Cost-effectiveness of Birmingham Hip Resurfacing compared to Total Hip Replacement

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1. Abstract

Objective: The purpose of this study was to investigate the cost-effectiveness of metal-on-metal Birmingham Hip Resurfacing (MoM BHR) versus ceramic-on-ceramic Total Hip Replacement (CoC THR), in younger OA patients, with use of decision analytic modelling considering the long term effects.

Methods:

A Markov decision analytic model was constructed to compare the quality-adjusted-life years (QALYs) and costs of MoM BHR versus CoC THR in a 15-year time horizon and from a healthcare perspective. Sensitivity analyses were performed to explore the robustness of the decision analytic model. The main outcome measure is the incremental cost effectiveness ratios (ICERs).

Results:

Estimates based on the model show that patients receiving a MoM BHR experience lower effectiveness, presented as less QALYs, and have lower health care costs compared to CoC THR patients. The ICER of CDN $ 35303/QALY calculated from lower gains in QALYs with lower health care costs will not necessarily be considered cost-effective. Subgroup analysis showed that MoM BHR was associated with higher effectiveness, lower costs and therefore cost savings both for females younger than 50 years of age and males younger than 60 years of age. Initial costs for MoM BHR and CoC THR and the utility post first revision MoM BHR had the largest impact on the results found.

Conclusions:

The results of this study confirm results reported in other studies that MoM BHR is cost-effective or cost savings for females younger than 50 years of age and males younger than 60 years of age. In the base case analysis, probability that MoM BHR is cost-effective compared to CoC THR is only 53% with a willingness-to-pay of $50,000.

2. Introduction

Advanced hip osteoarthritis (OA) is a common chronic condition causing severe joint pain and loss of joint function. The incidence and prevalence are rising as the population ages, nowadays OA is affecting an estimated 10% of Canadian adults (1). Total hip replacement (THR) has been recognized as one of the most effective surgical interventions to relieve pain and improve function for patients with severe OA, after all non-operative treatment options are exhausted (2;3).

Although many different prostheses are available, they generally consist of three parts: the acetabular component, which is fitted into the patient's native acetabular pelvic bone, the femoral component, which is inserted down the femoral canal, and the bearing surfaces (4). The most commonly utilized bearing surface for THR in Canada is a metal (cobalt-chrome) femoral head with a second-generation cross-linked polyethylene (59%), combined with cementless implant fixation (4). Choices in bearing surfaces can be made based on some selection factors such as patient's age, gender, regions and companies that provide the types of device. In Alberta, ceramic-on-ceramic (CoC) is the most often applied bearing surface. With a CoC bearing surface there is no potential for metal ion release and the shown increased strength and fracture resistance make CoC attractive for younger patients(4). Compared to other provinces, Alberta has a younger population, this might result in the preference for CoC bearing surfaces.

THR is a highly cost-effective intervention compared to non-surgical options in hip OA patients (4;5). Unfortunately, in about 10% of patients revision surgery is required (5;6). Revision surgery is more difficult to perform, more expensive than primary THR, and outcomes, such as mobility and pain are often less satisfactory (7). Therefore, people who are expected to outlive a primary THR are typically only considered for THR when their symptoms become unmanageable by non-surgical options.

The Canadian Institute for Health Information reported a 59% increase in THR's from 1996-1997 to 2006-2007 (37,943 hospitalizations) (8). Of THR's reported between 2006–2007, 86.4% of operations involved primary replacements, while 13.6% involved revisions. The most common reasons reported for hip replacement revisions in 2006–2007 were aseptic loosening (44%), osteolysis (22%), poly wear (21%) and instability (13%) (8). Instability is in this case an umbrella definition for dislocation and subluxation.

The majority of THR's were performed on people over the age of 65. However the increasing trend for total hip replacements in the younger age groups is important to monitor as these patients are more likely to outlive their devices and, subsequently, require a surgical revision.

Based on limited early evidence mainly from the United Kingdom, metal-on-metal hip resurfacing arthroplasty (MoM HRA) has emerged as an alternative to THR, for younger and more active patients. In addition, MoM HRA might also be appropriate for people ineligible for THR for clinical reasons other than age or activity (6). The first HRA was developed by Charnley in the early 1950s; a Teflon-on-Teflon bearing was responsible for a high failure rate and finally resulted in abandonment of the procedure (6). Some HRA with MoM bearing were developed in the 1970s and 1980s but the results were disappointing because of excessive wear, osteolysis, bone loss and early failure. Wagner and McMinn were the first to reintroduce MoM HRA about 20 years ago. The increased understanding of mechanical properties of materials related to wear has increased the interest in the use of MoM bearings.

In MoM HRA, the head of the femur is not completely removed; it only involves the removal of diseased or damaged surfaces of the proximal femur and the acetabulum. The acetabulum is then lined with a pair of metal bearings, which provide an articulating surface and the prepared femoral head is covered. Potential advantages of the MoM HRA over THR include minimum bone resection and conservation of femoral bone, and maintenance of normal femoral loading and stress(6;7). Theoretically the morbidity will decrease with MoM HRA and patient outcomes associated with future revision will improve because of the preserving of femoral bone(5). However, the safety of MoM HRA is controversial(5), especially due to the additional risk of developing a fracture of the femoral neck, component loosening and metallosis. Despite the safety concerns and the not yet conclusively demonstrated ease of future revision surgery, there is an increasing trend in the number of MoM HRA's in Canada. In the Canadian Joint Replacement Registry (CJRR) the number of reported MoM HRA's has increased from 75 procedures (0.7% of all hip replacement procedures) in 2003–2004 to 278 procedures (2.7% of all hip replacement procedures) in 2006–2007 (8).

MoM HRA rather than THR is particularly suitable for patients with a large femoral offset or a wide femoral canal, or those with femoral shaft deformity, in which it is difficult to fit a stem (9). Those characteristics are often related to male gender and therefore an important indication to consider MoM HRA is male gender (4).The preference for male gender towards MoM HRA is also a result of reported

increased rates of revision and a generally higher prevalence of failure for females (10-13); a poorer bone density in females results in a higher rate of femoral fractures (14;15).
In the contrary, reverse numbers related to gender are reported for THR: the risk of failure in THR is supposed to be higher in males (8;16). This is translated in the fact that there are twice as many females than males undergoing THR (14).

Besides gender, another often discussed criterion for the selection of patients for MoM HRA versus THR is age. Implant survival after THR in younger patients is generally lower; after 15 years the implant survival is approximately 70% in patients <50 years, approximately 75% in patients 50-59 years old, approximately 85% in patients 60-75 years old and approximately 95% in patients >75 years (16;17).
As mentioned above, MoM HRA has emerged as an alternative for younger patients (6) and as a result most published studies only show results in younger patient (13;18-21). Nevertheless, some studies suggest MoM HRA is also a suitable option for older patients (22-24).

At present, just a few randomised controlled trials comparing THR and MoM HRA, have been performed (25;26), and to our knowledge no randomised controlled studies were performed which compared quality of life and costs after the two procedures and specifically looked at gender and age differences. Moreover, MoM BHR was introduced in 1997(27) in the UK and therefore it is not possible to obtain long term follow-up information regarding MoM BHR outcomes. As pointed out, there are indications of differences between age and gender in performance of THR and MoM HRA but due to a lack of high quality data it is hard to make clear recommendations about the use of these prostheses. Therefore the current criteria for selecting patients for MoM HRA versus THR should be explored and evaluated to inform future health policy.

Given the lack of high quality and long-term follow-up data, decision analytic modelling is a useful approach to analyse performance of the MoM HRA and THR in specific subgroups The advantage of decision analytic modelling is the possibility to combine different data sources and to handle incomplete or missing information to obtain cost-effectiveness estimates. One of the concerns about decision analytic modelling is the lack of transparency which can lead to improper interpretation of the results, use of inappropriate comparators, the lack of “real world” data in the analysis, poor generalizability and the lack of appropriate subgroup analysis (28). Moreover, there is also critism about the timeliness of the information and inappropriate choice of assumptions.

Performance of MoM HRA and THR can be analysed by comparing lifetime costs and gains in quality of life (QoL) associated with the two procedures based on known information regarding costs, quality of life and probabilities of clinical outcomes like revisions and complications. Decision analytic modelling techniques also offer the potential to analyze the long-term performance of a new technology prior to the availability of long-term clinical outcome data. A Markov model is a state transition model and therefore appropriate to analyse recurrence of events (29). The time period of interest is divided into equal intervals, or cycles and a finite set of mutually exclusive health states is defined (29). The health states are defined such that, in any given cycle, a member of the cohort is in only one state. Transition probabilities define the possible movements between health states. Different utilities and costs are accumulated for each time interval spent in a particular state.

Within the cluster of MoM HRA, metal-on-metal Birmingham Hip Replacement is the most often applied device in Alberta, and is therefore chosen as the device to be compared to THR. THR with a ceramic-on-ceramic bearing surface (CoC THR) is the most often applied THR in Alberta and therefore the best procedure to use as comparator. The purpose of this study was to investigate the cost-effectiveness of MoM BHR versus CoC THR, in younger OA patients, with use of decision analytic modelling considering the long-term effects. Outcomes will be in incremental cost-effectiveness ratios (ICERs). Results of this study could be used to help inform Alberta Health Services (AHS) in long-term policy issues regarding hip replacements in Alberta. The specific objectives of this study were (a) to evaluate the cost-effectiveness of MoM BHR compared to CoC THR by patient age and gender, considering the long-term effects, and; (b) to explore uncertainty surrounding the estimates in the decision analytic model using a sensitivity analysis.

Sub questions:

1) Are there differences in cost-effectiveness by gender?
2) Are there differences in cost-effectiveness for by age?

Hypothesis:

1) We expect that MoM BHR generally shows a larger ICER than CoC THR in this cohort.
2) We expect that for male gender MoM BHR has a larger ICER than CoC THR. In the contrary, for female gender we expect MoM BHR to have a smaller ICER than CoC THR.

3) We expect MoM BHR has a higher ICER for younger patients: males and females under the age of 50.

3. Methods

This study employed a state-transition model to analyse cost-effectiveness (CEA) and cost-utility (CUA) of hip replacement treatment by capturing data from multiple sources. The decision tree used in the study structures the choice and subsequent consequences of two primary treatment alternatives; MoM BHR and CoC THR, in which each alternative is represented as a Markov state with mutually exclusive health states (figure 1). The analysis was performed using a decision analysis software package (TreeAge Pro 2011; TreeAge Software, Inc, Williamstown, MA).

3.1 Model structure

The model starts with a decision for either MoM BHR or CoC THR. After the primary surgery, patients' first cycle started in either Post-Primary MoM BHR or Post-Primary CoC THR health state. Thereafter, patients were able to move to different health states (table 1 and 2), as determined by the annual transition probabilities or remain in a state. For MoM BHR, the health states are post primary BHR, post first revision BHR, post conversion to THR, post first revision THR after a conversion to THR, post second revision THR after a conversion to THR and death. Thus, MoM BHR patients may experience either an initial failure requiring a first revision BHR or a conversion to THR, or a subsequent failure requiring a first and possibly second revision after THR. For CoC THR, the health states are post primary THR, post first revision THR, post second revision THR and death.

The cycle length is one year and the model assumes that the patient is always in one of finite number of states of health. In each state during each yearly interval, patients experience a quality of life and possibly incur medical costs. Transitions associated with revision surgery or major complications not requiring surgery are associated with a short-term decrement in QoL and an increase in medical costs. State transitions occurred at the beginning of a year and therefore a half cycle correction was applied. The base case estimates were derived from the HIP (Hip Improvement Project)(described later in section 3.2), National Joint Registries and literature. In health care, effects and costs often accrue for different durations of time and over different time periods. Therefore both utilities and costs were discounted at 3% to reflect society's rate of time preference (30-32).

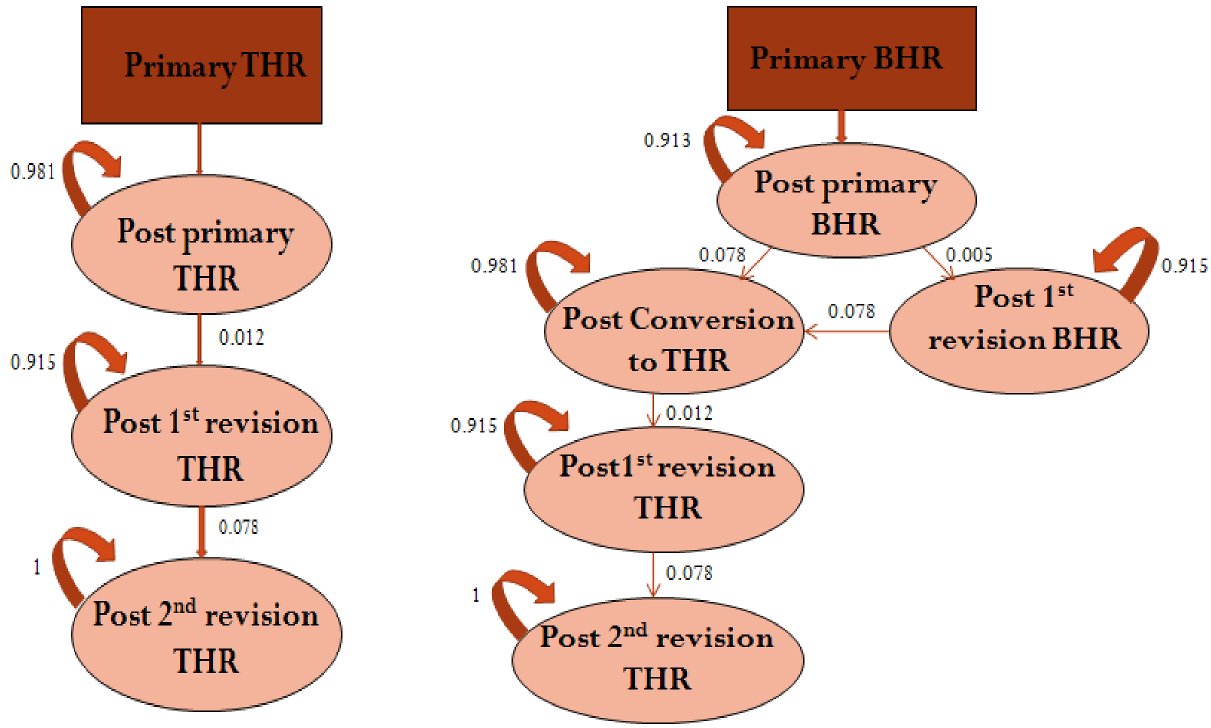


Figure 1 Markov models for both procedures with probabilities related to males <50 years. Transition to death state is possible from every health state (not shown in the diagram).

Table 1 Health states and transition probabilities in the first cycle for males <50 years who underwent primary MoM BHR

	Post-Primary BHR	BHR Post-1st Revision	Post-Conversion to THR	THR Conversion Post- 1st revision	THR Conversion Post-2nd revision	Death
Post-Primary BHR	0.913					
BHR Post-1st Revision	0.005	0.915				
Post-Conversion to THR	0.078	0.078	0.981			
THR Conversion Post-1st revision	0	0	0.012	0.915		
THR Conversion Post-2nd revision	0	0	0	0.078	0.993	
Death (mean 44 years)	0.004	0.007	0.007	0.007	0.007	1
Total	1	1	1	1	1	1

Note: a. Death in the first year is calculated as 0.25 * 90-day mortality and 0.75 * general mortality in Alberta.

b. Other data sources are described in table 3.

Table 2 Health states and transition probabilities in the first cycle for males <50 years who underwent primary CoC THR

	Post-Primary THR	THR Post-1st Revision	THR Post-2nd revision	Death
Post-Primary THR	0.984			
THR Post-1st Revision	0.012	0.915		
THR Post-2nd revision	0	0.078	0.993	
Death	0.004	0.007	0.007	1
Total	1	1	1	1

Note: a. Death in the first year is calculated as 0.25 * 90-day mortality and 0.75 * general mortality in Alberta.

b. Other data sources are described in table 3.

3.2 Study population for base case analysis

The data for the model was mainly derived from a large cohort study, The Hip Improvement Project (HIP), completed with data from National Joint Registries and large studies. The population of interest consisted of males and females under the age of 65 undergoing MoM BHR and CoC THR for advanced OA of the hip. The Hip Improvement Project (HIP) is an important source in the base case analysis. The HIP was designed to provide evidence for orthopaedic surgeons and decision makers in Alberta regarding current and new orthopaedic devices. In partnership and collaboration with Alberta Health and Wellness, the Alberta Orthopaedic Society, former Regional Health Authorities of Alberta Health Services, the University of Calgary and the University of Alberta, Alberta Bone and Joint Health Institute (ABJHI) has been leading the HIP since June, 2004. In the HIP, eligible patients were at least 18 years old and under age 65 for males and under age 55 for females. Patients had evidence of degenerative joint disease and were able to provide written consent. Exclusion criteria included renal failure, childbearing potential, inappropriate femoral anatomy, inflammatory arthritis, or unwillingness to consent. Patients were identified, screened and recruited by participating orthopaedic surgeons from their offices during the patient's visit. The selected cohort for this cost-effectiveness model consists of the cohort enrolled at the HIP who underwent either conventional CoC THR or MoM BHR for treating disabled hip OA and (a) have data on baseline (before surgery), (b) have hospital chart review, and (c) were followed up to 3 years (Figure 2). Patients were not randomized to either MoM BHR of CoC THR but the choice for MoM BHR or CoC THR was already made by a physician before enrollment in HIP.

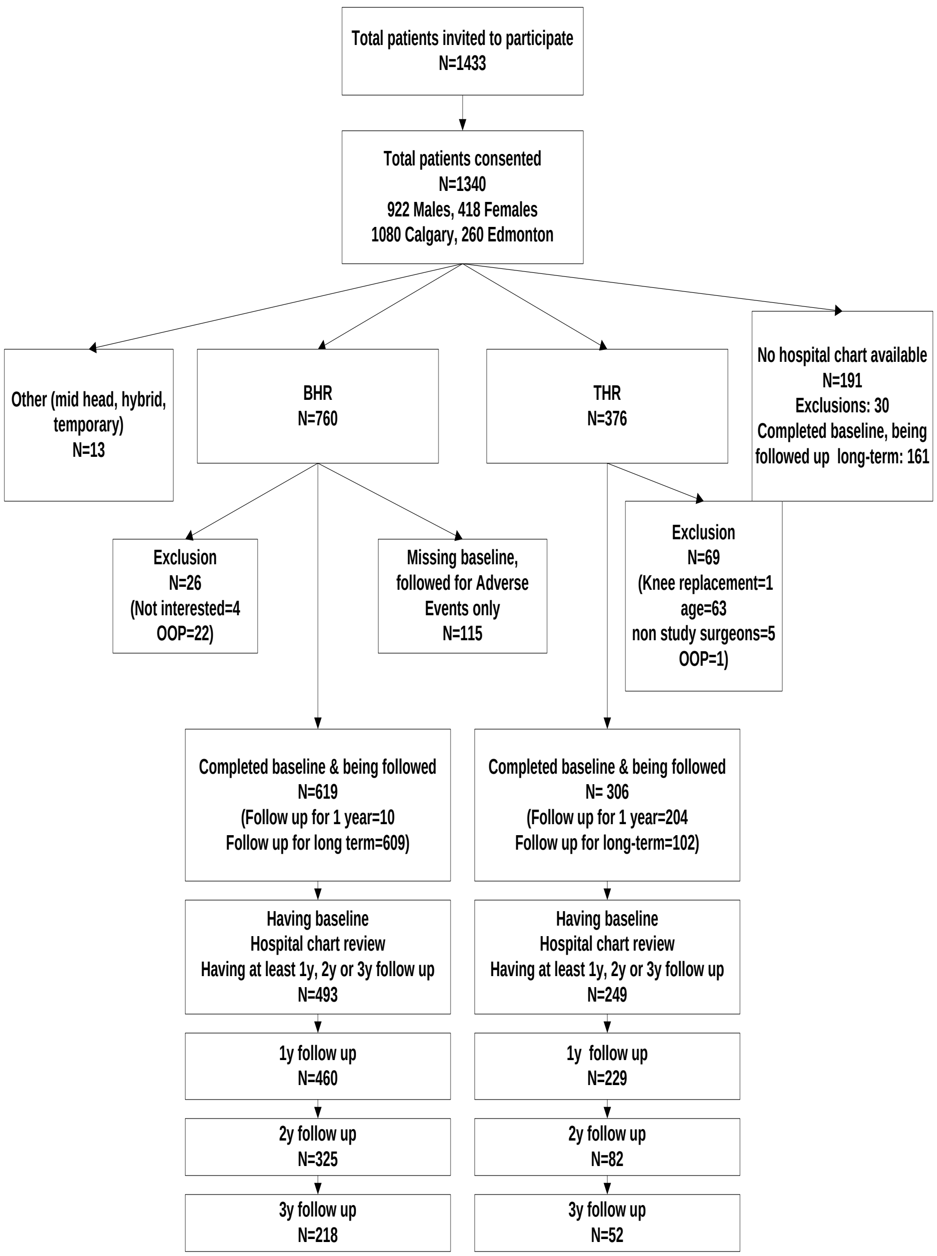


Figure 2 Population included in the HIP

Mean age in the base case cohort was 49.7 years in the MoM BHR groups (23% female) and 49.6 years in the CoC THR group (48% female). Age distributions in the specific age groups were obtained from distributions in the HIP cohort. Moreover utility measures and costs used in the model were also obtained from data derived in the HIP. As the proposed model horizon greatly exceeds the trial length of the HIP project, no reliable information regarding revision rates was available. Therefore the National Swedish Registry and McBryde et al. were used to obtain information about annual revision probabilities for the base case (14;33).

3.3 Model Inputs

The utilities, costs and event probabilities applied in the decision model were determined by type of procedure, patients' gender, patients' age and the cycle number.

3.3.1 Event probabilities

Information on clinical outcome probabilities, including revision rates, major complications not requiring surgery, conversion from MoM BHR to CoC THR, dying from surgical procedure and death related to other cause, were derived from the HIP project, National Joint Registries and studies with large study samples. Data was sufficient to estimate procedure, age and gender specific probabilities of revision and death. The Swedish Hip Arthroplasty Register provides cumulative percentages of patients who underwent revision surgery for 15 years after primary THR in 188,299 patients. Revision probability is defined as the replacement or extraction of one, several or all parts of the prosthesis (16;33). This revision probability will change over years, therefore a specific revision probability is calculated for every year (cycle) in the decision model.

In the National Joint Registries no specific information was found about annual revision probabilities regarding MoM BHR. Therefore McBryde et al. (14) was used as a source for annual revision probabilities in MoM BHR; with 2123 OA patients who underwent MoM BHR, annual revision probabilities were reported for a period of 10 years. MoM BHR was introduced in 1997 (27); therefore it is not possible to obtain information to 15 years. Annual revision probabilities up to 15 years were calculated with use of fractional polynomial regression.

No information about second revisions after primary CoC THR and probabilities on a conversion to CoC THR were reported in the National Swedish Joint Registry, therefore this information was obtained from the Australian Joint Registry (34). Given the very low probability of more than 2 revisions, as approximately either 0.8% of hip replacement patients in Canada will require a 3rd or 4th revision, no 3rd

or more revisions were built into the model (8). Transitions probabilities, costs and utilities were considered only to revisions, as re-operations are not frequent in Alberta, and don't seem to have a relevant impact on final outcome measures.

Major complications not requiring revision surgery were based on all-cause adverse events related to the procedure: pulmonary embolism (PE), myocardial infarct (MI), deep venous thrombosis (DVT), infection, dislocation, unexpected pain, fracture, component loosening, metallosis, avascular necrosis (AVN) and osteolysis. Only major complications were considered in this analysis, as minor complications are solved in a short period of time and don't seem to have a relevant impact on final costs and utilities. Moreover, general minor complications are assumed to be equal for both groups.

Surgical (including joint-related) mortality rates were derived from the Swedish Registry (16). Annual gender- and age-specific all-cause mortality rates were based on Alberta Life Tables.

3.3.2 Utilities

The effectiveness of MoM BHR and CoC THR was based on quality adjusted life years (QALYs) associated with each procedure. To calculate QALYs, values (utilities) were assigned to all health states in the model and specifically to each year of follow-up. Utilities are defined as a measure of how a patient defines the value of a specific health state. Guidelines define utility along a continuum with a value of 1.0 representing perfect health and a value of 0.0 representing death (35). Arthritis has consistently been shown to have a utility value near 0.7 and hip replacement has been shown to increase quality of life weightings close to normal values (36). A major source of input for the decision analytic model regarding utility information is the HIP project. In the HIP SF-36 scores were obtained to measure quality of life. To facilitate the use of SF-36 scores in CUA, equations were constructed which use results from the SF-36 to predict a preference-based summery score(SF-6D) (37-40). Preference-based measures of health can be used to derive utility values. Utilities can be used to calculate QALYs by multiplying the utility value with the expected life years. The QALY therefore quantifies both health-related QoL and life expectancy, and allows comparison across interventions (37). Mean baseline utility scores of 0.608 in the MoM BHR group and 0.570 in the CoC THR group were observed in HIP. A baseline correction was applied to make groups comparable.

Decrements in utility, as a measure of the transient lower QoL associated with revision surgery or major complications were derived from Coyle et al. (41) and scaled to the SF-6D scores calculated with SF-36 scores obtained in HIP. Those decrements in utility represent the temporary lower health state of a patient in the period before surgery or treatment of major complications, when patients have increased pain and decreased mobility. It is assessed as a one-time toll within the model.

3.3.3 Costs

The incremental cost-effectiveness of MoM BHR versus CoC THR was examined from a healthcare system perspective and therefore the focus is on direct health care costs, like physician costs and health care resources(28). Indirect costs like costs for society as a result of missed work or time cost for patient, family and other non health care providers were not included in this analysis. The advantages of using actual cost data rather than charges in cost-effectiveness models have been well documented in literature (42). Although health care might be a non-profit organization, charges are not equal to costs. Canadian hospitals are publicly funded but in terms of delivery, Canadian hospitals are almost all owned and operated by private not-for-profit organizations. From healthcare provider perspective, costs represent how much the healthcare provider paid to provide care and charges represent how much the healthcare provider billed the payer.

For this reason, costs in the model were based on actual hospital costs for CoC THR versus MoM BHR procedures in Alberta for patients included in the HIP and Hip and Knee Replacement Project (HKRP). The objective of the HKRP was to compare a new care pathway to the conventional method of service delivery. The pilot was performed as a randomized, controlled study with an intention-to-treat analysis. Individuals with similar conditions were allocated randomly to two or more treatment groups, and outcomes of the groups are compared after 12 months of follow-up. HKRP was completed in 2006 and involved 1,638 patients who underwent a hip or knee replacement, either under the new continuum or under the conventional method of service delivery. For the costing of this study only hip replacement patients were included.

Costs were derived from the hospital chart review, physician billing data and patient questionnaires. The hospital chart review reports among others, device used, cement used, OR time, length of stay, blood transfusion and readmissions. Subsequently, physician billing information which captures all types of visits, specialty, place of services and estimated costs were used to calculate the health care provider costs. Finally, patient questionnaires were used to obtain information about post-surgical care. Patients were asked to fill in those questionnaires pre-surgery, at 3-months follow-up and 12-months follow-up. All cost estimates were in Canadian dollars.

As reported in literature, MoM BHR, is in many aspects similar to THR; it is likely to involve substantially the same configurations of staff, requires a similar setting and (in uncomplicated cases) requires the same follow-up (6). Regarding alternative providers (physiotherapist, chiropractor) only visits paid by AHS were included as costs in the model.

Costs for major complications after surgery were calculated as an average cost for possible complications after MoM BHR and CoC THR. Those costs include treatment costs and hospitalization costs. Due to the small number of patients reported with a complication, it was not possible to calculate a reliable cost for complications for different age, gender or procedure groups.

Table 3 Variables used in cost-effectiveness analysis including low and high values used for the deterministic sensitivity analyses

	Mom BHR				CoC THR			
Variable	**Average**	**Low value**	**High value**	**Source**	**Average**	**Low value**	**High value**	**Source**
Event probabilities								
First revision surgery	0.0147	0.0146	0.0149	McBryde et al (2010)	0.0091	0.0091	0.0092	Swedish Registry 2007
Second revision surgery	#	#	#	#	0.0777	0.0684	0.0870	Australian Registry, Annual report 2010
Conversion to THR	0.0788	0.0425	0.1426	Australian Registry, Annual report 2010	#	#	#	#
Major complications after primary surgery	0.0095	0.0047	0.0142	HIP cohort	0.0156	0.0078	0.0233	HKRP pilot
Major complications after first revision surgery	0.0095	0.0047	0.0142	HIP cohort	0.0156	0.0078	0.0233	HKRP pilot
Major complications after second revision surgery	#	#	#	#	0.0156	0.0078	0.0233	HKRP pilot
Major complications after conversion to THR	0.0156	0.0078	0.0233	HIP cohort	#	#	#	#
Death, primary surgery	0.0076	0.0000	0.0220	Swedish Registry 2007	0.0076	0.0000	0.0220	Swedish Registry 2007
Death, first revision surgery	0.0230	0.0087	0.0260	Swedish Registry 2007; Zhan et al. (2007) (43)	0.0230	0.0087	0.0260	Swedish Registry 2007; Zhan et al. 2007
Death, second revision surgery	#	#	#	#	0.0230	0.0087	0.0260	Swedish Registry 2007; Zhan et al. (2007)
Death, conversion to THR	0.0230	0.0087	0.0260	Swedish Registry 2007; Zhan et al. (2007)	#	#	#	#
Death, all-cause mortality (mean age BHR: 49, THR: 49)	0.0030	NA	NA	Alberta Life Tables	0.0030	NA	Na	Alberta Life Tables
Utilities								
Post primary surgery	0.7990	0.3930	1	HIP cohort	0.7950	0.4510	1	HIP cohort
Post first revision surgery	0.4874	0.2397	0.6100	HIP cohort/scaled to numbers of Coyle et al.	0.4850	0.2751	0.6100	HIP cohort/scaled to numbers of Coyle et al.
Post second revision surgery	#	#	#	#	0.4850	0.2751	0.6100	HIP cohort/scaled to numbers of Coyle et al.
Post conversion to THR	0.4850	0.2751	0.6100	HIP cohort/scaled to numbers of Coyle et al.	#	#	#	#

	MoM BHR				CoC THR			
Variable	**Average**	**Low value**	**High value**	**Source**	**Average**	**Low value**	**High value**	**Source**
Decrement first revision surgery	0.1653			HIP cohort/scaled to numbers of Coyle et al.	0.1620			HIP cohort/scaled to numbers of Coyle et al.
Decrement second revision surgery	#	#	#	#	0.0730			HIP cohort/scaled to numbers of Coyle et al.
Decrement conversion to THR	0.1665			HIP cohort/scaled to numbers of Coyle et al.	#	#	#	#
Decrement complications primary surgery	0.2395			HIP cohort/scaled to numbers of Coyle et al.	0.2375			HIP cohort/scaled to numbers of Coyle et al.
Decrement complications first revision surgery	0.0837			HIP cohort/scaled to numbers of Coyle et al.	0.0825			HIP cohort/scaled to numbers of Coyle et al.
Decrement complications second revision surgery	#	#	#	#	0.0825			HIP cohort/scaled to numbers of Coyle et al.
Decrement complications conversion to THR	0.0825			HIP cohort/scaled to numbers of Coyle et al.	#	#	#	#
Costs								
Total costs year 1 after primary surgery	$ 13,198	$ 6,599	$ 19,796	HIP and HKRP cohort	$ 14,103	$ 7,051	$21,154	HIP and HKRP cohort
Total costs year 1 after revision surgery	$ 19,651	$ 9,826	$ 29,477	HIP and HKRP cohort scaled to numbers in Coyle et al.	$ 20,999	$ 10,499	$ 31,498	HKRP cohort scaled to numbers in Coyle et al.
Second revision surgery	NA	NA	NA	NA	$ 20,999	$ 10,499	$ 31,498	HKRP cohort scaled to numbers in Coyle et al.
Total costs year 1 after conversion to THR	$ 20,999	$ 10,499	$ 31,498	HKRP cohort scaled to numbers in Coyle et al.	NA	NA	NA	NA
Complication after surgery	$ 7,024	$ 3,512	$ 10,536	HIP cohort/HKRP cohort	$7,024	$ 3,512	$ 10,536	HIP cohort/HKRP cohort

Utilities, costs and event probabilities vary by age, gender and year after surgery; estimates are shown for the whole cohort in the first year after surgery. Event probabilities, utilities and costs reported for first and second revision CoC THR were also applied for first and second revision CoC THR after a conversion from MoM BHR to CoC THR

not applicable

NA: not available

3.4 Model assumptions

In constructing the decision model we used the following general assumptions:

1. Each patient receives either CoC THR or MoM BHR.
2. Cycle Length: 1 year.
3. Time Horizon: 15-year time horizon starting at time of primary surgery.
4. Cohort size: 10,000 patients.
5. CoC THR: patients may undergo up to 2 revision surgeries. As described above, a 3rd or 4th revision surgery after CoC THR is very uncommon.
6. MoM BHR: patients may undergo either a revision or a conversion to conventional THR. After a first revision patients can receive a conversion to THR and patients may undergo up to 2 revision surgeries after conversion to conventional THR. Those are the most common treatment orders offered to OA patients who underwent a primary MoM BHR.
7. Bilateral surgeries performed on the same day were evaluated as one hip surgery. Although bilateral hip surgeries performed at the same day might affect the length of stay (LOS), it is assumed the clinical outcomes will not be affected. Due to the small number of patients enrolled at the HIP study that underwent bilateral hip surgery we decided to treat bilateral surgeries like this.
8. Patients are always at risk of death from surgery-related or other causes (death = absorbing state) and therefore can always move to the death state.

In constructing the decision model we used the following assumptions related to event probabilities:

1. The event probabilities for the model were annual revision probabilities, mortality and major complications not requiring surgery.
2. No age and gender differences were applied for the 2nd THR revision and the conversion to THR. Adequate data of annual 2nd revision probabilities and conversion to THR probabilities was not available in the HIP cohort and literature.
3. Mortality in the first year after surgery was stated for the first 90 days as the probability reported in the Swedish Registry for 90-day mortality and the rest of the year as general mortality probabilities in Alberta.

4. 90-day mortality was assumed to be similar after primary CoC THA and primary MoM BHR because no literature described the difference in surgical mortality between MoM BHR and CoC THR.
5. With use of expert opinion it was assumed 90-day mortality after 1st revision surgery, 2nd revision surgery and conversion to THR was higher than 90-day mortality after primary surgery. No information was available from the HIP cohort and National Registries therefore numbers in Aynardi et al.(44) were used as a source to scale 90-day mortality after primary to surgery reported in the Swedish Registry. Aynardi et al. retrospectively reviewed 7478 consecutive patients undergoing cementless primary or revision THR between January 2000 and July 2006.
6. Probabilities for major complications were considered similar for all age and gender groups and primary and revision surgeries. The only difference shown is the probability for a major complication in THR, versus the probability for a major complication for BHR. Due to a small number of complications reported in the HIP cohort it was not possible to apply complication probabilities for different age and gender groups.

In constructing the decision model we used the following assumptions related to utilities:

1. The utility value for year one was calculated as a weighted average from 3 months after surgery scores and 1 year after surgery scores. Those time intervals were chosen as 3 months and 1 year were measurement moments in the HIP cohort.
2. The utility pattern was assumed to continue stable after 2 years post surgery. This number is calculated as the average score of 2 and 3 years after surgery, obtained in the HIP cohort.
3. In HIP no utility scores after revision surgery and conversion to CoC THR were available. Therefore, utilities after revision surgery were calculated by scaling our utility numbers to the numbers in Coyle et al(41). In Coyle et al. a review of economic evaluations was performed comparing the minimally invasive approach to standard THR. A Markov model was created to estimate the long-term costs and QALYs for patients undergoing minimally invasive THR and standard THR. Short-term utility and cost data were obtained from a recent Canadian RCT. In our study only results reported for standard THR were used in the model.

4. Due to a lack of literature for an alternative assumption, utilities after a conversion to THR were assumed to be similar to utilities after a first revision for THR.
5. A utility decrement in the year before revision surgery was calculated as: 0.5 *(utility post primary surgery – utility post first revision). Due to a lack of literature, a decrement is calculated as a half year decrease in utility calculated from the 2+ year after primary surgery minus the utility value directly after revision surgery. The half year decrease in utility before revision surgery was decided with use of expert opinion.
6. A decrement for major complications was applied for half a year, decided with used of expert opinion.
7. Decrements for major complications were calculated with numbers of Coyle et al(41).

In constructing the decision model we used the following assumptions related to costs:

1. Costs were reported in Canadian dollars 2005 and inflated to values as of 2011 with the Costing Inflation Factor (CPI) of 1.089 (45).
2. Regarding costs, first and second revision surgeries post conversion to THR were treated similar to first and second revision surgeries post THR. Due to the absence of costs information for revision surgeries we had to scale our numbers to numbers in Coyle et al. This was only possible for the costs for a first revision surgery.
3. Costs for primary surgery were obtained from actual hospital costs for CoC THR versus MoM BHR procedures in Alberta for patients included in the HIP and HKRP.
4. Costs for revision surgery were calculated as our costs for primary surgery, scaled to numbers reported in Coyle et al(41).
5. Due to a lack of literature, costs for a conversion to THR were assumed to be similar to costs for a first revision THR.
6. Costs for major complications were calculated as an average cost for all observed adverse events in the BHR and THR cohort. As only a few complications were reported in HIP, it was not possible to apply age, gender and procedure specific costs.
7. As the model is built from a healthcare perspective, only costs paid by Alberta Health Services were included. For example: as AHS only reimbursed the first 6 physiotherapy visits, only costs of 6 physiotherapy visits were included in the model.

8. Missing MD costs in the <50 years group were assumed to be similar to costs in the 50-59 years group.

3.5 Model Analysis: base-case and subgroup analysis

A 15-year time horizon was used to evaluate the incremental cost per quality adjusted life-year (QALY) for both procedures and incremental cost-effectiveness ratio (ICER), starting at time of primary surgery. The 15-year time horizon was chosen because reliable information from the Swedish Hip Arthroplasty Register regarding revision rates, was available up to 15 years after primary surgery(33).

In the main analysis comparable groups were analyzed: males under 60 years of age and females under 60 years of age. Moreover, separate models were estimated for more specific different age and gender groups (e.g. males <50y, males 50-59y, males 60-65y, females <50y and females 50-59y). The age strata were chosen with knowledge of the included patients in HIP (males <65y and females <55y) and age strata used in the Swedish Registry, an important information source for the model. The clinical path of MoM BHR patients is compared to the clinical path of CoC THR patients by comparing the cumulative total QALYs and cumulative costs of MoM BHR with the cumulative total QALYs and cumulative costs of CoC THR. Cumulative total QALYs and cumulative total costs are related to the 15 year time period of the decision model.

The measure of cost-effectiveness in this model is expressed as an incremental cost-effectiveness ratio (ICER), which is calculated by dividing the difference in costs between MoM BHR and CoC THR by the differences in effectiveness between MoM BHR and CoC THR: $\text{ICER} = \frac{\text{costs MoM BHR} - \text{costs CoC THR}}{\text{effect MoM BHR} - \text{effect CoC THR}}$

QALY is used as the unit of measurement for effectiveness and costs are in Canadian dollars, which will result in a ratio expressed in Canadian dollars per QALY. Thresholds for medical interventions to be cost-effective are often considered as a willingness-to-pay of CDN $50,000/QALY gained (46;47). The willingness-to-pay of CDN $50,000/QALY gained is also applied for this model.

Uncertainty was addressed through a deterministic sensitivity analysis.

3.6 Sensitivity Analysis

Sensitivity analyses were performed to explore the robustness of the model uncertainty from sources other than the imprecision of the input parameters. Uncertainties arise from number of factors: (a) randomised trials frequently have shorter follow-up periods than the appropriate time horizon of the decision analytic model; (b) measurement of effectiveness in terms of intermediate endpoints rather than ultimate measures of health gain; (c) lack of external validity in terms of patients recruited (e.a. co-morbidities may not be analyzed); (d) failure to measure important endpoints, such as resource use (48;49).

The degree of influence of each factor on the outcome of the entire analysis was examined using deterministic sensitivity analyses, by changing one variable at a time. One-way sensitivity analyses were performed for each important variable: utility values, revision probabilities, cost drivers and annual probabilities for major complications not requiring surgery (table 3). In these analyses, each variable was varied based on reported confidence intervals or low and high values of specific variables reported in literature. In case of the annual revision probabilities, no confidence intervals were reported and to our knowledge no other literature reports annual revision probabilities for MoM BHR and CoC THR. Confidence intervals were reported for specific years (mostly at year 1 after surgery) and therefore, it is assumed confidence intervals continue stable over the years. Standard deviations around costs were not adequate because the small numbers in some subgroups, therefore values were varied from 50% to 150% of the point estimate. The impact of each variable on the ICER was calculated for the base case.

3.7 Face Validity

To ensure the model outcomes are valid, the analyses were also performed with numbers mentioned in Coyle et al. (41) Coyle et al. only reports values for THR, therefore only this arm is tested in this analysis. As Coyle et al. only reports about a first revision surgery, probabilities for a second revision were similar to the values in our base case, based on the Australian Registry (34). As our base case is a cohort of patients undergoing MoM BHR or CoC THR for advanced OA of the hip in Alberta, general mortality rates in Alberta were applied in this validation analysis. To obtain required information about incremental QALYs and costs a Monte Carlo simulation using 10,000 samples was performed.

4. Results

4.1 Base case analysis

In the base case analysis mean age in the studied MoM BHR cohort is almost equal to mean age in the studied CoC THR cohort. As TreeAge software applied a truncate method (mean age is rounded down to full years) life years calculated by the model were equal for MoM BHR and CoC THR. Overall, estimates based on the model show MoM BHR patients experience lower gains in QALYs and have lower health care costs compared to CoC THR patients (table 4). The ICER of CDN $35303/QALY calculated from lower gains in QALYs with lower health care costs will not necessarily be considered cost-effective. This can be explained by the cost-effectiveness plane (figure 3). ICERs with a negative value are in the south-east (SE) or north-west (NW) quadrant. In the SE quadrant the new treatment is more effective and involves less costs compared to the conventional treatment (50). The new treatment dominates the old treatment. In the NW quadrant it is the other way around; the new treatment is less effective and involves higher costs. Here the old treatment dominates the old treatment. ICERs in the NE and SW quadrant have a positive value. In the NE quadrant the new treatment is more effective but also more costly. The maximum ICER has been defined for this quadrant and often differs per country (CDN $50,000/QALY in this study). In the SW quadrant the new treatment is less effective and saves money compared to the old treatment (50). There is no discussion about the ICERs in the SE and NW quadrants as their consequences are clear. However there may be disparity in the way ICERs falling in the SW and NE are interpreted. If the ICER is plotted right to the dotted line in figure 3, then MoM BHR is considered cost-effective and if the ICER is plotted left to the dotted line, then MoM BHR is considered cost-ineffective.

The ICER calculated in the base case analysis is located in the SW quadrant and therefore a subject of discussion. As the ICER is falling in the SW quadrant, right to the dotted line, MoM BHR is considered cost-effective.

Table 4 Cost-effectiveness of MoM BHR compared to CoC THR for all males and females less than 65 years of age

	Procedure	Mean age (years)	Life years	Effectiveness (QALYs)	Incremental effectiveness	Costs	Incremental costs	ICER (CDN $/QALY)
Base case	MoM BHR	49.7	14.48	9.25	-0.031	CDN $16,708	-$1,103	35303
	CoC THR	49.6	14.48	9.28		CDN $17,810		

4.2 Analysis of gender specific differences

To investigate the cost-effectiveness for males and females, MoM BHR and CoC THR patients under the age of 60 were analysed (table 5). Age distribution used in the model were derived from the HIP cohort; the cohort of females under 60 years of age had a lower mean age than the males under 60 years of age. This, and lower general mortality rates for females (appendix 2) resulted in the estimated higher life years for females under 60 years of age. In the females under 60 years cohort, estimates regarding effectiveness showed less QALYs for the patients who underwent MoM BHR (9.09 QALYs) compared to patients who underwent CoC THR (9.27 QALYs). Costs in the females under 60 years cohort were considered lower for the MoM BHR procedure. The ICER of CDN $7494/QALY calculated from lower gains in QALYs with lower health care costs will not necessarily be considered cost-effective.

In the males under 60 years of age cohort, effectiveness was estimated to be higher for patients who underwent a MoM BHR procedure (9.33 QALYs after the MoM BHR procedure compared to 8.99 QALYs after the CoC THR procedure). As costs were estimated to be lower for the MoM BHR procedure is this cohort, MoM BHR was considered cost savings in the males under 60 years of age cohort.

Table 5 Cost-effectiveness of MoM BHR compared to CoC THR for younger patients

	Procedure	Mean age (years)	Life years	Effectiveness (QALYs)	Incremental effectiveness	Costs	Incremental costs	ICER (CDN $/QALY)
Female <60y	MoM BHR	47.0	14.68	9.09	-0.174	CDN $17,471	-$1,308	7494
	CoC THR	48.2	14.65	9.27		CDN $18,778		
Male <60y	MoM BHR	49.3	14.42	9.33	0.338	CDN $16,238	-$2,001	Cost savings
	CoC THR	49.6	14.42	8.99		CDN $18,240		

4.3 Analysis of age specific differences

Table 6 shows the combined influence of gender and age on the ICER. Differences in life years between MoM BHR and CoC THR in a specific age and gender group can be explained by the little differences in mean age between the MoM BHR and CoC THR cohort per age group.

The effectiveness estimates in the females under 50 years of age cohort show a little preference for the MoM BHR procedure (9.16 QALYs for MoM BHR compared to 9.14 QALYs for CoC THR). Cost for the MoM BHR procedure were estimated to be lower for MoM BHR. Therefore MoM BHR was considered to be cost savings for the females under 50 years of age cohort.

In contrary to the effectiveness estimates in the females under 50 years cohort, a preference for CoC THR procedure is shown in the females 50-59 years of age cohort (8.93 QALYs after the MoM BHR procedure compared to 9.25 QALYs for the CoC THR procedure). Costs were estimated to be a little higher for the CoC THR procedure. MoM BHR was considered not cost-effective with an ICER of 1061 $/QALY. Like mentioned above: ICERs falling in the SW quadrant should be interpreted with care. Here the ICER is falling left from the dotted line and therefore MoM BHR should be interpreted as cost-ineffective.

As the females under 50 years of age cohort, the males under 50 years of age cohort also showed a higher effectiveness for the MoM BHR procedure (9.51 QALYs for the MoM BHR procedure compared to 8.99 QALYs for the CoC THR procedure). Costs were estimated to be lower for the MoM BHR procedure and therefore MoM BHR was considered cost savings for the males under 50 years of age cohort.

The males 50-59 years of age cohort showed comparable results; a higher effectiveness for the MoM BHR procedure (9.13 QALYs for MoM BHR compared to 9.04 QALYs for the CoC THR procedure) and lower costs for the MoM BHR procedure. Therefore, MoM BHR was considered cost savings in the males 50-59 years of age cohort.

The estimated effectiveness in the males 60-65 years of age cohort was different; a higher effectiveness was found for the CoC THR procedure (8.53 QALYs for the MoM BHR procedure and 9.29 QALYs for the CoC THR procedure). As with the other age ranges cohorts, costs were estimated to be lower for MoM BHR. The ICER of CDN S2243/QALY calculated from lower gains in QALYs with lower health care costs will not necessarily be considered cost-effective. As the ICER is falling in the SW quadrant left from the dotted line (figure 3) MoM BHR should be interpreted as cost-ineffective.

Table 6 Cost-effectiveness of MoM BHR compared to CoC THR for the specified gender and age groups

	Procedure	Mean age (years)	Life years	Effectiveness (QALYs)	Incremental effectiveness	Costs	Incremental costs	ICER (CDN $/QALY)
Female <50y	MoM BHR	43.2	14.77	9.16	0.022	CDN $17,683	-$3,501	Cost savings
	CoC THR	41.5	14.81	9.14		CDN $21,184		
Female 50-59y	MoM BHR	53.0	14.44	8.93	-0.328	CDN $17,320	-$348	1061
	CoC THR	53.1	14.44	9.25		CDN $17,668		
Male <50y	MoM BHR	44.3	14.63	9.51	0.516	CDN $16,437	-$2,228	Cost savings
	CoC THR	40.2	14.73	8.99		CDN $18,664		
Male 50-59y	MoM BHR	53.9	14.16	9.13	0.084	CDN $15,976	-$2,115	Cost savings
	CoC THR	54.9	14.07	9.04		CDN $18,091		
Male 60-65y	MoM BHR	62.1	13.10	8.53	-0.762	CDN $14,601	-$1,708	2243
	CoC THR	62.1	13.10	9.29		CDN $16,309		

4.4 The cost-effectiveness plane

The cost-effectiveness plane is often employed to show how decisions can be related to both costs and effects. The plane is divided into four quadrants indicating four situations in relation to effects and costs of a new treatment compared to a standard treatment (50). Figure 4 shows all the cost-effectiveness scenarios are falling in the SW and SE quadrant, close to the origin in the cost-effectiveness plane. The ellipse around the base case ICER is presenting a wide 95% confidence interval (CI); the 95% CI is overlapping all four quadrants.

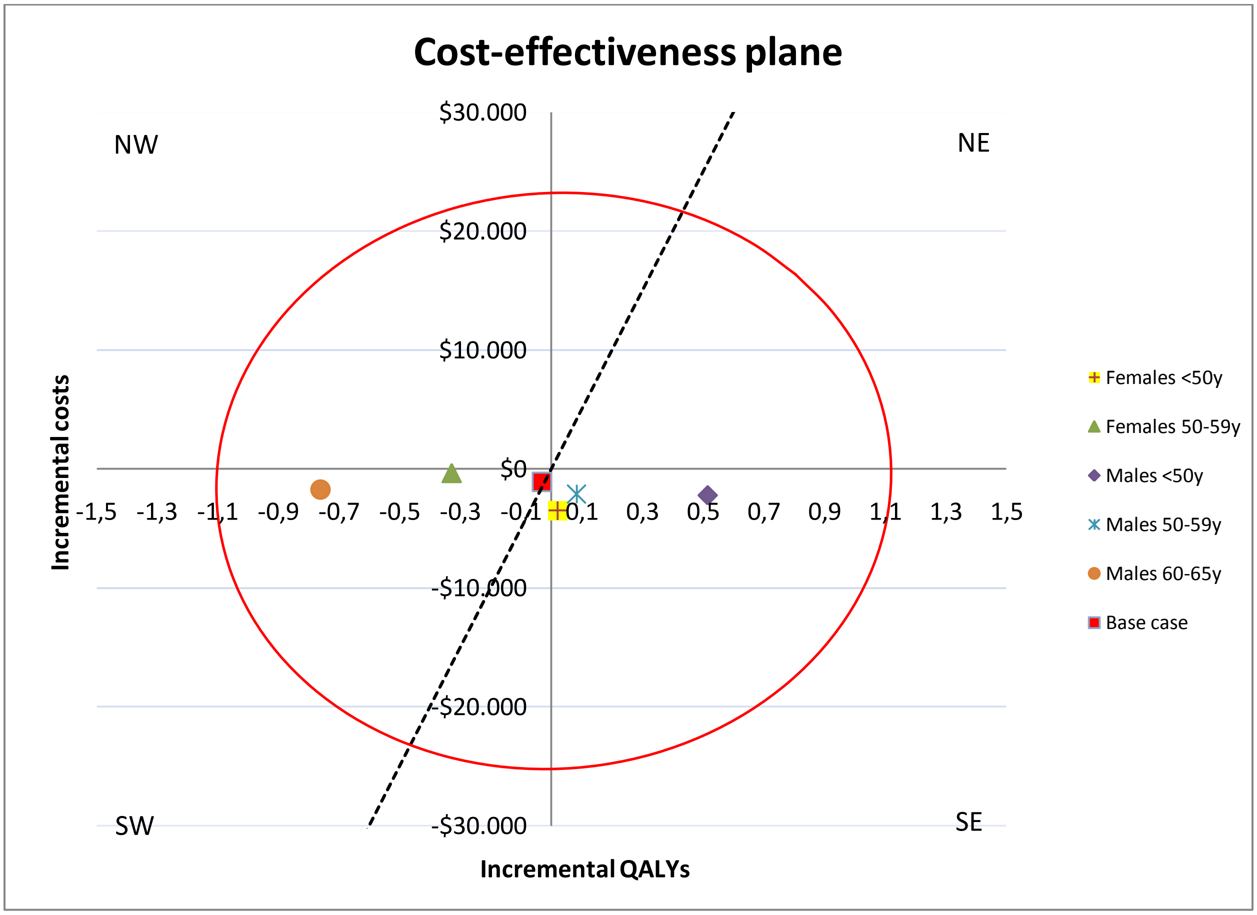


Figure 3 Cost-effectiveness scenarios for different age and gender groups illustrated on the cost-effectiveness plane with the 95% confidence interval around the ICER in the base case.

4.5 Cost-effectiveness acceptability curves

Cost-effectiveness acceptability curves are derived from the joint density of incremental effects and incremental costs for the intervention of interest and represents the proportion of density where the intervention is cost-effective(40). Figure 4 shows the cost-effectiveness acceptability curves (CEACs) of the base case scenario, females <60 years of age scenario and males <60 years of age scenario. Figure 3 describes that in the base case analysis the probability that MoM BHR is cost-effective compared to CoC THR is 53% with a willingness-to-pay of $50,000. The males under 60 years of age shows a higher probability; the probability that MoM BHR is cost-effective compared to CoC THR is 86%. In the females under 60 years of age cohort the results are the other way around. The CEAC show a probability of 29% that MoM BHR is cost-effective compared to CoC THR.

CEACs have been widely accepted as a technique of representing uncertainty in cost-effectiveness analysis (40). The CEAC is derived from the joint density of incremental effects and incremental costs, and represents the proportion of density where the intervention is cost-effective for a range of values of willingness-to-pay. This will result in a nice graph specifically for a smooth curve starting at probability zero with an asymptote to 1, as we consider higher willingness-to-pay for a health outcome. The fact is that CEACs can take many shapes and turns because it is a graphic transformation from the cost-effectiveness plane (40). The joint density of the incremental effects and incremental costs may change quadrants with attendant discontinuities. Therefore it is useful to present the results of the different cost-effectiveness scenarios also in the cost-effectiveness plane (figure 3).

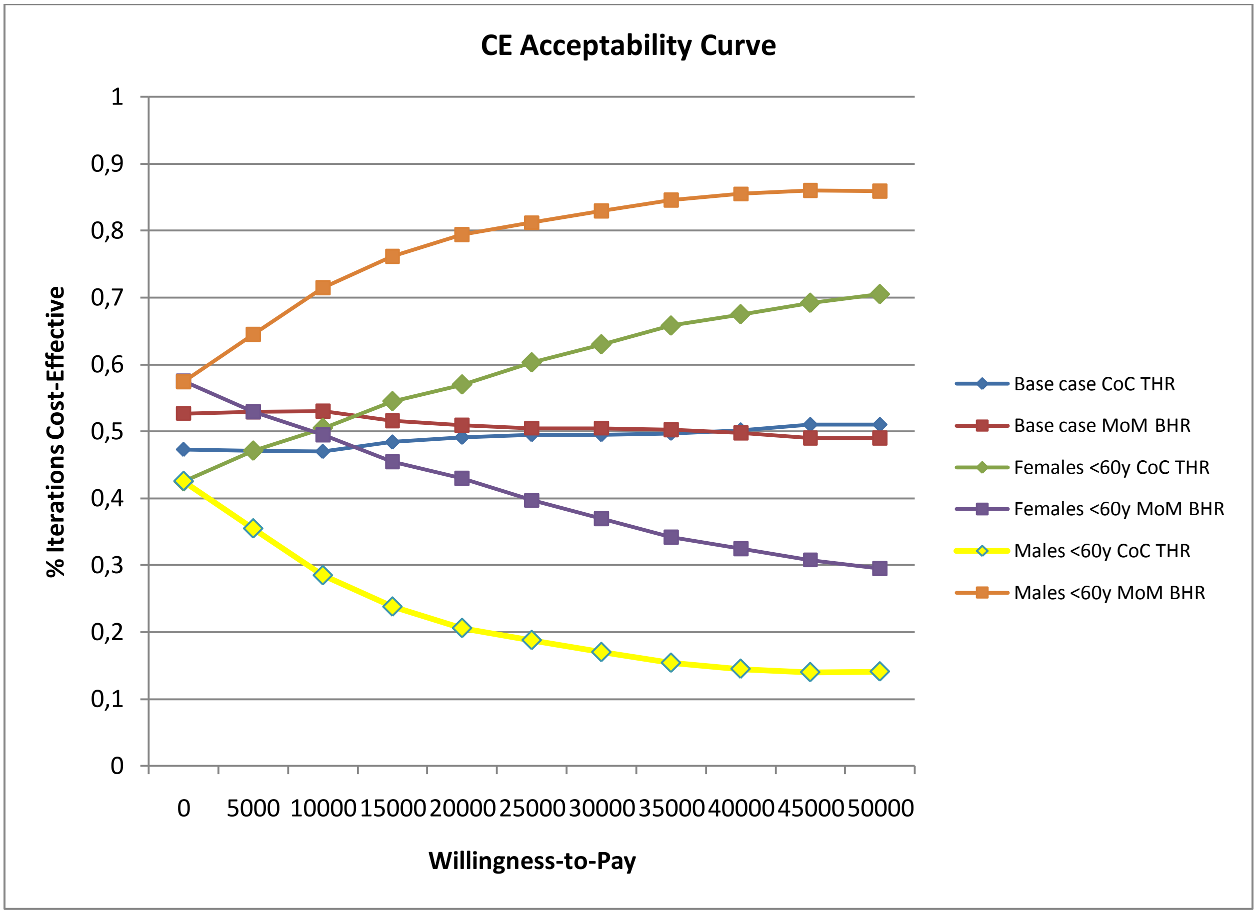
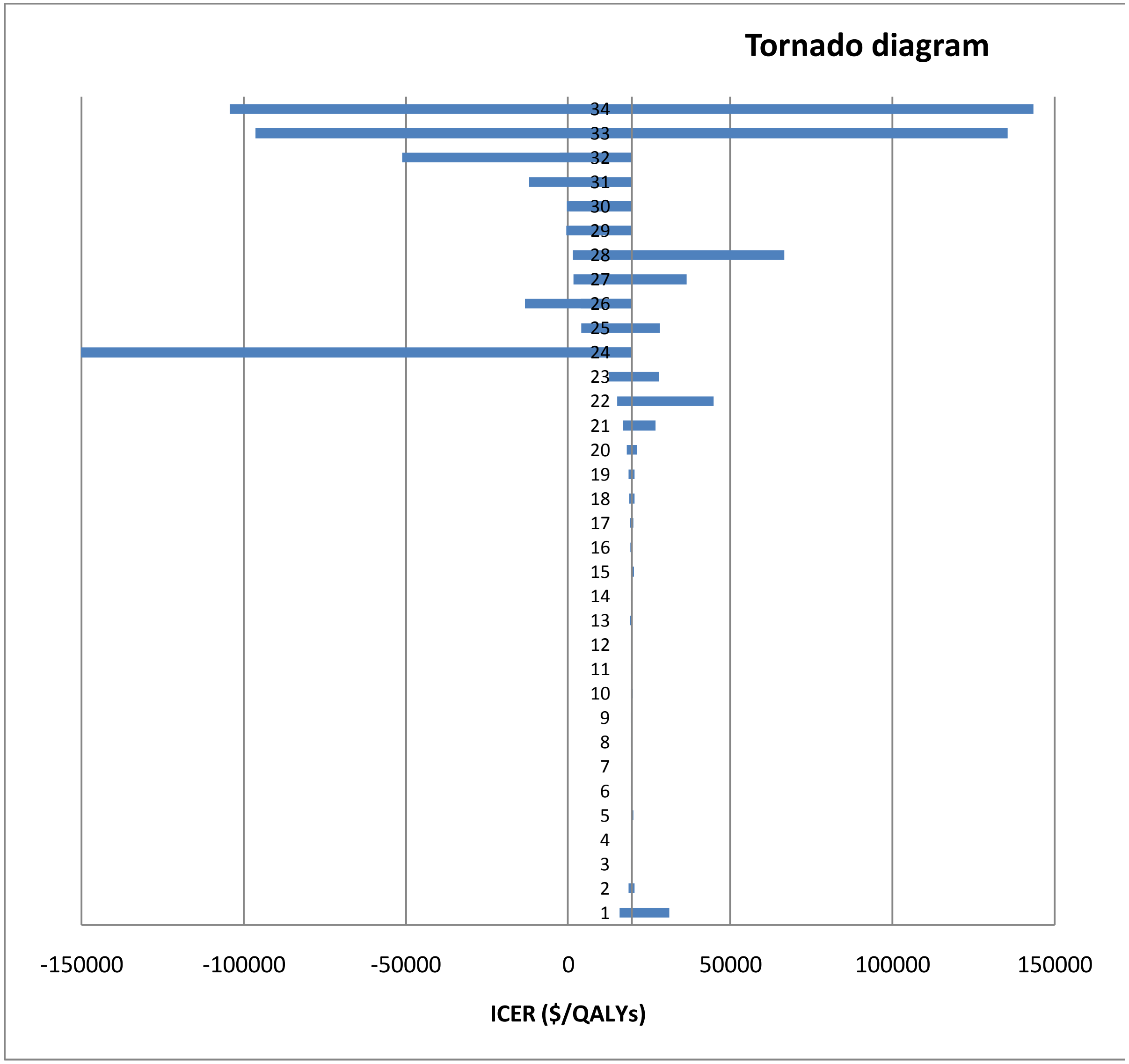


Figure 4 Cost-effectiveness acceptability curve comparing MoM BHR and CoC THR in the base case scenario, in the females <60 years of age cohort and in the males <60 years of age cohort.

4.6 Deterministic sensitivity analysis

Results of the deterministic sensitivity analysis are shown in the format of a Tornado diagram (figure 5). A tornado diagram is a single graph presenting a set of one-way sensitivity analyses. A horizontal bar is generated for each variable being analyzed. ICER is displayed on the horizontal axis, so each bar represents the range of ICER values generated by varying the related variable.

The deterministic sensitivity analysis showed that initial costs for BHR and THR and the utility post first revision BHR had most influence on the results found.



	Legend
1	Utility post second revision THR
2	Probability complications after primary BHR
3	Probability complications after conversion to THR
4	Probability complications after first revision BHR
5	Probability 1st Revision THR
6	Costs complications after 2nd revision THR
7	Probability complications after 2nd revision THR
8	Costs complications after 1st revision BHR
9	Surgical mortality 2nd revision THR
10	Surgical mortality 1st revision THR
11	Costs complications after 1st revision THR
12	Costs complications after conversion to THR
13	Probability 1st Revision BHR
14	Probability complications after first revision THR
15	Surgical mortality conversion to THR
16	Surgical mortality 1st revision THR
17	Costs complications after primary BHR
18	Probability 2nd Revision THR
19	Costs complications after primary THR
20	Probability 2nd Revision THR
21	Costs 2nd revision THR
22	Surgical mortality primary THR
23	Surgical mortality primary BHR
24	Utility post first revision BHR
25	Costs 1st revision BHR
26	Utility post conversion to THR
27	Costs conversion to THR
28	Costs 1st revision THR
29	Utility post primary BHR
30	Utility post primary THR
31	Utility post first revision THR
32	Probability conversion to THR
33	Costs primary BHR
34	Costs primary THR

Figure 5 One-way sensitivity analyses of ICER to effectiveness measures, probabilities and costs in the base case analysis. The width of each bar indicates the range of the ICER as an individual variable changes over its range.

8 Discussion

In this economic analysis we evaluated a relatively new technique, MoM BHR with the conventional technique used in Alberta: CoC THR. With decision analysis we were able to compare the cost-effectiveness of MoM BHR by gender and age. Moreover we identified key factors that influenced the clinical effectiveness and costs of MoM BHR compared to CoC THR and the uncertainty in these estimates. The potential advantages of MoM BHR for specific patient groups were reported in literature (4;6;9). Information derived from National Joint Registries often showed higher revision rates for females with a HRA, compared to age-matched males and females with a THR (51). On the other side, males younger than 65 years of age at time of surgery showed slightly lower revision rates with HRA than with THR (51). McGrory et al (2010) reported a 2.5 times lower risk for HRA failure in males than in females, irrespective of age (52).

Our results confirm other findings reported in literature. The often reported higher costs for MoM BHR (5) could be seen as a problem when applying MoM BHR in older patients. In older patients, generally only a very small increase in costs could ever be justified, because of the shorter life expectancy(2). In younger patients higher costs could be justified by a longer life expectancy with a higher QoL. However, contradictory with other literature(5), lower costs for MoM BHR compared to CoC THR were found in this study. Despite the higher costs of the MoM BHR device (appendix 1), the CoC THR procedure showed higher total costs. The reported lower total costs for MoM BHR were mainly explained by the lower costs for surgery and lower hospitalization costs. Patients who received a MoM BHR had generally a shorter LOS; 3.3 days for MoM BHR compared to 4.7 days for CoC THR. Costs were generally lower for males, both for MoM BHR and CoC THR, with differences mainly due to device costs. We estimated costs from a healthcare perspective, as only direct hospital costs were included in the analysis. This may be seen as a limitation, as it is well know that hip OA patients requiring surgery often also have costs related to society. The costs of hospital treatment, however, capture most of the total costs (53).

In patients who underwent a MoM BHR, QoL in the years after surgery was generally higher in males less than 60 years of age compared to females (mean is 0.826 vs 0.795). The contrary was seen in CoC THR: QoL in years after surgery was generally higher in females less than 60 years of age (0.803 vs 0.790). Nevertheless, the differences are small; therefore little change in QoL could result in different interpretations. Our results confirm the reported more preferable results for males, but this gender

effect should be interpreted with care. Amstutz et al. (54) and McBryde et al. (14), reported that the effect of gender disappeared after adjustments for component size.
Another noticeable result is the very small ICERs calculated; cost-effectiveness scenarios close to the origin are less stable and uncertainty is larger compared to cost-effectiveness scenarios further away from the origin. Moreover the wide 95% CI, overlapping all four quadrants should be taken into account. Therefore the results should be interpreted with care. Spiegelhalter et al. (55) report comparable small ICERs (£739/QALY in males 55-64 and £683/QALY in females 55-64).

Although randomised controlled trials (RCTs) are often thought of as the gold standard to derive input for economic evaluation studies, evaluation of MoM BHR and CoC THR is a context where the use of RCT's is of limited use due to the nature of the procedure (56). A long-term follow-up is necessary to observe time until and effects after revision surgery. As a result, the number of published investigations on economic evaluation of THR with use of other techniques has noticeably increased. Since the typical measurements of outcomes in CEA usually have a limited scope, the results of a CEA should be carefully interpreted. Bozic et al. reported in a review the limited quality of economic evaluation in THR studies (2). Given that effects and costs associated with THR accrue over a period of many years, the duration and costs associated with performing a high quality economic analysis can be not worthwhile. Furthermore, only 12% of the studies used a discounting technique and only 22% of the studies performed a sensitivity analyses (2). Discounting techniques are important to make valid comparisons between treatments. Providing sensitivity analysis results allows the reader to assess the strength of conclusions of the study.

Limitations of this study should be considered while interpreting the results. To complete the model, it was necessary to make a few assumptions (as described in the methods). The generalizability and variability of the results were limited by accuracy and availability of data inputs used in the decision model. Especially because MoM BHR is a relatively new technique it is not possible to obtain information about long-term effectiveness of the procedure (27). Moreover, no adequate QoL or utility measures were reported for MoM BHR. Therefore, short-term (up to 3 years) follow up in the HIP was the most accurate measure available to represent effectiveness. No direct estimates of utilities after revision surgeries and conversion to THR were available, so these values were derived from scaling our numbers to the values reported in Coyle et al. (41) To investigate the influence of uncertainty of those data inputs, sensitivity analyses were performed. As the utility after first revision MoM BHR was noticed a variable having a major influence on the results, we have to await the long term utility measured obtained from the HIP to confirm our long term utility estimates. The lack of possibilities to perform a probabilistic sensitivity analysis around all the important variables should be taken into account when interpreting the results of this study.

To test the face validity of the decision model, the model is also analysed with data reported in Coyle et al. (41) as model inputs. As only THR is reported in Coyle et al. it is only possible to compare our THR result to results obtained with data of Coyle et al. Results of the analysis performed with numbers reported in Coyle et al. (41) are shown in table 7. The effectiveness of CoC THR in our base case model (9.28 QALYs) was comparable to effectiveness results with data of Coyle et al. (8.9 QALYs). Costs were also comparable (CDN $17,810 for our base case model and CDN $18,391 in the model with Coyle et al. data).

Comparing our base case analysis with the base case analysis in the model of Coyle et al. we see moderately comparable results for effectiveness (9.28 QALYs vs 8.9 QALYs) and costs (CDN $17,810 vs CDN $19,100).

Table 7 Face validity with data reported in Coyle et al. (41)

Procedure	Effectiveness (QALYs)	Costs
THR	8.9 (0.4 to 9.6)	CDN $18,391 (CDN $10,185 to CDN $40,176)

The time horizon of this economic evaluation was 15 years due to a lack of reliable long term input data. Life time evaluation would be preferable if we follow the economic guidelines, but realistically 15 years is a more reliable time horizon. To investigate the cost-effectiveness from a societal perspective, a recommendation for future research should be to add societal costs to the analyses.

The results of this study will inform decision makers about cost-effectiveness of MoM BHR versus CoC THR for younger OA patients, differentiated for gender and age groups. The results of this study confirm results reported in other studies: MoM BHR is possibly cost-effective for patients less than 65 years but results should be interpreted with care as the 95% CI around the ICER in the base case is wide and overlapping all four quadrants in the cost-effectiveness plane and the CEAC show the probability MoM BHR is more cost-effective compared to CoC THR is only 53%. Cost savings results were found in the following subgroups: females under 50 years of age, males under 50 years of age and males 50-59years of age. Differences were seen between gender and age groups; therefore it gives decision makers the opportunity to consider effectiveness and costs for different patient groups.

9 Abbreviations

OA	Osteoarthritis
HRA	Hip Resurfacing Arthroplasty
THR	Total Hip Replacement
BHR	Birmingham Hip Replacement
CoC	Ceramic-on-Ceramic
MoM	Metal-on-Metal
CJRR	Canadian Joint Replacement Registry
HIP	Hip Improvement Project
AHS	Alberta Health Services
CEA	Cost-effectiveness analysis
CUA	Cost-utility analysis
ICER	Incremental cost-effectiveness ratio
QALY	Quality adjusted life year
QoL	Quality of life
LOS	Length of stay
ABJHI	Alberta Bone and Joint Health Institute

10 Appendix

10.1 Appendix 1: Costing specification Base Case

	MoM BHR					CoC THR				
Costs payed by AHW (year 1)	**Average**	**SD**	**low value**	**high value**	**Source**	**Average**	**SD**	**low value**	**high value**	**Source**
Primary Surgery										
Prosthesis	$5,402	$ 566			HIP cohort	$ 4,884	$ 1,293			HKRP cohort
Physiotherapy visits	$ 87	$ 138			HIP cohort	$ 141	$ 191			HKRP cohort
Chiropractor visits	$ 17	$ 52			HIP cohort	$ 9	$ 34			HKRP cohort
Transfusion	$ 108	$38 2			HIP cohort	$ 126	$ 436			HKRP cohort
Surgery	$ 3,971	$ 1070			HIP cohort	$ 4,966	$ 2,360			HKRP cohort
Analgesic within 3 months after surgery	$9	$ 47			HIP cohort	$ 13	$ 50			HKRP cohort
Analgesic within 3 months to 1 year after surgery	$9	$ 50			HIP cohort	$ 31	$ 103			HKRP cohort
MD surgery	$ 1,778	$ 208			HKRP cohort	$ 1,725	$ 333			HKRP cohort
MD inpatient primary	$ 27	$ 61			HKRP cohort	$ 95	$ 216			HKRP cohort
MD inpatient secondary	$ 282	NA			HKRP cohort	$ 282	NA			HKRP cohort
Other MD costs	$ 429	$ 539			HKRP cohort	$ 678	$ 795			HKRP cohort
Total costs year 1 after primary surgery	$ 13,198	NA	$ 6,599	$ 19,796		$ 14,103		$ 7,051	$ 21,154	
Revision Surgery (first and second)										
Total costs year 1 after revision surgery	$ 19,651	NA	$ 9,826	$ 29,477	HKRP cohort scaled to Coyle et al.	$ 20,999	NA	$ 10,499	$ 31,498	HKRP cohort scaled in Coyle et al.
Conversion to THR										
Total costs year 1 after conversion to THR	$ 20,999	NA	$ 10,499	$ 31,498	HKRP cohort scaled to Coyle et al.	NA	NA	NA	NA	NA
Complications										
Total cost complication	$ 7,024	NA	$ 3,512	$ 10,536	HIP and HKRP cohort	$ 7,024	NA	$ 3,512	$ 10,536	HIP and HKRP cohort

10.2 Appendix 2: Alberta Life Tables

	Mortality rate		
Age	Males	Females	Base Case
1 year	0.00041	0.00074	0.00050
2 years	0.00027	0.00027	0.00027
3 years	0.00027	0.00014	0.00023
4 years	0.00026	0.00007	0.00021
5 years	0.00031	0.00005	0.00024
6 years	0.00018	F	F
7 years	0.00007	0.00008	0.00007
8 years	0.00006	0.00008	0.00007
9 years	F	0.00008	0.00008
10 years	0.00007	0.00009	0.00008
11 years	0.00008	0.0001	0.00009
12 years	0.00013	0.00014	0.00013
13 years	0.00024	0.00018	0.00022
14 years	0.00039	0.00023	0.00034
15 years	0.00056	0.00029	0.00048
16 years	0.00071	0.00033	0.00060
17 years	0.00082	0.00037	0.00069
18 years	0.00088	0.00039	0.00074
19 years	0.00092	0.0004	0.00077
20 years	0.00094	0.0004	0.00078
21 years	0.00094	0.0004	0.00078
22 years	0.00094	0.00039	0.00078
23 years	0.00093	0.00038	0.00077
24 years	0.0009	0.00036	0.00074
25 years	0.00086	0.00033	0.00071
26 years	0.00084	0.00032	0.00069
27 years	0.00084	0.00033	0.00069
28 years	0.00087	0.00036	0.00072
29 years	0.00092	0.00041	0.00077
30 years	0.00099	0.00047	0.00084
31 years	0.00106	0.00053	0.00091
32 years	0.00112	0.00059	0.00097
33 years	0.00117	0.00063	0.00101
34 years	0.00121	0.00068	0.00106
35 years	0.00125	0.00072	0.00110
36 years	0.00131	0.00077	0.00115
37 years	0.00137	0.00082	0.00121
38 years	0.00145	0.00088	0.00129
39 years	0.00154	0.00095	0.00137

Age	Males	Females	Base Case
40 years	0.00165	0.00102	0.00147
41 years	0.00176	0.00111	0.00157
42 years	0.0019	0.0012	0.00170
43 years	0.00205	0.00131	0.00184
44 years	0.00222	0.00142	0.00199
45 years	0.00241	0.00154	0.00216
46 years	0.00261	0.00168	0.00234
47 years	0.00283	0.00184	0.00255
48 years	0.00306	0.002	0.00276
49 years	0.00329	0.00217	0.00297
50 years	0.00354	0.00236	0.00320
51 years	0.00385	0.00257	0.00348
52 years	0.00422	0.00283	0.00382
53 years	0.00464	0.00312	0.00420
54 years	0.00512	0.00344	0.00464
55 years	0.00565	0.0038	0.00512
56 years	0.00625	0.00419	0.00566
57 years	0.00694	0.00463	0.00628
58 years	0.00771	0.00511	0.00696
59 years	0.00854	0.00564	0.00771
60 years	0.00945	0.00621	0.00852
61 years	0.01045	0.00679	0.00940
62 years	0.01155	0.00739	0.01036
63 years	0.01274	0.00793	0.01136
64 years	0.014	0.00843	0.01240
65 years	0.01536	0.00898	0.01353
66 years	0.01686	0.00966	0.01479
67 years	0.01852	0.01054	0.01623
68 years	0.02027	0.01162	0.01779
69 years	0.0221	0.01284	0.01944
70 years	0.0241	0.01422	0.02126
71 years	0.02638	0.01578	0.02334
72 years	0.02904	0.01755	0.02574
73 years	0.03199	0.01943	0.02838
74 years	0.03516	0.02142	0.03122
75 years	0.03869	0.02363	0.03437
76 years	0.04271	0.02621	0.03797
77 years	0.04737	0.02927	0.04217
78 years	0.05257	0.03265	0.04685
79 years	0.05822	0.03625	0.05191
80 years	0.06445	0.04034	0.05753
81 years	0.0714	0.04518	0.06387
82 years	0.07919	0.05104	0.07111

Age	Males	Females	Base Case
83 years	0.08774	0.05773	0.07913
84 years	0.09697	0.0651	0.08782
85 years	0.10699	0.07339	0.09735
86 years	0.11794	0.08287	0.10787
87 years	0.12996	0.0938	0.11958
88 years	0.14641	0.09963	0.13298
89 years	0.16055	0.11014	0.14608
90 years	0.17569	0.12154	0.16015
91 years	0.19185	0.13388	0.17521
92 years	0.20903	0.14719	0.19128
93 years	0.22725	0.16153	0.20838
94 years	0.24651	0.17692	0.22653
95 years	0.2668	0.1934	0.24573
96 years	0.28811	0.21099	0.26597
97 years	0.31042	0.22972	0.28725
98 years	0.33369	0.2496	0.30955
99 years	0.35789	0.27064	0.33284
100 years	0.38297	0.29283	0.35710
101 years	0.40887	0.31616	0.38226
102 years	0.43554	0.34063	0.40830
103 years	0.46288	0.36619	0.43512
104 years	0.49085	0.3928	0.46270
105 years	0.51934	0.42043	0.49095

F: too unreliable to be published

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