide, Australia

Inari Laaksonen, MD, PhD
Orthopaedic surgeon Turku Univeristy Hospital, Turku, Finland

Michelle Lorimer, PhD
Senior statistician South Australia Health and Medical Research Institute and affiliated with the Australia Orthopaedic Association National Joint Replacement Registry, Adelaide, Australia

Maziar Mohaddes, MD, PhD
Orthopaedic surgeon Department of Orthopaedics, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg and affiliated with the Swedish Hip Arthroplasty Register.

Robert Namba, MD
Orthopaedic surgeon Southern California Medical Group, Irvine, CA and affiliated with the Kaiser Permanente National Implant Registries

Acknowledgements

I would like to thank the many individuals from the US, Sweden, and Australia who provided significant contributions critical to the success of this thesis. I would like to express my sincere gratitude to:

Ola Rolfson for all the incredible support and guidance he provided to me in his role as my main supervisor. His expertise, generosity, friendship, and mentorship will have a lasting effect on me.

Henrik Malchau for his ongoing encouragement and support to apply to the program and throughout the entire process. I am especially grateful for the international connections he facilitated for me which have changed my life on a personal and professional level.

Johan Kärrholm for his clinical expertise, amazing attention to detail, and critical feedback which enhanced this body of work.

Don Fithian for the many opportunities he created for me, his mentorship, and most importantly his friendship throughout the years.

Robert Namba for his clinical leadership and expertise and the opportunity to collaborate with him over the past 20 years.

Guy Cafri for his expert consultation on the statistical methods, his analytical support and providing a sounding board for my methodological questions.

Maziar Mohaddes for his clinical expertise, guidance, and feedback on the methodology paper.

Inari Laaksonen for her clinical expertise and collaboration on the methodology paper.

Michelle Lorimer for her incredible turnaround time, analytical support, and statistical expertise.

Erik Bülow for his statistical expertise, analytical support, and responsiveness to requests for analyses.

Margo Gordon for her continued support and encouragement which allowed me to pursue a PhD while working full time.

To my family at Surgical Outcomes and Analysis for all their amazing work and support through this process and for their important contributions to the success of the Kaiser Permanente Implant Registries.

To all the surgeons at Kaiser Permanente for contributing to the success of the Kaiser Permanente Registries and providing key clinical consultation.

To my son, Brett, who is such an incredible person. I am so proud of him and know he will have tremendous success as he pursues his own advanced education.

To my parents, Bill and Elecia, for their ongoing support, encouragement and pride in my accomplishments.

To my husband, Steve, the love of my life and my best friend, who supports and encourages me in all aspects of life.

References

Continuum Total Conventional Hip Investigation. Australian Orthopaedic Association National Joint Replacement Registry: Adelaide.

ODEP Orthopaedic Data Evaluation Panel. 2017.

The Prostheses List Advisory Committee (PLAC). 2017.

Anand R, Graves S E, de Steiger R N, Davidson D C, Ryan P, Miller L N, Cashman K. What is the benefit of introducing new hip and knee prostheses? J Bone Joint Surg Am 2011; 93 (Supplement_3): 51–4.

AOANJRR. Australian Orthopaedic Association National Joint Replacement Register Annual Report.: Adelaide, SA, Australia; 2017.

Bachmeier C J, March L M, Cross M J, Lapsley H M, Tribe K L, Courtenay B G, Brooks P M. A comparison of outcomes in osteoarthritis patients undergoing total hip and knee replacement surgery. Osteoarthritis and cartilage 2001; 9 (2): 137–46.

Badarudeen S, Shu A C, Ong K L, Baykal D, Lau E, Malkani A L. Complications After Revision Total Hip Arthroplasty in the Medicare Population. J Arthroplasty 2017; 32 (6): 1954–8.

Berry D J, Harmsen W S, Cabanela M E, Morrey B F. Twenty-five-year survivorship of two thousand consecutive primary Charnley total hip replacements: factors affecting survivorship of acetabular and femoral components. J

Bone Joint Surg Am 2002; 84-A (2): 171–7.

Bozic K J, Lau E, Ong K, Chan V, Kurtz S, Vail T P, Rubash H E, Berry D J. Risk factors for early revision after primary total hip arthroplasty in Medicare patients. Clin Orthop Relat Res 2014; 472 (2): 449–54.

Charlson M E, Pompei P, Ales K L, MacKenzie C R. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. Journal of chronic diseases 1987; 40 (5): 373–83.

Cnudde P, Nemes S, Bulow E, Timperley J, Malchau H, Karrholm J, Garellick G, Rolfson O. Trends in hip replacements between 1999 and 2012 in Sweden. J Orthop Res 2018; 36 (1): 432–42.

Corbett K L, Losina E, Nti A A, Prokopetz J J, Katz J N. Population-based rates of revision of primary total hip arthroplasty: a systematic review. PLoS One 2010; 5 (10): e13520.

Cram P, Lu X, Kaboli P J, Vaughan-Sarrazin M S, Cai X, Wolf B R, Li Y. Clinical characteristics and outcomes of Medicare patients undergoing total hip arthroplasty, 1991–2008. Jama 2011; 305 (15): 1560–7.

Cross M, Smith E, Hoy D, Nolte S, Ackerman I, Fransen M, Bridgett L, Williams S, Guillemin F, Hill C L, Laslett L L,

Jones G, Cicuttini F, Osborne R, Vos T, Buchbinder R, Woolf A, March L. The global burden of hip and knee osteoarthritis: estimates from the global burden of disease 2010 study. Ann Rheum Dis 2014; 73 (7): 1323–30.

de Steiger R, Lorimer M, Graves S E. Cross-Linked Polyethylene for Total Hip Arthroplasty Markedly Reduces Revision Surgery at 16 Years. J Bone Joint Surg Am 2018; (Aug 1;100(15)): 1281–8.

Doyle D J, Garmon E H. American Society of Anesthesiologists Classification (ASA Class). StatPearls Publishing,Treasure Island, FL; 2019.

Dy C J, Bozic K J, Pan T J, Wright T M, Padgett D E, Lyman S. Risk factors for early revision after total hip arthroplasty. Arthritis Care Res (Hoboken) 2014; 66 (6): 907–15.

Elixhauser A, Steiner C, Harris D R, Coffey R M. Comorbidity measures for use with administrative data. Med Care 1998; 36 (1): 8–27.

Garellick G, Karrholm J, Lindahl H, Malchau H, Rogmark C, Rolfson O. The Swedish Hip Arthroplasty Register Annual Report. 2014.

Garellick G, Kärrholm J, Rogmark C, Rolfson O, Herberts P. Swedish Hip Arthroplasty Register. 2016.

Gliklich R, Dreyer N, Leavy M. Registries for Evaluating Patient Outcomes: A User's Guide. US Department of Health and Human Services, Agency for Healthcare Research and Quality (AHRQ): Rockville, MD; 2010.

Gordon M, Stark A, Skoldenberg O G, Karrholm J, Garellick G. The influence of comorbidity scores on re-operations following primary total hip replacement: comparison and validation of three comorbidity measures. Bone Joint J 2013; 95-b (9): 1184–91.

Graves S E. The Value of Arthroplasty Registry Data. Acta Orthopaedica 2010; 81 (1): 8–9.

Hanna S A, McCalden R W, Somerville L, Howard J L, Naudie D D, MacDonald S J. Morbid Obesity Is a Significant Risk of Failure Following Revision Total Hip Arthroplasty. J Arthroplasty 2017; 32 (10): 3098–101.

Havelin L I, Robertsson O, Fenstad A M, Overgaard S, Garellick G, Furnes O. A Scandinavian experience of register collaboration: the Nordic Arthroplasty Register Association (NARA). J Bone Joint Surg Am 2011; 93 Suppl 3: 13–9.

Herberts P, Malchau H. Many years of registration have improved the quality of hip arthroplasty. Lakartidningen 1999; 96 (20): 2469–73, 75–6.

Herberts P, Malchau H. Long-term registration has improved the quality of hip replacement: a review of the Swedish THR Register comparing 160,000 cases. Acta Orthop Scand 2000; (Apr;71(2)): 111–21.

Inacio M C, Paxton E W, Dillon M T. Understanding Orthopaedic Registry Studies: A Comparison with Clinical Studies. J Bone Joint Surg Am 2016; (Jan 6;98(1):e3).

Jamsen E, Peltola M, Eskelinen A, Lehto M U. Comorbid diseases as predictors of survival of primary total hip and knee replacements: a nationwide register-based study of 96 754 operations on patients with primary osteoarthritis. Ann Rheum Dis 2013; 72 (12): 1975–82.

Jeschke E, Citak M, Günste r C, Halder A M, Heller K D, Malzahn J, Niethard F U, Schräder P, Zacher J, Gehrke T. Obesity Increases the Risk of Postoperative Complications and Revision Rates Following Primary Total Hip Arthroplasty: An Analysis of 131,576 Total Hip Arthroplasty Cases. J Arthroplasty 2018; (Jul;33(7)): 2287–92.

Johnson V L, Hunter D J. The epidemiology of osteoarthritis. Best Pract Res Clin Rheumatol 2014; (Feb;28(1):): 5–15.

Karter A J, Ferrara A, Liu J Y, Moffet H H, Ackerson L M, Selby J V. Ethnic disparities in diabetic complications in an insured population. JAMA 2002; 287 (19): 2519–27.

Kawamura H, Mishima H, Sugaya H, Nishino T, Shimizu Y, Miyakawa S. The 21- to 27-year results of the Harris-Galante cementless total hip arthroplasty. Journal of orthopaedic science : official journal of the Japanese Orthopaedic Association 2016; 21 (3): 342–7.

Khatod M, Barber T, Paxton E, Namba R, Fithian D. An analysis of the risk of hip dislocation with a contemporary total joint registry. Clin Orthop Relat Res 2006; 447: 19–23.

Khatod M, Cafri G, Namba R S, Inacio M C, Paxton E W. Risk factors for total hip arthroplasty aseptic revision. J Arthroplasty 2014; 29 (7): 1412–7.

Kirksey M, Chiu Y L, Ma Y, Della Valle A G, Poultsides L, Gerner P, Memtsoudis S G. Trends in in-hospital major morbidity and mortality after total joint arthroplasty: United States 1998–2008. Anesthesia and analgesia 2012; 115 (2): 321–7.

Koebnick C, Langer-Gould A M, Gould M K, Chao C R, Iyer R L, Smith N, Chen W, Jacobsen S J. Sociodemographic characteristics of members of a large, integrated health care system: comparison with US Census Bureau data. Perm J 2012; 16 (3): 37–41.

Kurtz S M, Lau E, Ong K, Zhao K, Kelly M, Bozic K J. Future young patient demand for primary and revision joint replacement: national projections from 2010 to 2030. Clin Orthop Relat Res 2009; 467 (10): 2606–12.

Liu W, Wahafu T, Cheng M, Cheng T, Zhang Y, Zhang X. The influence of obesity on primary total hip arthroplasty outcomes: A meta-analysis of prospective cohort studies. Orthopaedics & traumatology, surgery & research : OTSR 2015; 101 (3): 289–96.

Mahomed N N, Barrett J A, Katz J N, Phillips C B, Losina E, Lew R A, Guadagnoli E, Harris W H, Poss R, Baron J A. Rates and outcomes of primary and revision total hip replacement in the United States medicare population. J Bone Joint Surg Am 2003; 85-a (1): 27–32.

Malchau H, Garellick G, Berry D, Harris W H, Robertson O, Karrlholm J, Lewallen D, Bragdon C R, Lidgren L, Herberts P. Arthroplasty implant registries over the past five decades: Development, current, and future impact. J Orthop Res 2018.

Malchau H, Graves S E, Porter M, Harris W H, Troelsen A. The next critical role of orthopedic registries. Acta Orthop 2015; 86 (1): 3–4.

Morshed S, Bozic K J, Ries M D, Malchau H, Colford J M, Jr. Comparison of cemented and uncemented fixation in total hip replacement: a meta-analysis. Acta Orthop 2007; 78 (3): 315–26.

Nemes S, Gordon M, Rogmark C, Rolfson O. Projections of total hip replacement in Sweden from 2013 to 2030. Acta Orthop 2014; 85 (3): 238–43.

Nederlandse Orthopaedische Vereniging Classification of Orthopaedic Implants (NOV) 2019.

Palazzo C, Nguyen C, Lefevre-Colau M, M,, Rannou F, Poiraudeau S. Risk factors and burden of osteoarthritis. Ann Phys Rehabil Med 2016; (Jun;59(3)): 134–8.

Paxton E, Cafri G, Havelin L, Stea S, Pallisó F, Graves S, Hoeffel D, Sedrakyan A. Risk of revision following total hip arthroplasty: metal-on-conventional polyethylene compared with metal-on-highly cross-linked polyethylene bearing surfaces: international results from six registries. J Bone Joint Surg Am 2014; 96 Suppl 1: 19–24.

Paxton E W, Ake C F, Inacio M C, Khatod M, Marinac-Dabic D, Sedrakyan A. Evaluation of total hip arthroplasty devices using a total joint replacement registry. Pharmacoepidemiol Drug Saf 2012; 21 Suppl 2 (2012): 53–9.

Paxton E W, Inacio M C, Kiley M L. The Kaiser Permanente Implant Registries: effect on patient safety, quality improvement, cost effectiveness, and research opportunities. Perm J 2012; 16 (2): 36–44.

Paxton E W, Inacio M C, Namba R S, Love R, Kurtz S M. Metal-on-conventional polyethylene total hip arthroplasty bearing surfaces have a higher risk of revision than metal-on-highly crosslinked polyethylene: results from a US registry. Clin Orthop Relat Res 2015; (Mar;473(3)): 1011–21.

Petheram T G, Whitehouse S L, Kazi H A, Hubble M J, Timperley A J, Wilson M J, Howell J R. The Exeter Universal cemented femoral stem at 20 to 25 years: A report of 382 hips. Bone Joint J 2016; 98-b (11): 1441–9.

Prokopetz J J, Losina E, Bliss R L, Wright J, Baron J A, Katz J N. Risk factors for revision of primary total hip arthroplasty: a systematic review. BMC Musculoskelet Disord 2012; 13: 251.

Rolfson O, Karrholm J, Dahlberg L E, Garellick G. Patient-reported outcomes in the Swedish Hip Arthroplasty Register: results of a nationwide prospective observational study. J Bone Joint Surg Br 2011; 93 (7): 867–75.

Santaguida P L, Hawker G A, Hudak P L, Glazier R, Mahomed N N, Kreder H J, Coyte P C, Wright J G. Patient characteristics affecting the prognosis of total hip and knee joint arthroplasty: a systematic review. Can J Surg 2008; 51 (6): 428–36.

SHAR. Swedish Hip Arthroplasty Register Annual Report. Gothenburg, Sweden; 2014.

SHAR. The Swedish Hip Arthroplasty Register Annual Report. Gothenburg, Sweden; 2017.

Sheth D, Cafri G, Inacio M C, Paxton E W, Namba R S. Anterior and Anterolateral Approaches for THA Are Associated With Lower Dislocation Risk Without Higher Revision Risk. Clin Orthop Relat Res 2015.

Sheth D, Cafri G, Inacio M C, Paxton E W, Namba R S. Anterior and Anterolateral Approaches for THA Are Associated With Lower Dislocation Risk Without Higher Revision Risk. Clin Orthop Relat Res 2015; 473 (11): 3401–8.

Singh J A, Lewallen D G. Increasing obesity and comorbidity in patients undergoing primary total hip arthroplasty in the U.S.: a 13-year study of time trends. BMC Musculoskelet Disord 2014; 15: 441.

Wagner E R, Kamath A F, Fruth K M, Harmsen W S, Berry D J. Effect of Body Mass Index on Complications and Reoperations After Total Hip Arthroplasty. J Bone Joint Surg Am 2016; 98 (3): 169–79.

Wright E A, Katz J N, Baron J A, Wright R J, Malchau H, Mahomed N, Prokopetz J J, Losina E. Risk factors for revision of primary total hip replacement: results from a national case-control study. Arthritis Care Res (Hoboken) 2012; 64 (12): 1879–85.