Master thesis in Medicine

Title:

Introduction of New Acetabular Designs Does Not Influence Risk of Early Failure in Hip Arthroplasty

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Gothenburg, Sweden 2015

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Table of Contents

Abstract/Summary

Introduction

According to a recent study there is an increased risk of early revision surgery when new implants are introduced in Finnish hospitals.

Aim/Objective

To investigate if the introduction of new primary or revision cups was associated with a temporary early risk of revision or re-revision when introduced in Swedish hospitals.

Materials and Methods

All primary total hip arthroplasties and first-time cup revisions recorded in The Swedish Hip Arthroplasty Register performed during years 1993-2011 were primarily included. Selection was based on a countrywide usage of at least 374 cases. The cup should not represent minimal modifications of a previously used design on the Swedish market. Further, only hospitals that had reported use of more than 50 cups of at least one of the designs selected were included. These selection criteria resulted in a total amount of 52,903 cups being analysed. All cups were given an order number based on the order in which the cup had been inserted in each hospital. The influence of order number of the cups was analysed in a regression model. Adjustments were made for potentially confounding covariates. Splines were applied to establish changes in risk of early revisions based on the order number. Revision within 2 years (n=902) was used as endpoint.

Results

The adjusted logistic regression analysis showed no increased risk of early revision surgery within 2 years during the implementation phase of new cups (p=0.97). According to the splines there was an increased risk of the first 120 cups and in cups being inserted with order numbers 281-600. Using the aforementioned numbers as cut off values did not change the risk of revision within two years (p≥0.14).

Conclusion

We were not able to demonstrate an increased risk of early revision when new cup designs are being introduced in Swedish hospitals.

Keywords

Swedish Hip Arthroplasty Register, total hip arthroplasty, implant introduction, implementation phase.

Introduction/Background

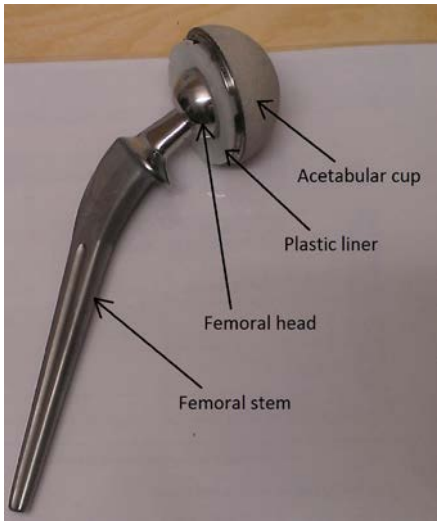

Figure 1. Hip prosthesis, with the femoral stem component and the acetabular cup component. The plastic liner is seen covering the inner part of the acetabular cup component.

Total hip arthroplasty (=joint replacement) (THA) is a type of orthopedic surgical procedure where the hip joint of a patient is exchanged to a hip joint prosthesis. A hip prosthesis is an artificial replica of the human hip joint and it consists of two main parts: The stem component ("stem") and the cup component ("cup"). The stem is implanted on the femoral side of the joint and resembles the proximal part of femur. The cup is implanted on the acetabular side of the joint (on the pelvis). The cup has been given its name due to the shape of the acetabulum resembling a cup. Hip prostheses mainly consist of metallic materials and plastic (high-molecular polyethylene). In most designs of uncemented cups the inner part of the cup (facing the artificial femoral head) is called liner and is usually made of different type of the plastic materials. There are some designs where the femoral head and/or the liner are made of ceramic materials instead of metallic and plastic materials.

The fixation of the stem and the cup to the bone can be done either with use of bone cement (cemented fixation) or by press-fitting the implant to the bone (uncemented fixation) with the intention to achieve osseointegration and implant stability.

In Sweden and Norway and in a few other countries outside of Scandinavia cemented fixation is widely used. In Scandinavia this is a result of deeply rooted knowledge and skill in using cemented fixation (1-3). However, the cemented fixation technique is viewed as more

demanding in other part of the world and for the last two decades, surgeons in centres around the world have increasingly been using uncemented fixation.

Since the 1960's, THA has increasingly been performed to relieve pain and improve function for patients with advanced disease of the hip joint (4). Meanwhile, surgical techniques, instrumentation and implant designs have improved, which have led to an improved surgical outcome. In Sweden, The Swedish Hip Arthroplasty Register (SHAR) has played an important role for this development. The SHAR was founded in 1979 by Peter Herberts and colleagues. The SHAR collects data on all patients that are operated with THA in all Swedish hospitals. Patient data like age, sex, primary diagnosis, surgical techniques and type of prosthesis are registered (5). The reporting rate to the register is high. A validation of the reporting rate published in the year 2000 showed that >95% of all primary THAs and revision surgeries were reported during years 1986-1995 (6). One of the main purposes of The SHAR is to do research on the data to effectively be able to detect complications and learn from mistakes and to secure increasingly better results in the long term. Since the beginning of The SHAR, the register has given yearly feedback to hospitals about their surgical results, and today Sweden is among the countries with the best overall results for THA (5).

Most patients operated with THA is among 60-80 years of age. The most common indication for THA is end-stage osteoarthritis. Other indications are rheumatoid arthritis, avascular necrosis of the femoral head, femoral neck femoral neck fracture, other reasons for secondary osteoarthritis (childhood hip disorders, different types of earlier trauma) and tumours (4).

The majority of the patients operated with THA can expect a more or less pain free hip and restoration of function for many years (4, 7, 8). On average, the risk of patients to require

further surgical intervention (revision) is 1% per year for the first 15 years after primary THA (4), and about 20% of the patients are revised within 25 years. However, there is a rather large difference between age groups, with about 35% of the youngest patients (<50 years old) revised within 25 years and only about 5% of the oldest patients (>80 years old) revised within 25 years (4, 7).

Revision surgery is defined as an exchange or removal of the entire implant or at least one of its parts. The most usual reason for revision is loosening of an implant component, followed by dislocation problems, deep infection, periprosthetic femoral neck fracture and other causes (9).

Revision rates are used as a measure of implant failure rates in THA research (10).

There is different patient-, surgical- and implant-related factors affecting the risk of revision surgery. The impact of these risk factors differs in different study-populations, but some overall trends have been observed. Patient related factors such as younger age and increased co-morbidity at the primary operation are associated with increased risk revision. Younger age is the most important risk factor (4, 11, 12). The type of hip disease causing the primary operation also influences the outcome. Of all diagnoses primary osteoarthritis is associated with lowest risk of revision (11) while fracture of the femoral neck is associated with the highest risk (4). Male sex has been associated with increased risk for revision due to several reasons, but has not consistently been associated with increased overall risk of revision. Uncemented fixation of both the stem and cup has not been consistently associated with increased risk of revision when compared to cemented fixation, however a tendency towards increased risk for uncemented fixation has been observed (1, 11). In the Nordic countries, where cemented fixation has traditionally been preferred, cemented fixation is associated with

a lower risk of revision after 10 years for patients aged 65 years or older (2). Operations performed by surgeons with higher yearly caseload have also been associated with lower risk of early revision surgery compared to surgeons with a lower yearly caseload (13, 14).

Only a few studies have evaluated risk factors for re-revision (revision after an earlier revision). Recently, Mohaddes et al. found an increased risk of re-revision after first-time cup revisions in younger age groups and for male patients. The type of hip disease causing the primary operation and the use of cemented or uncemented fixation at this operation had no influence. These authors also found that the risk of re-revision after a first-time cup revision is higher than the risk of revision after primary THA (3).

To further improve the results of THA, new implant designs are continually being introduced on the market. However, not much research has been done to determine the effect of implant introduction on the result of THA. A recent study from The Australian National Joint Replacement Registry (NJRR) found that of implants introduced on the Australian market between years 2003-2007 and used in more than 100 operations, none performed better than established implants. Thirty percent of them even performed worse than established implants (15). In a study from The National Joint Registry of England and Wales (NJREW) it was shown that about 25% of all implants available on the market in England and Wales during year 2011 had no readily identifiable evidence to support their use, and these implants were used in about 8% of all primary THAs (16). In both the study from The NJRR and The NJREW, suggestions were made for a more discriminatory and evidence-based uptake of new implant designs the respective countries (15, 16).

In comparison to the situation in many other countries, Swedish hospitals have tried to avoid experimenting with the introduction of new implant designs. Instead, Swedish hospitals have focused more on improving surgical techniques, especially cementing fixation techniques (5).

When an orthopedic surgeon initially learns to perform THA or when an orthopedic surgeon is learning new surgical techniques there is most often a learning curve for mastering the new techniques properly. During the learning curve, there might be a slightly increased risk of intraoperative complications, short-term complications and early implant failure. The learning curve of the individual surgeon probably varies depending on the amount of previous experience, the complexity of the acquired technique and how much the new technique resemble techniques that the surgeon is used to. The surgeon can most likely decrease the effect of the learning curve from practicing with new techniques before using them on patients. This can be done by practising on cadavers and exchange of knowledge and skills with other surgeons already familiar with the techniques (17).

Researchers have studied the effect of the learning curve for different surgical techniques in THA. These techniques include uncemented THA with standard lateral (18) and posterolateral incisions (18, 19), anterior minimal invasive incisions (20-22) and hip resurfacing (a modern, bone sparing implant) (23, 24). This has been done by examination of consecutive operation series by single surgeons (19-24), or by studies of two surgeons sharing one operation series (18). Most research has been done on small study populations from one or two hospitals (18-24). Different outcome measures have been used to represent the learning curve, such as intraoperative outcome measures such as blood loss and operation time (19-22), intraoperative complications (18, 20, 21), early postoperative complications (18-24), radiological follow-up of implant positioning (18-21, 23, 24) and clinical outcomes measures such as clinical tests

forms that measure the result of clinical examinations and patient reported variables (18, 20, 24). In most studies, a learning curve has been observed (18-23).

Peltola et al. performed the first register study that evaluated learning curve based on data from a national register. Since new implant designs most often come with a new set of surgical instruments and surgical techniques, Peltola et al. hypothesized that there might be a learning curve to fully master these new surgical techniques, and that this could lead to an increased risk of early revision for patients operated during the surgeons' learning curves. As mentioned above, when studying the learning curve for different surgical techniques in THA, this has traditionally been done by studying consecutive operations performed by single surgeons. The FAR does not give information on individual surgeons. Therefore, it is not possible to study consecutive operations performed by single surgeons in this register. Consecutive operations performed at single hospitals in the FAR can however be studied. Hence, Peltola et al. came up with an idea to study the learning curve at Finnish hospitals by finding out the order in which new implants had been used in each hospital. Then they compared the risk of early revision for the patients operated during the first 100 operations with patients operated when more than 100 operations had been done. By studying 39,125 operations from the FAR, the researchers showed there was an increased risk of early revision during the implementation phase of new cup and stem pairs in Finnish hospitals during years 1998-2007. However, when stems and cups were studied separately, no increased risk of early revision was found (25).

To date, it has not been known whether the introduction of new implants in Swedish hospitals has been associated with an increased risk of early revision during the implementation phase.

Aim/objective

To find out whether there is an increased risk of early revision when new cup designs are introduced in Swedish hospitals and whether there are any differences in risk between different cup designs.

Material and Methods

Materials and selection criteria

Data was extracted from The Swedish Hip Arthroplasty Register. The data consisted of all primary THAs, revisions and re-revisions reported to the register, primary and revision surgery databases during years 1979-2013 (n=319,596). Index stem-revisions and index liner-revisions were excluded since only operations where cups had been implanted were intended to be studied. Index re-revisions were also excluded since these operations usually are more complex and often include bone-grafting and other factors that will influence the results. Hip resurfacings were excluded since they were few and differ from conventional THA in the patient selection, surgical technique and outcome (26). Hence, only primary THAs and first time cup revisions were included. First time cup revisions were included since many surgeons perform both primary and revision surgery and both types of operations may contribute to the overall experience of the individual surgeon with a specific implant. All cases operated after year 2011 were excluded to ensure follow-up of 2 years for all cases. Year 1993 was chosen as the first year of the study period, so all cases operated before year 1993 were excluded. Hence, the study period was years 1993-2011 with the latest follow-up date being December 31, 2013.

Only cup designs that were judged to represent a substantial change of design of its precursor

cups on the Swedish market were selected. The reason for this was to increase the probability that the surgical techniques associated with the new cup designs were not already familiar to the surgeons. Sufficient data on the cup designs used in primary THA before year 1992 were not available. Therefore, to find out which of the cup designs that fulfilled our selection criteria for cups introduced during years 1993-2011 were compared to the designs of the cups used in the same hospital during the year before introduction. For the cup designs used in revision surgery, data on cup designs were available during years 1979-1992. Therefore, the designs of the cups that was used in revision surgery and introduced during years 1993-2011 could be selected based on studies of cup designs in use from 1979 and onwards. Changes corresponding to exchange of the plastic or metallic material without any other changes of surface structure or shape were not included. If anything else in the design was different, a subjective assessment was made to determine whether the cup design should be considered as being or not being a minor modification of a precursor. If there were any uncertainty in this matter, the manufacturer was contacted.

To get sufficient statistical power of analyses, only cups that were used in more than 500 cases in Sweden during the study period were selected. To enable a reasonable survey of the implementation phase, only hospitals where at least one of the selected cups had been used more than 50 times were included. After this selection was made, two of the selected cups were used in less than 500 cases in Sweden during the study period. One was used 428 times and the other was used 374 times. However, it was decided to still keep these cups.

The selected study population included 52,903 operations performed on 46,392 patients. Hence, 6,511 patients were included twice. Of these operations, 5,962 operations were performed on the patients' contralateral hip as primary THAs or index revisions. The other 549 operations were index cup revisions performed on the patients' ipsilateral hip. Fifteen of 119 cup designs introduced on the Swedish market during the study period were included.

Hence, 104 cup designs were not included. The majority of these cups were used in less than 100 cases during the study period.

Sixty-three of 106 hospitals in Sweden during the study period were included. Of the included hospitals, there were 11 University hospitals, 17 County hospitals, 24 Rural hospitals and 11 Private hospitals. The selection criteria are summarized in figure 2.

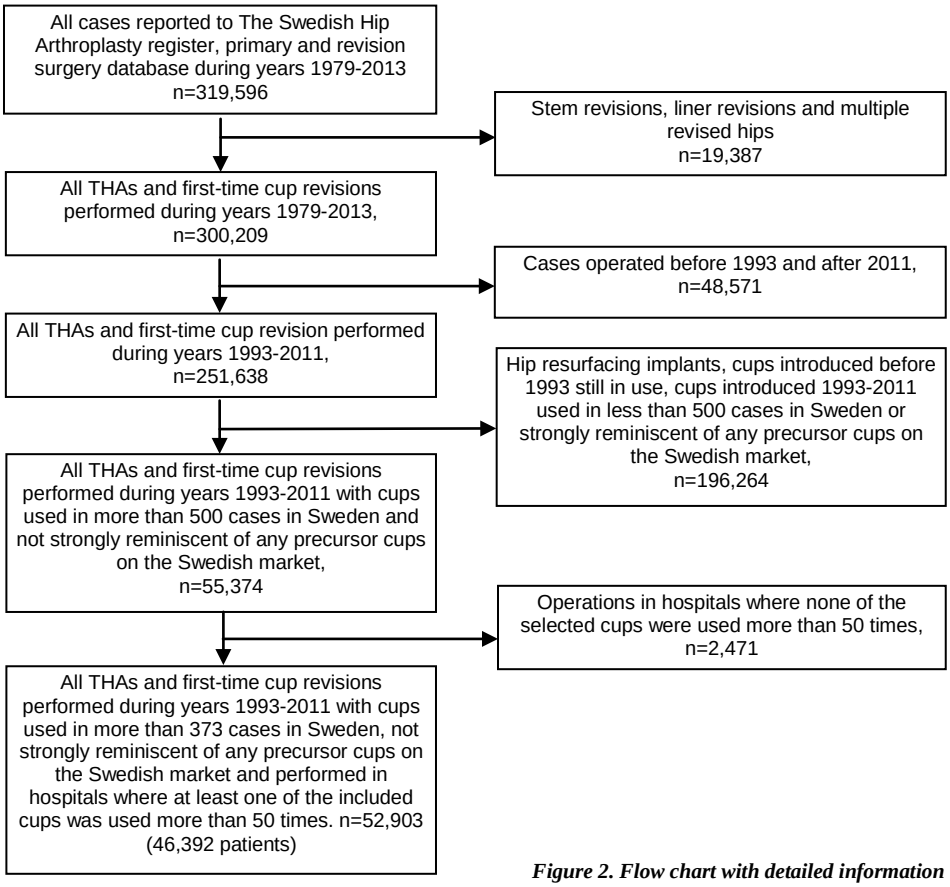

Figure 2. Flow chart with detailed information on case selection

Models for analysis

A cup order number variable was created based on the order in which the included cups had been inserted in each hospital (figure 3).

Date of operation	**10**/Nov./2009	**11**/Nov./2009	**12**/Nov./2009	**.....**
Hospital A	Cup design **X** --> order number=**1**	Cup design **Y** --> order number=**1**	Cup design **X** --> order number = **2**	**.....**
Hospital B	Cup design **Y** --> order number=**1**	Cup design **X** --> order number = **1**	Cup design **Y** --> order number = **2**	**.....**

Figure 3. Illustration of the order number variable.

The order number variable was analysed in three different binary logistic regression models. Revision within 2 years for all reasons, except deep infections (n=51), was used as endpoint (n=902). Deep infections were excluded since the risk of deep infections is most likely not associated with the potential risks related to learning a new surgical techniques. Instead, the risk of deep infections is rather associated with hygienic factors such as ventilation quality in the operating rooms (27, 28). Revision within 2 years was chosen as the outcome variable since early revisions are more likely to be due to technical shortcomings in the primary operation (29), while later revisions are more likely to be due to normal wear (30, 31). A 95% confidence interval was used and a significance value of <0.05 was considered as statistically significant.

In the first model (model 1), the order number variable was used as a continuous (uncategorized) covariate.

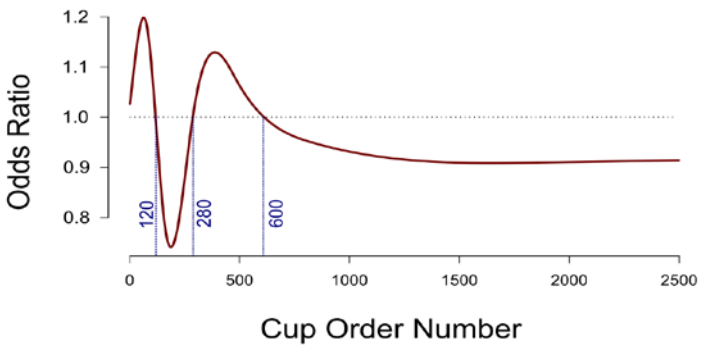

Figure 4. Cubic spline for order numbers.

The second model (model 2) was created by first creating a spline function (described below) based on the odds ratio for each order number value of the order number **variable**. This was done to establish if there were any limits for changes in risk of early revision among

the order numbers. As shown in figure 4, three such limits were found: Order numbers 120, 280 and 600. Therefore, categorized values of the order number variable were used in model 2, with the aforementioned limits used as cut off values, giving the categories 1-120, 121-280, 281-600 and >600. Over 600 was used as the reference category.

Of the covariates available in The SHAR, the ones that were considered to be of most importance in affecting the risk of early revision were age, sex, primary diagnosis, fixation technique, type of hospital and whether the index surgery was a primary or revision surgery. It can be favourable for the statistical model to minimize the number of values of the covariates. Therefore, the nine groups of primary diagnoses reported to The SHAR were merged into three values. The first value represented primary osteoarthritis, which is associated with lowest risk of revision. The second value represented femoral neck fracture, which is associated with highest risk of revision. The third value represented inflammatory joint disease (such as RA), sequelae of childhood illness (such as congenital deformities), avascular necrosis of the femoral head, tumor disease and secondary osteoarthritis due to trauma or other reasons.

In the covariate representing fixation techniques, cemented and uncemented fixation was included.

In the covariate representing type of hospital, University, County, Rural and Private hospital was included.

Models for analyses of whether there were any differences in the early risk of revision between the individual cup designs could not be created. The reason for this was that the

number of early revisions for each cup design was too small to get results of enough reliability. To get reliable results, a minimum of five to ten outcomes per covariate is recommended for binary logistic regression models (32). Ten of the 15 cups did not have 10 or more revisions per covariate and seven of the 15 cups did not have five or more revisions per covariate.

Statistical methods

Binary logistic regression is used to describe the relationship between a dichotomous dependent variable (early revision in our models) and one or several independent covariates. The dichotomous dependent variable represents two outcome values such as 1 or 0, or yes or no. One of the outcomes is chosen as the outcome of interest, for example yes or no. The independent covariates can consist of continuous or categorical values. The results of the analysis are odds ratios. The odds ratios represent the association of the values of the independent covariates with outcome of interest. For continuous covariates, the odds ratio represents the mean change of the odds ratio when the value of the covariate increases by one unit. For categorical covariates, a reference value is chosen. The reference value will have an odds ratio of 1, and the odds ratios for the other values of the covariate are computed in relation to the reference value. An odds ratio over 1 means that the value is positively associated with the outcome of interest, and vice versa. The binary logistic regression adjusts the odd ratios of each independent covariate to the other covariates in the model.
The odds is the ratio of the probability of the outcome to happen to the probability of the outcome not to happen (32). The odds ratio is the ratio of the odds of a value to be related to the outcome of interest to the odds of the reference value to be related to the outcome of interest (32, 33). It can be difficult to intuitively grasp what the odds ratio means, but when

the outcome is rare (as in our analyses), the odds ratio is approximately equal to relative risk (33).

The statistical software package SPSS was used for the logistic regression analyses.

A spline is a function that can be made to fit a given set of data, and is often used to create a curve to fit the data in a coordinate system of two dimensions. A certain number of data points are chosen to be the "knots" of the spline function. The knots are points through which the curve must pass. In the intervals from one knot to the other, the spline function is made of polynomial functions of different degrees. Polynomial functions of degree three (cubic spline) is most commonly used. At the knots, the adjacent polynomial functions must have the same first and second derivate. This makes the curve continuous at the knots (34). The curve plotted in figure 3 is a cubic spline fitted to our data with the help of five knots.

The statistical software R was used to create the cubic spline function.

The regression models 1 and 2 were tested with the Akaike information criterion (AIC) (described below). The tests showed that both models performed best with the age covariate used as a continuous covariate. The tests also showed that both models performed best when adjusted for all the covariates that were considered to be of most importance in affecting the risk of early revision. Hence, both regression models were adjusted for age, sex, primary diagnosis, fixation technique, type of hospital and whether the index surgery was a primary or revision surgery.

The Akaike information criterion (AIC) is a statistical method for selection of models for analysis. The AIC tests the quality of models for a given set of data. To test the models, all the independent covariates anticipated being associated with the dependent variable (outcome) is included. Then models with all possible combinations of covariates included are tested in

relation to the other models to predict the model with the best fit to the data. If a model has too many covariates, there is a risk of over-adjusting the model. Over-adjusting increases the variance in the model, which leads to less significant predictions with broader confidence intervals. This will make the model less capable to predict the outcome. To deal with this, the AIC increasingly penalizes models with increasing numbers of covariates (35).

The statistical software R was used to perform the model selection with the AIC.

Ethics

Patients are recruited to The SHAR in connection to the surgery of the hip joint. The patients are given oral information about The SHAR by the examining doctor and are further informed that he or she have the right to be removed from the register according to guidelines designed in the Privacy Act. Furthermore, an information booklet containing information about The SHAR is handed to each patient.

This project was a register study. No additional information than provided by the register data was required. There were no contacts between the researchers and the research subjects.

The project had no experimental elements. No examinations or procedures were performed on individual patients, no drugs were administered and no biological materials were collected.

Since the data is published in an aggregated form, we assess the ability to identify individual patients as negligible. We do not believe that research subjects were exposed to any risks in this project.

No animal testing was performed.

The project was assessed to be compatible with the principles of the Declaration of Helsinki and the United Nations Declaration of Human Rights.

Results

Study population

The mean age of the study population (n=52,903) was 66.7. The distributions between different age groups were 7.6% under 50 years of age, 17.2% between age 50-59, 32.0% between age 60-69, 29.5% between age 70-79 and 13.7% were over 79 years of age. The distributions of sex were 57.7% male and 42.3% female.

The distributions of all characteristics of the study population are shown in table 1.

Comparison of characteristics of the study population and the population of all THAs and first-time cup revisions performed during the study period (table 1) showed that the selected study population was slightly younger (mean age of reference population was 69.1) and included relatively more men than women. The study population included relatively more cases with primary osteoarthritis and less with femoral neck fracture as primary diagnosis. The study population also included relatively more cases operated with uncemented fixation rather than cemented fixation and relatively more cases operated in University and Private hospitals rather than in Rural hospitals. There were also relatively more cases for which the index operation was a first-time cup revision in relation to a primary THA.

The cup designs included are shown in table 2.

Table 1. Characteristics of selected cases operated during years 1993-2011 (n=52,903). Characteristics of all THAs and first-time cup revisions operated during years 1993-2011 (n=251,638) are shown in brackets in the percent column for comparison.

Covariates and values	n	Percent (see description in table heading)
Age group (age were continuous in the models for analysis)		
<50	4,010	7.6 (4.9)
50-59	9,122	17.2 (13.2)
60-69	16,907	32.0 (29.2)
70-79	15,620	29.5 (35.9)
>79	7,244	13.7 (16.8)
Total	52,903	100.0
Sex		
Female	30,505	57.7 (59.5)
Male	22,398	42.3 (40.5)
Total	52,903	100.0
Primary diagnosis		
Primary osteoarthrosis	43,373	82.0 (79.4)
Femoral neck fracture	3,770	7.1 (10.4)
Other diagnoses	5,760	10.9 (10.2)
Total	52,903	100.0
Fixation technique		
Cemented	34,968	66.1 (87.0)
Uncemented	17,935	33.9 (11.7)
Total	52,903	100.0 (1.1 hip resurfacings; 0.2 missing)
Type of hospital		
University hospital	11,280	21.3 (15.6)
County hospital	19,200	36.3 (38.0)
Rural hospital	13,798	26.1 (35.9)
Private hospital	8,625	16.3 (10.5)
Total	52,903	100.0
Index surgery primary or revision		
Primary	48,331	91.4 (93.8)
Revision	4,572	8.6 (6.2)
Total	52,903	100.0
Order number, model 2		
1-120	14,476	27.4 (23.3)
121-280	11,601	21.9 (15.7)
281-600	12,048	22.8 (19.7)
>600	14,778	27.9 (41.3)
Total	52,903	100.0

Table 2. Cups included in analyses. The cups were introduced on the Swedish market during years 1993-2011 and not strongly reminiscent of any precursor cups on the Swedish market.

Fixation technique and cup design	n	Percent
Cemented fixation (n=7)		
Contemporary Hooded Duration	10,686	20.2
ZCA XLPE	10,264	19.4
FAL	6,397	12.1
OPTICUP	4,182	7.9
Weber all-poly cup	1,665	3.1
Exeter X3 RimFit	1,400	2.6
Avantage Cemented	374	0.7
Total	34,968	66.0
Uncemented fixation (n=8)		
Trilogy	10,661	20.2
Trident HA	2,551	4.8
Allofit	1,523	2.9
TMT	879	1.7
Ranawat/Burstein	652	1.2
Reflection HA	625	1.2
ABG II HA	616	1.2
TOP Pressfit HA	428	0.8
Total	17,935	34.0

Analyses

The adjusted regression analysis model 1 showed no increased risk of early revision within 2 years during the implementation phase of new cups. The significance of the continuous cup order number variable in model 1 was 0.93.

The spline function describing the relationship between the order number values and the odds ratios for each order number value showed an increased risk for the first 120 cups and for the cups being inserted with order numbers 280-600 (figure 4). Using the aforementioned numbers as cutoff values for the order number variable in model 2 did not result in any significantly increased risk of revision within 2 years during the implementation phase of new cups ($p \geq 0.14$).

Complete results of analyses are shown in table 3.

For all reasons for revision except deep infections, 1.7% (n=902) of the study population (n=52,903) were revised within 2 years. For all reasons for revision, 1.8% (n=953) of the study population were revised within 2 years.

Analyses of whether there were any differences in early the risk of revision between the individual cup designs could not be done since the number of early revisions for each cup design was too small to get results of enough reliability.

Table 3. Results of binary logistic regression analysis for models 1 and 2. Odds ratio (OR) for revision within two years, with 95% Confidence Interval (CI) and Significance (Sig.) is shown for each order number value. Adjusted and unadjusted results are shown. Adjusted results are adjusted for age, sex, primary diagnosis, fixation technique, type of hospital and if index surgery was a primary or revision surgery.

Model for analysis	Covariate	OR (95% CI)	Sig.
1	Order number, continuous (adjusted)	1.0 (1.0-1.0)	0.97
	Order number, continuous (unadjusted)	1.0 (1.0-1.0)	0.22
2	Order number, categorized (adjusted)		
	1-120	1.1 (0.9-1.3)	0.28
	121-280	0.9 (0.7-1.1)	0.14
	281-600	1.1 (0.9-1.3)	0.30
	>600 (reference)	1.0	
	Order number, categorized (unadjusted)		
	1-120	1.2 (1.0-1.4)	0.04†
	121-280	0.9 (0.8-1.1)	0.41
	281-600	1.2 (1.0-1.4)	0.14
	>600 (reference)	1.0	

†Significant ($p < 0.05$)

Discussion

The adjusted logistic regression analyses showed no increased risk of early revision surgery within 2 years during the implementation phase of new cups.

A recent study by Peltola et al. found an increased relative risk (1.3 (95% CI: 1.1-1.5) of early revision during the first 15 operations with new stem and cup pairs in Finnish hospitals. However, when the order numbers of stems and cups were analyses in separate models, no increased risks of early revisions were found (25). Hence, our analyses confirm their result for cups. However, there were some differences between their and our models. Their model was adjusted for age, sex and the order number of stems. They tested models with more covariates included but those models performed worse according to the information criterion and were therefore discarded.

Peltola et al. also used a longer follow-up than we did, with a minimum of 3 years of follow-up. However, they reported that most early revisions occurred within the first year after the index surgery.

The distribution of sex in the study populations was similar between our study and the Finnish study. The distribution of age was quite similar, but our study population had a relatively larger proportion of cases in the youngest and oldest age groups. The Finnish study only selected cases with primary osteoarthritis as primary diagnosis, probably to avoid bias due to an increased risk of early revision for other diagnoses. We included all nine primary diagnoses registered in The SHAR. However, when adjusting analyses for diagnoses we used a covariate with seven of the nine diagnoses merged into a single value called "other diagnoses" to minimize the amount of values in analyses.

The Finnish study only included primary THAs as index operations while we include both primary THAs and first time cup revisions. Many implants are used in both primary THAs and revision surgeries and about 5-10% of all hip surgeries performed annually are revisions (29). The exclusion of revisions could therefore lead to missing operations in the cup order number variable. Since first-time cup revisions are associated with an increased risk of revision compared to primary THAs, we adjusted our analyses for whether the index operation was a primary THA or a revision surgery.

Regarding differences in characteristics of out study population and the population of all primary THAs and first-time cup revisions performed in Sweden during the study period, differences in distribution of age, sex and primary THAs relative first-time cup revisions was small. However, the difference in use of uncemented fixation was higher, 34% in the study population and 12% in the reference population. This reflects that uncemented cups were increasingly introduced in Swedish hospitals during the last decade (29). The study population included relatively more cases operated in University and Private hospitals rather than in Rural hospitals. This could potentially reflect a more conservative approach regarding the introduction of new cup designs in Rural hospitals. It could also reflect the fact that Rural hospitals operate a smaller share of revisions and "difficult cases" in relation to University hospitals. This could possibly lead to a smaller need for the introduction of new cup designs. Cup designs aimed to improve the results for patients revised due to dislocation problems is one such example. Why relatively more operations with new cups are performed in Private hospitals we do not know.

Methodological considerations

A statistical method that is similar to binary logistic regression is Cox-regression. Cox-regression is more flexible than binary logistic regression. In Cox-regression, patients with different follow-up times can be included and the method adjusts the results for patients that die before the end of follow-up (36). Even though Cox-regression due to its flexibility is more widely used than binary logistic regression in THA research, it was unnecessary in our analyses to adjust for patients that die before the end of follow-up, since very few patients die within two years after THA. Furthermore, since we had a fixed time limit of follow-up, different follow-up times were not needed to be considered.

The Akaike information criterion is widely used for model selection.

Spline functions are not widely used in THA research. However, we assess it was an interesting approach to use a spline function to visualize trends of different risks of revision among the order number values, even though the observed trends turned out not to be significant when studied in a regression model.

There are many advantages to study data with coverage on a national level.

First, with data covering a large number of operations, the probability of finding even small differences in risks between values increases.

Second, studying data from a register with a high reporting rate gives the advantage of accurate follow-up and only a small number of cases lost to follow-up.

Third, if data are collected from only a few selected surgeons and/or hospitals, there is a greater risk of performance bias to occur.

However, there are limitations of this project that should be considered.

First, we had no information on individual surgeons. With such information one could create the order number variable based on the order in which the cups were inserted by each surgeon instead of the order in which the cups were inserted in each hospital. Obviously, when creating the order number variable based on the order in which the cups were inserted in each hospital, the more surgeons operating in a hospital, the more surgeons will share the operations that give the order number values. Surgeons in hospitals with more surgeons could therefore be earlier in their learning curves than surgeons in hospitals with fewer surgeons for each value of the order number variable. If a clinical learning curve for mastering new techniques associated with new cup designs exist, more surgeons per hospital would be a negative bias. Under these circumstances, adjusting analyses for the number of surgeons operating with the cups per hospital would be optimal. However, there was no available information on number of surgeons per hospital during the study period. However, to the best of our knowledge, University hospitals usually have most surgeons per hospital followed by County, Rural and Private hospitals, even if there are exceptions. Therefore, we adjusted for type of hospital as a surrogate measure of surgeons per hospital. However, since the number of surgeons per hospital varies among hospitals of the same type, type of hospital is a gross measure of surgeons per hospital.

Another consequence of not being able to follow single surgeons is that we did not know if any surgeons moved to a new hospitals during the study period. A surgeon moving to a new hospital could start using a cup he or she is familiar with from previous practice. If this occurred it could have biased our analyses.

Second, we did not know the true change in surgical technique associated with the introduction of a new cup design. It is not known how much change in a cup design that would be needed to give a change in surgical technique that is sufficient enough to alter the surgical outcome. When the only thing that differed between a new cup design and any

precursor was the material of the plastic liner or the material of the metallic cup shell, this type of modification were not included. However, for other changes in cup designs, the assessments were not based on any established criterion, but were subjective and therefore a potentially gross measure of the change in surgical techniques. Furthermore, we did not have sufficient data on cup designs used in primary THA before year 1992 and some designs could have been used temporarily before 1992 without our knowledge.

Third, of the 902 early cup revisions in our study population, it is possible that there were cases where the reason for the revision was a failed stem but where the cup was revised along with the stem despite that the cup had not failed. Our data did not tell us whether any such cases were included in our study population.

Fourth, it is likely that some of the cases operated with a new cup design simultaneously received a new stem design. If new stem designs are associated with an increased risk of early revision during the implementation phase, this could have biased our result. We do not know how many such cases that were included in our study population.

Fifth, some of the revisions within 2 years in our study population were most likely stem revisions only. This could have biased our result. We do not know how many such cases that were included.

Conclusions and Implications

We were not able to demonstrate an increased risk of early revision when new cup designs are being introduced in Swedish hospitals. This finding is surprising but may partly be explained by the structured and stepwise introduction of new implant designs applied in Sweden.

Our results give no indication that any specific changes are necessary in today's procurement procedures for cups or in the routines regarding the introduction of new cup designs in

Swedish hospitals on a national level.

Since analyses of the risk of early revision for individual cup designs could not be done, it can not with certainty be ruled out that any of the cup designs included could potentially be associated with an increased risk of early revision during the implementation phase.

Further research will be required to assess whether there is an increased risk of early revision when new stem designs or implants that are completely new are introduced in Swedish hospitals.

Populärvetenskaplig sammanfattning (svenska)

Operation med höftprotes är idag ett rutiningrepp. De goda resultat som idag presenteras bygger på välfungerande rutiner i hela sjukvårdskedjan. Trots detta införs nya höftprotesmodeller kontinuerligt i syfte att ytterligare förbättra utfallet vid höftproteskirurgi. En höftprotes består av två delar. Den ena delen ersätter den övre delen av lårbenet och kallas för stam. Den andra delen ersätter ledpannan på bäckenet och kallas för cup. Hypotesen för detta arbete var att introduktionen av nya protesmodeller på svenska sjukhus skulle kunna innebära ett temporärt försämrat utfall för patienterna. Detta på grund av att det skulle kunna ta ett antal operationer innan läkarna fullt ut lärt sig att bemästra den nya operationstekniken som är kopplad till att operera med en ny protesmodell. I detta arbete undersökte vi detta specifikt för nya cupmodeller. Tack vare Svenska Höftprotesregistret kunde vi få information om alla operationer med nya cupmodeller på svenska sjukhus som registrerades mellan 1993 och 2011. Sammanlagt inkluderades 52,903 operationer och 15 nya cupmodeller i undersökningen. Operationerna utfördes på 63 av 106 svenska sjukhus som utförde höftproteskirurgi mellan 1993 och 2011. Först tog vi reda på i vilken ordning cuparna hade använts på respektive sjukhus. Med hjälp av en statistisk metod jämförde vi sedan utfallet för de operationer som gjordes då cuparna var nya på sjukhusen med utfallet för de operationer som gjordes efter att cuparna använts mer än 600 gånger. Utfallet var ifall patienterna hade behövt omopereras inom två år efter operationerna eller inte. Resultatet visade att det inte var någon förhöjd risk för omoperation då cuparna var nya jämfört med när de använts mer än 600 gånger. Vi undersökte även om risken för omoperation minskade för varje gång i ordningen cuparna hade använts på sjukhusen. Inte heller denna undersökning visade på någon förhöjd risk för omoperation då cuparna var nya på sjukhusen. Resultatet är

förvånande, men kan troligen delvis förklaras av de välstrukturerade rutiner som finns för hur nya protesmodeller introduceras i Sverige.

Acknowledgements

I want to thank My Supervisor and co-Supervisor for a great commitment in tutoring me all throughout this project. I also want to thank The Swedish Hip Arthroplasty Register for providing the data.

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