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Cost Effectiveness of Primary Total Hip Arthroplasty for Varying Levels of BMI

Karthikeyan E. Ponnusamy, *The University of Western Ontario*

Supervisor: Edward Vasarhelyi, *The University of Western Ontario*
Co-Supervisor: Jacquelyn Marsh, *The University of Western Ontario*
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Abstract

The demand for hip arthroplasty is increasing rapidly due to a combination of an aging population as well as an increasing level of obesity in the country. The purpose of this study is to evaluate the risks and benefits of arthroplasty for patients of different obesity classes. The first two parts were to use a systematic review with meta-analysis and retrospective chart review to quantify the risks and benefits in different obesity classes. The third part was to perform a cost-effectiveness analysis to weight the balance between the two. We found that higher obesity classes are at higher risk of complications and comparable improvement after an arthroplasty. Our cost-effectiveness analysis determined that greater obesity levels had a higher incremental cost-effectiveness ratio than lower obesity levels, but was within generally used willingness-to-pay thresholds. In conclusion, patients of all obesity levels have a greater benefit to cost ratio for total hip arthroplasty.

Keywords

Total hip arthroplasty, obesity, meta-analysis, cost-effectiveness analysis

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Chapter 1

1 Introduction

1.1 Obesity

The World Health Organization (WHO) defines obesity as an abnormal or excessive fat accumulation that presents a risk to health.[1] The common metric used to measure obesity is body mass index (BMI). It is calculated by dividing weight (kg) by the square of height (m) resulting in units of kg/m^2. The WHO categorizes individuals into different weight classifications based on the magnitude of the BMI: underweight (BMI<18.5), normal weight (BMI 18.50-24.99), overweight (BMI≥25.00), obese class I (BMI = 30.00-34.99), obese class II (BMI = 35.00-39.99), and obese class III (BMI≥40.00).[2] Due to major clinical differences between the higher BMIs in obese patients, the medical literature commonly further subcategorizes them as severe obesity (BMI > 35), morbid obesity (BMI > 40), and super (morbid) obesity (BMI > 50).[2–4] There are limitations to the use of BMI to quantify obesity as it does not account for muscle versus fat mass, physical characteristics, or racial differences. Another issue is that it does not account for the distribution of fat since it can be central (abdominal) or peripheral (hip and thighs). Central obesity is more strongly associated with diabetes, heart disease, and metabolic syndrome.[5] However, due to BMI's ease of calculation and widespread adoption, it has become the standard for quantifying obesity.

The prevalence and severity of obesity has been increasing rapidly across the world. In the early 1980s, obese individuals composed only 10.8% of Canada's and 14.7% of the United States' adult population. By 2004-2006, those numbers doubled to 23.1% in Canada and 33.9% in the United States[6] (Figure 1-1). Similarly, European countries have reported dramatic increases in obesity rates over the last few decades. France had a rate of 6.3% in 1980, which increased to 16.9% in 2007, while the United Kingdom went from 6.7% in 1982 to 22.7% in 2002.[6] The increase in obesity rates is related to the rise in conditions such as heart disease, stroke, high blood pressure, diabetes, sleep apnea, and arthritis.[6] These associated conditions drive increased medical resource use since their

direct medical costs can be 36%-100% greater than the non-obese patient. It is estimated in the United States that the annual healthcare costs due to obesity is $86-147 billion. Obesity also leads to significant indirect costs, and it is estimated to cost $3.38-$6.38 billion from reduced productivity and absenteeism.[7] The direct and indirect costs of obesity in Canada are estimated to be between $4.6 and $7.1 billion.[8]

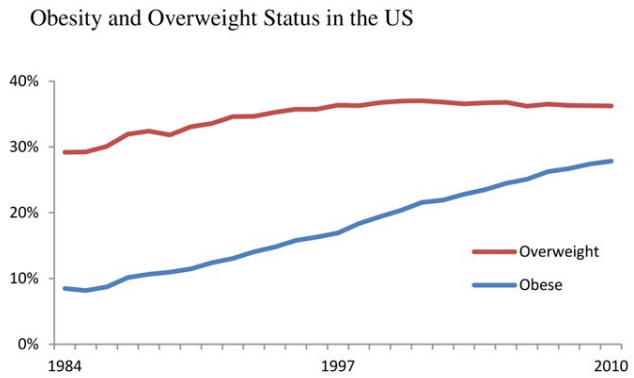

Figure 1-1: Trends in Overweight and Obesity Levels in the United States

Reprinted with permission from Derman, P. B., Fabricant, P. D. & David, G. The Role of Overweight and Obesity in Relation to the More Rapid Growth of Total Knee Arthroplasty Volume Compared with Total Hip Arthroplasty Volume. J. Bone Joint Surg. Am. 96, 922–928 (2014).[9]

1.2 Obesity and Arthritis

Arthritis is a term for all processes that lead to swelling, stiffness, and pain in a joint. The most common form is osteoarthritis, which is when cartilage, the smooth coating at the end of bones, becomes worn out leading to the rubbing of bone on bone at the joint.[10] Obesity predisposes patients to develop osteoarthritic changes in their hip and knee joints. Obese individuals have been found to have a 60% greater likelihood of having arthritis relative to the non-obese population.[11] Evidence has demonstrated that increased weight leads to increased biomechanical forces through the joints placing the individual at a higher risk for wear and tear resulting in arthritis.[12] Biomechanical studies suggest that the hip experiences forces of three times body weight with single leg stance and the

knee experiences forces four to five time bodyweight with activity.[13] Another explanation for the increased rate of arthritis development in obese individuals is their altered metabolic state.[15] Increased fat stores can release pro-inflammatory cytokines such as TNFa and IL-6 which can cause cartilage destruction or alter cartilage metabolism even in cases of osteoarthritis.[14,16] Obesity also alters adipokine hormones including leptin and adiponectin, which can have a pro-inflammatory effect. Through incompletely understood pathways, it is thought these changes have deleterious effects on cartilage.[17]

Regardless of the exact etiology for developing arthritis, higher levels of obesity are associated with an increased risk for undergoing a THA. A study by Bourne et al. reported that obesity increased the relative risk for THA: 1.00 for non-obese, 1.92 for overweight, 3.41 for obesity class I, 5.24 for obesity class II, and 8.56 for obesity class III.[18] Similar results were found in Australia, with a relative risk of 1.26 per every 5 kg/m2 increase in BMI (95% confidence interval (CI): 1.15-1.38).[14]

Higher BMI levels also increase the risk of undergoing an arthroplasty at a younger age. Vulcano et al. found that each BMI obesity class was associated with having an arthroplasty two years earlier than the next higher BMI class.[19] Gandhi et al. found that patients who had a BMI greater than 35 kg/m^2 underwent a THA seven years earlier than an individual with BMI less than 25 kg/m^2.[20] Another study reported an even earlier age for undergoing arthroplasty, with morbidly-obese patients undergoing a THA 10 years before those with a normal BMI.[21]

Concurrently with the growing obesity epidemic, there has been a rapid increase in arthroplasties performed. Derman et al. reported that both THAs and TKAs have increased dramatically from 1993 to 2009 (Figure 1-2).[9] Derman evaluated factors that affected the supply and demand of arthroplasty to identify the source of this growth, and they determined obesity played a significant role in this increase.[9]

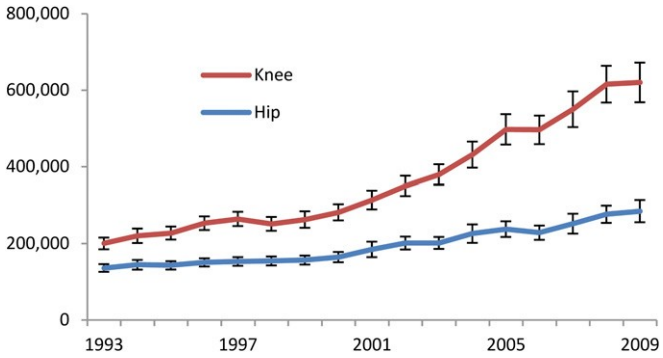

Figure 1-2: Trend in THA and TKA Procedures in the United States from 1993-2009

Reprinted with permission from Derman, P. B., Fabricant, P. D. & David, G. The Role of Overweight and Obesity in Relation to the More Rapid Growth of Total Knee Arthroplasty Volume Compared with Total Hip Arthroplasty Volume. J. Bone Joint Surg. Am. 96, 922–928 (2014).[9]

As a result of increasing rates of obesity, obese patients now comprise a greater proportion of the arthroplasty population. Fehring et al. reported that 52.1% of their arthroplasty patients were obese in 2005, and those numbers are higher now.[22] Singh and Lewallen reported that the severity of obesity is also increasing. Patients with a BMI greater than 40 comprised 6.3% of the primary THAs performed in 2002-2005, which is up from 2.3% in 1993-1995.[23] In addition, arthroplasty rates are projected to increase rapidly in the coming years. Kurtz et al. projected in the United States that relative to 2005, there will be a 174% increase in the number of THAs performed by 2030.[24] The rapid growth of obesity appears to be inextricably tied together with the rapid growth of THA, and that raises the question of whether obese patients experience similar outcomes following THA as non-obese patients.

1.3 Benefits of Arthroplasty for Obese Patients

There has been debate in the orthopedic community regarding how much obese patients benefit from arthroplasty. Although evidence shows improvement in functional outcome following arthroplasty[25–28], there is controversy whether they achieve the same level of

function as non-obese patients. McLawhorn et al. reported EQ-5D scores for normal, overweight, obese class I, obese class II, and obese class III patients.[25] The EQ-5D is a standardized questionnaire to measure generalized health related quality of life. They found that preoperatively, the obese class II (0.58±0.01) and III (0.54±0.03) patients had lower utility scores than the normal weight patients (0.66±0.01). The lower scores persisted two years after a THA with normal at 0.90±0.004, obese class II at 0.84±0.01, and obese class III at 0.85±0.02, however the change scores were similar for all obesity classifications. In fact, the obese class III cohort had a greater improvement following THA compared to the normal weight cohort (0.31±0.02 vs 0.24±0.01, $p = 0.0216$).[25] Other studies also suggest that despite having lower preoperative functional scores, obese patients achieve the same degree of improvement after an arthroplasty.[29,30] Although obese patients clearly benefit from a THA, this comes with increased risks and complications from surgery.

1.4 Risks of Arthroplasty for Obese Patients

The main concern for performing arthroplasty in obese patients is the risk for perioperative complications. One contributing factor is that obese patients tend to have a greater number of comorbidities. Odum et al. found nearly 30% of obese patients had greater than 3 comorbidities compared to only 7% of the non-obese populations.[31] The comorbidities that are more common among obese patients include diabetes, metabolic syndrome, and obstructive sleep apnea. Multiple studies have demonstrated that these conditions are associated with a greater risk of perioperative complications that can lead to an increased length of stay.[32–36] Kremers et al. reported an increased length of stay of 0.16 days for every 5 kg/m^2 over BMI 30.[37]

Infection is one of the most devastating complications following arthroplasty, and in an obese patient the risk of infection is increased. Wagner et al. reported the hazard ratios relative to the normal weight population for infection across a range of BMIs: obese class I 1.6 (95% CI: 1.2-2.2), obese class II 1.9 (95% CI: 1.3-2.8), and obese class III 4.1 (95% CI: 2.8-5.9).[38] Similarly, they also found the risk for revision is higher relative to the normal weight cohort: obese class I HR= 0.9 (95% CI: 0.8-1.01), obese class II HR=0.9

(95% CI: 0.7-1.1), and obese class III is 1.3 (95% CI: 1.04-1.7).[38] This study suggests that patients with a BMI greater than 40 are at a dramatically greater risk of infection by more than 4 times and revision by 30% compared to normal weight patients.[38] Due to the greater number of comorbidities among obese patients and increased risk of perioperative complications, existing evidence suggests the overall cost of performing THA in this population is also significantly greater.

1.5 Economic Considerations

Many studies have reported increased overall costs in higher BMI cohorts. For example, Kim found that hospital costs for morbidly obese patients were 9% greater for primary THA compared to non-obese patients.[39] Dowsey et al. reported that the index hospitalization costs AUS$128.91 (95% CI: $34.53-$223.28) more per unit of BMI increase.[40] Kremers et al. reported that every 5 units of BMI over 30 kg/m^2 is associated with a US$500 increase in hospital costs and US$900 greater 90-day costs after a primary THA.[37] The increasing demand for the procedure has led to changes in healthcare policy placing a greater emphasis on decreasing costs for arthroplasty care. Some healthcare systems are now instituting bundled payment plans for arthroplasty procedures where physicians and hospitals will be held financially accountable for complications within 90 days of a surgery. The majority of these bundled payment initiatives do not risk stratify patients.[41] Given the known increased risks and costs of obese arthroplasty patients, many providers have arbitrarily chosen specific BMI cut-off levels (anywhere from 35-45) to determine eligibility for an arthroplasty procedure. These cut-off levels were determined only considering the short-term risk of complications and increased costs without any evaluation of the long-term benefit of arthroplasty in obese patients. There have been no cost-effectiveness analysis published for obese arthroplasty patients to guide this decision to justify a cut-off threshold. A more thorough evaluation of both the risks and benefits over the long-term is warranted prior to instituting BMI cut-off levels.

1.6 Rationale for Study

With increasing obesity levels and resulting rising demand for arthroplasty procedures, it is crucial to evaluate the most efficient allocation of resources to achieve optimal patient outcomes. Due to greater comorbidities and increased risk of complications, performing arthroplasty for obese patients is more expensive. However, given that obese patients also experience significant benefit from the procedure, there is a need to evaluate the value of THA in this population. With increasing population weight, more people are in higher BMI groups (BMI>45 and 50) that weren't developed when the WHO BMI categories were initially defined. Subjective surgical experience and reporting in the literature suggests that the higher BMI categories carry with them a higher complication rate and subsequent cost. There is a need to evaluate the cohorts at the extreme end (BMI above 45 or 50) and understand how to appropriately establish risk and stratify costs. The objective of this research is to evaluate the magnitude of the benefits and risks associated with primary THA for patients with varying BMI levels (including patients with a BMI above 45 or 50) and to estimate both short term (90-day) and long term economic implications.

1.7 Economic Analysis Tools

One of the tools to conduct health economic analysis is the Markov model, which is a diagram representing all the possible health states an individual can have and the possible paths to change health states.[42] Each of the health states and transitions between them have a cost and/or utility score (a metric to quantify the health of an individual with 1 representing perfect health and 0 death) tied to it. There is a probability associated with each of the transitions and the model is cycled a predetermined number of times to simulate the individual passing through different health states over the time period of interest. By tallying the costs and utility scores over the time period of interest, the total costs and utilities can be quantified. If a time period of one year is utilized, the utilities can be simply summed to have units of quality-adjusted life years (QALYs). One QALY means having a utility score of 1 (perfect health) for one year. Consequently having a utility score of 0.5 for 2 years of a utility score of 1 for 1 year would be equivalent

QALYs.[43] For time periods other than one year, the utility score will need to be adjusted for the year to calculate a QALY.

In cost-effectiveness analysis, generally two different treatment options are compared using the average cost-effectiveness ratio (ACER) or the incremental cost-effectiveness ratio (ICER). The ACER is calculated by dividing the total cost of a treatment by the total QALYs it provides. Then the ACER value for the two treatment options are directly compared. Historically, this was the more common metric to compare the cost-effectiveness of treatment options. However, this approach is limited in situations where one treatment option provides a significant number of QALYs for a low cost and the other treatment provides slightly more QALYs for a much greater cost. The ACER value for both treatment options could be within reasonable levels, but in the second treatment the sizeable additional cost to get a small improvement in QALYs may not be justified. As a result, ICERs are the standard metric used in cost-effectiveness analysis currently. It is calculated by determining the incremental cost and QALY gains with one treatment over another and then taking the ratio. By this method, treatments that provide small additional QALY gains at a much higher cost can be easily identified.[44] The ICER number can be compared against different willingness-to-pay (WTP) thresholds to determine if the treatment is cost-effective. This WTP number is based on what society would determine as an appropriate cost for obtaining one additional QALY. There is controversy over whether or not to use this assessment. In cases where it is used, there is debate over how the WTP level should be determined. Commonly the WTP is determined based on standards set by other accepted medical interventions, such as an ICER of US$50,000-100,000+ for a lifetime of dialysis. As a result some studies use a WTP of US$50,000-100,000.[45] We will apply these tools to determine the cost-effectiveness of THA for different BMI levels.

1.8 Study Objectives

1) To systematically review the existing literature and determine differences in reoperations, aseptic and septic revisions, and change in functional outcome scores for various BMI categories.

2) To assess 90 day costs and mid-term outcome scores for the following BMI categories: <25, 25-29.9, 30-34.9, 35-39.9, 40-44.9, and 45+.

3) To estimate the cost-effectiveness of THA compared to nonoperative management among these BMI categories over 15 years.

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Chapter 2

2 A Systematic Review and Meta-Analysis of Revision Rates and Functional Outcome Scores for Severely, Morbidly, and Super-Obese Primary Total Hip Arthroplasty Patients

2.1 Introduction

The demand for hip and knee arthroplasty is rising rapidly due to a combination of an aging population as well as an increasing level of obesity in the US and Canada.[1–4] Obese patients (BMI>30) who undergo an arthroplasty report significant improvements in pain, function, and activity levels after the procedure.[5] However, obese patients are at a greater risk for perioperative complications, infections, revision,[6–8] and increased costs of care.[9] All patients with a BMI greater than 30 are not same. The degree of obesity impacts the level of risk and benefits for the individual. Since both the extent and degree of obesity is rising worldwide, studies have begun investigating the impact of having a BMI greater than 35, 40, 45, and even 50 on outcomes following arthroplasty.[8,10–14] Current studies[10,12–14] tend to have small sample sizes followed for a few years post surgery, or larger patient populations analyzed for short follow up times of a few months.[8] Prior systematic reviews and meta-analyses[15–17] focusing on outcomes of total hip arthroplasty with obesity have only evaluated outcomes in patients with a BMI greater than 30. These studies may be missing important differences in outcomes with higher BMIs. For example, Wagner et al.[18] found that revision rates are only significantly greater than the non-obese cohort at a BMI greater than 40. We therefore propose a systematic review and meta-analysis assessing the outcomes for patients following THA separated into BMI categories greater than 30.

The purpose of this study is to perform a systematic review and meta-analysis to determine differences in functional scores, reoperations, and aseptic and septic revisions following THA in severely (BMI>35), morbidly (BMI>40), and super-obese (BMI>50) patients versus a non-obese BMI population (BMI<25). We hypothesized that there

would be an increased risk for reoperations, aseptic, and septic revisions for the higher BMI categories, while the functional scores would be comparable.

2.2 Methods

We conducted a systematic search of the online bibliographic databases Medline (1946 to week 3 of August 2016), AMED (1985 to August 2016), Ovid Healthstar (1966 to August 2016), and Embase (1947 to week 3 of August 2016) to identify studies evaluating outcomes between varying BMI categories. We used database appropriate search terms including a combination of synonyms for obesity (obesity, body-mass index, overweight) linked with hip arthroplasty or replacement found in the abstract, title, text words, or keywords. The search was limited to articles written in the English language. The reference lists of included studies were reviewed to identify any additional studies that would be eligible. Three pairs of reviewers assessed the titles and abstracts of articles found in the initial search for eligibility. Eligible studies included those that 1) evaluated primary total hip arthroplasty outcomes by BMI, 2) BMI was evaluated as a categorical variable and the highest BMI category was at minimum 35 or above, and 3) included the outcomes of interest (reoperations, revision (aseptic and septic) and change scores (preoperative to postoperative) of functional scores). All titles and abstracts that met the eligibility criteria and any marked uncertain were obtained in full text for further review. Each abstract and full-text article were independently reviewed by two authors using the same eligibility criteria. Any discrepancies were discussed between the authors until a consensus was reached. In cases of duplicate reports on the same patient sample, we chose to include the most recent study. We calculated a Kappa statistic to provide a measure of interobserver agreement for study eligibility. The Kappa statistic is a standard tool used to measure the degree of interobserver agreement beyond chance alone.[19]

A quality assessment of the included studies was performed with the ROBINS-I tool for non-randomized studies developed by the Cochrane Bias Methods Group.[20] This tool assesses internal validity based on seven criteria including 1) bias due to confounding, 2) bias in selection of participants into the study, 3) bias in classification of interventions, 4) bias due to deviations from intended interventions, 5) bias due to missing data, 6) bias in measurement of outcomes, and 7) bias in selection of the reported result. For bias due to

confounding we assigned a low risk of bias to studies with a prospective design and retrospective studies with matched cohorts or analysis controlling for baseline factors, while a moderate risk of bias was attributed for other retrospective studies. For selection bias, studies were considered at serious risk of bias if they excluded those that did not meet a minimum follow-up requirement (ex. retrospective study requiring 1 year follow-up therefore missing patients with early complications). For bias in classifications of interventions, we considered how BMI was measured. If BMI was directly measured it was defined as low, if obtained retrospectively from a patient chart defined as moderate, or if patient self reported defined as serious. For deviations from intended intervention, we assessed the risk of bias based on whether there was differential treatment between the BMI cohorts. For bias due to missing data, if studies had less than 15% missing data and similar distributions across BMI categories it was graded as a moderate risk of bias.[20] If the proportion of missing data was greater than 15% or there was differential missing data it was considered a serious risk of bias. For bias in outcome measurement, we considered items such as subjective or objective outcome, blinding and differential outcome assessment between BMI categories. Bias in reported results was based on whether all planned analyses proposed in the methods were included in the results. Information about specific databases/registries gained from other literature sources were utilized to evaluate the risk of bias in other papers using the same data source if data was missing or not clear in the original report.

For the meta-analysis, results were categorized into severely (BMI>35), morbidly (BMI>40), and super-obese (BMI>50) patients, and were compared to a non-obese (BMI<25) group within the same paper. If the paper did not have a BMI less than 25 group, then the smallest equivalent BMI group was used for comparison. Data was extracted from all eligible studies. In addition to recording author name, study title, journal name, issue, and page numbers; we extracted number of patients, patient demographics, means, standard deviations, range, 95% confidence intervals, interquartile range and change scores for functional outcomes and event rates for reoperations and aseptic and septic revisions. If the change in functional outcome scores was not provided, they were calculated based on the difference in means from preoperative to postoperative. In these cases, the standard deviation of change scores were estimated to be the same as

for comparable studies with the same functional outcome scores that provided change scores with standard deviation. The order of preference for functional outcome scores were: Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Oxford Hip Score, Harris Hip Score, and EuroQol (EQ-5D). Authors were contacted when data in the paper was unclear or missing. Meta-analysis was performed using a random effects model where appropriate. Change scores were converted to standardized mean difference for comparison across studies using different outcome measures. Relative risks were used as summary measures for reoperation and revision rates. We calculated pooled estimates and 95% confidence intervals (CI) for both the standardized mean difference and relative risk.

We performed heterogeneity calculations using the I^2 statistic on all outcomes. Sensitivity analyses for short (less than a year) and longer (equal to or greater than a year) follow-up were performed for all outcomes. All calculations were performed with RevMan software (RevMan 5.3, Cochrane Collaboration, London, United Kingdom).

2.3 Results

We identified 1,692 potentially relevant articles from the literature search. We screened 448 full-text articles and 33 studies met the eligibility criteria and were included in the final analyses (Figure 2-1). Inter-rater agreement was good-to-excellent for determining eligibility for titles and abstracts (K=0.84) and full-text articles (K=0.84).

Our quality assessment identified 2 prospective studies, 6 retrospective studies with matched comparison group, and 2 retrospective studies with controlled analysis (Table 2-1). The remaining 23 studies were retrospective studies without a matched comparison group or controlled analysis. Bias due to selection and missing data were the most frequent. Lack of information provided in reports made bias in classification of BMI and deviation from intended intervention difficult to evaluate. Overall, for the majority of studies and categories, the studies had moderate to serious risk of bias (Table 2-2).

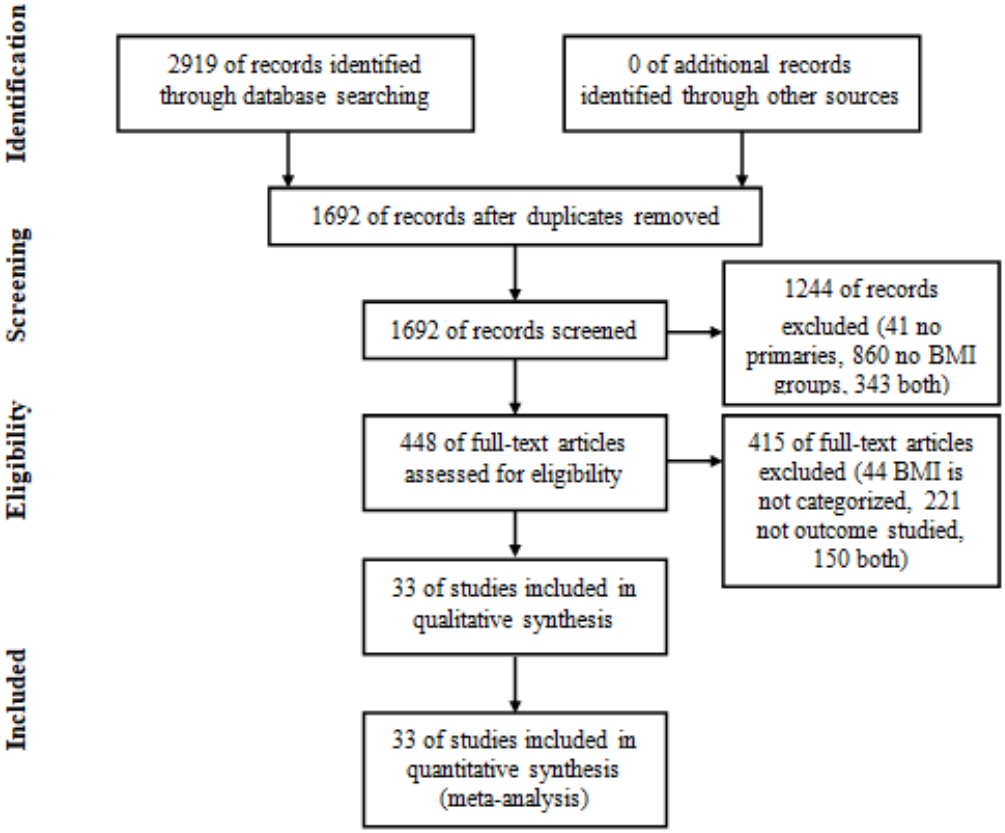


Figure 2-1: Flowchart of Article Selection

Table 2-1: Demographics of Included Studies

Demographics of Included Studies. R = Retrospective, P = Prospective, M = Matched cohort, C = Controlled analysis, N/A = information not available in paper

		Non-Obese Cohort				Obese Cohort(s)			
Study	Study Type	BMI	N	Age	Sex (%Female)	BMI	n	Age	Sex (%Female)
McLawhorn et. al. (2016)	R	18.5-25	865	66.35±0.36	70.8	35-40	186	61.90±0.65	51.6
						>=40	73	60.51±1.08	52.1
Fu et. al. (2016)	R, C	18.5-29.9	10997	N/A	58.6	35-39.9	2557	N/A	53.7
						>=40	1596	N/A	59.6
Purcell et. al. (2016)	R	<35	1417	63.3±11.0	56.7	>=35	204	59.3±10.26	60.3
Hanly et. al. (2016)	R	18.5-25	186	67.2±13.9	54.3	>=40	39	61.4±9.6	76.9
Walls et. al. (2015)	R	18.5-40	45895	65.4±12.0	55.2	>40	3580	60.5±9.8	60.8
Lash et. al. (2013)	R	<30	985	N/A	N/A	>35	144	N/A	N/A
Issa et. al. (2016)	R, M	<30	135	55 (range: 48-75)	N/A	>=50	45	54 (range 36-71)	
Foster et. al. (2015)	R	<30	274	N/A	N/A	>40	23	N/A	N/A
Arsoy et. al. (2014)	R, M	<50	84	56.7±11.6	70.0	>=50	42	56.5±12.3	72.0
Murgatroyd et. al. (2014)	R	20-24.99	1136	69.18±12.03	63.1	>40	219	59.95±10.02	62.6
Jameson et. al. (2014) Cemented Stems	R	19-29.9	1640	74.3±7.6	62.5	>=35	321	70.7±7.4	72.3
Jameson et. al. (2014) Cementless Stems	R	19-29.9	1738	66.7±9.6	56.3	>=35	428	62.9±9.1	58.2
Khatod et. al. (2014)	R	<30	21574	N/A	N/A	>=35	5778	N/A	N/A
Judge et. al. (2014)	R	18.5-25	864	N/A	N/A	35-40	150	N/A	N/A
						>40	47	N/A	N/A

Table 2-1 (continued): Demographics of Included Studies

Demographics of Included Studies. R = Retrospective, P = Prospective, M = Matched cohort, C = Controlled analysis, N/A = information not available in paper

Issa et. al. (2013)	R, M	<25	46	N/A	N/A	>=50	23	50 (range 25-71)	55.0
Rajgopal et. al. (2013)	R, M	18.5-24.9	39	53.1 (range 29-72)	85.0	>50	39	53 (range 31-72)	83.0
Namba et. al. (2012)	R	18.5-30	17569	N/A	N/A	>=35	4754	N/A	N/A
Jamsen et. al. (2012)	R	<25	1105	N/A	N/A	35-39	559	N/A	N/A
						>=40	193	N/A	N/A
Jones et. al. (2012)	R	<25	52	N/A	N/A	>=35	32		
Michalka et. al. (2012)	R	<30	113	67.7±13.20	58.4	>=35	21	65.4±8.96	42.9
Lehman et. al. (1994)	R	20-30	142	48 (range 19-73)	25.4	>=40	8	52 (range 37-72)	25.0
Traina et. al. (2011)	R	18.5-24.9	6102	N/A	71.0	>=40	187	N/A	66.8
McCalden et. al. (2011)	R	<25	647	71.0 (range 23.77-95.74)	70.6	>=40	206	59.7 (range 26.51-82.36)	63.6
Chee et. al. (2010)	R, M	<30	55	63.6 (range 45-83)	77.4	>=40 or >=35 with 1 major comorbidity	55	63.7 (range 45-83)	77.4
Dowsey et. al. (2010)	P	<30	277	68.6±10.8	58.1	>=40	21	65.6±10.7	85.7
Judge et. al. (2010)	R	<30	623	N/A	N/A	>=40	11	N/A	N/A
Bennett et. al. (2010)	R, M	20-25	29	61.6 (range 43-74)	72.4	>=40	29	61.4 (range 42-74)	72.4
Andrew et. al. (2008)	P	<30	1069	69.1±11.1	62.4	>40	18	60.6±12.3	72.2
Dowsey et. al. (2008)	R	<25	301	N/A	N/A	>=40	44	N/A	N/A

Table 2-1 (continued): Demographics of Included Studies

Demographics of Included Studies. R = Retrospective, P = Prospective, M = Matched cohort, C = Controlled analysis, N/A = information not available in paper

McLaughlin et. al. (2006)	R	20-25	33	N/A	N/A	>=35	30	N/A	N/A
Namba et. al. (2005)	R	<=35	922	66±13	57.0	>35	149	62±9	62.0
Jibodh et. al. (2004)	R	<25	51	68±12	63.0	>=40	18	59±15	78.0
Stickles et. al. (2001)	R	<25	131	N/A	N/A	35-40	51	N/A	N/A
						>40	27	N/A	N/A
Werner et. al. (2016)	R, C	<30	702360	N/A	61.0	40-49.9	62556	N/A	66.3
						>=50	3244	n	72.2

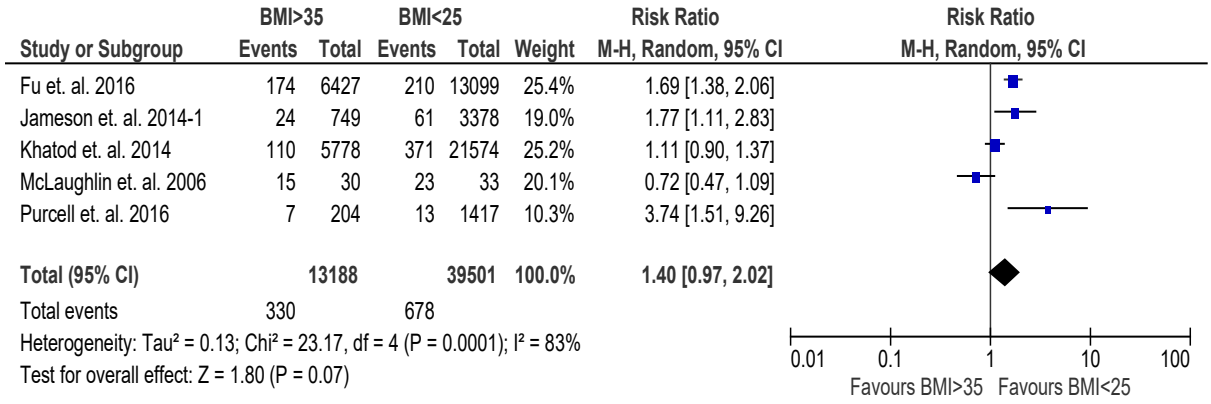
Table 2-2: Summary of Quality Assessment of Included Studies. 1 = Low risk of bias; 2 = Moderate risk of bias; 3 = Serious risk of bias; NI = Not enough information to evaluate.

	Confounding	Selection of Participants in Study	Classification of BMI	Deviation from Intended Intervention	Missing Data	Measurement of Reoperation/ Aseptic/Septic Revisions	Measurement of Functional Outcome Scores	Selection of Reported Result
McLawhorn et. al. (2016)	2	3	3	NI	3		2	2
Fu et. al. (2016)	1	2	1	NI	2	1		2
Purcell et. al. (2016)	2	2	NI	2	NI	2		2
Hanly et. al. (2016)	2	3	2	NI	NI	2		2
Walls et. al. (2015)	2	2	1	NI	2	1		2
Lash et. al. (2013)	2	2	NI	NI	3		2	2
Issa et. al. (2016)	1	2	2	2	NI	2	2	2
Foster et. al. (2015)	2	3	2	NI	2		2	2
Arsoy et. al. (2014)	1	2	1	NI	3	2	2	2
Murgatroyd et. al. (2014)	2	2	NI	NI	2	2		2
Jameson et. al. (2014)	2	3	3	NI	2	2	2	2
Khatod et. al. (2014)	2	2	2	NI	2	2		2
Judge et. al. (2014)	2	2	NI	NI	3		2	2
Issa et. al. (2013)	1	2	NI	2	NI	2	2	2
Rajgopal et. al. (2013)	1	2	2	2	NI	2	2	2
Namba et. al. (2012)	2	2	2	3	NI	2		2
Jamsen et. al. (2012)	2	3	2	2	NI	1		2
Jones et. al. (2012)	2	2	2	2	2		2	2

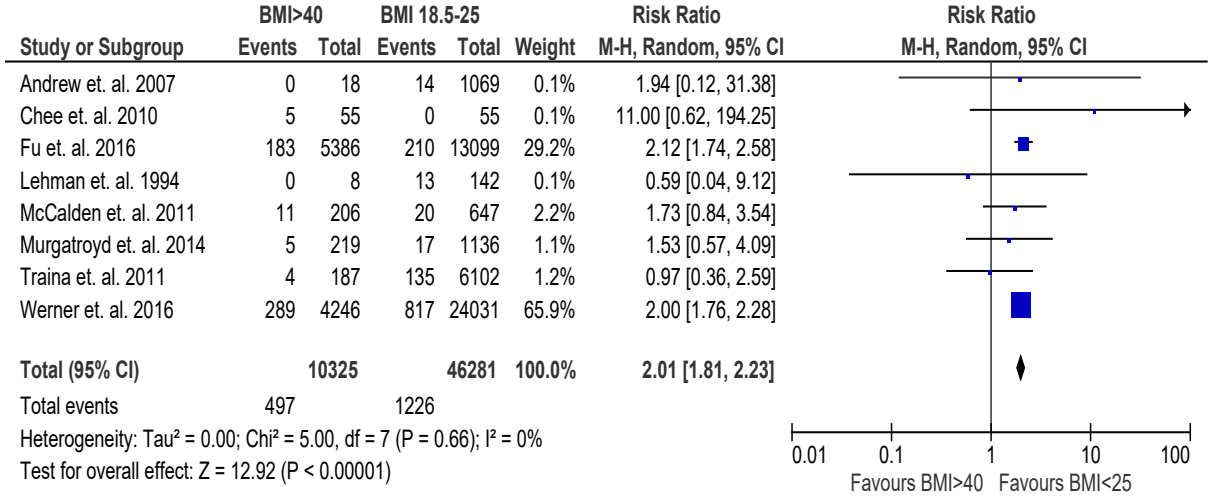
Table 2-2 (continued): Summary of Quality Assessment of Included Studies. 1 = Low risk of bias; 2 = Moderate risk of bias; 3 = Serious risk of bias; NI = Not enough information to evaluate.

Michalka et. al. (2012)	2	2	1	NI	2		2	2
Lehman et. al. (1994)	2	3	2	NI	2	NI		2
Traina et. al. (2011)	2	2	NI	NI	NI	NI		2
McCalden et. al. (2011)	2	3	2	2	2	2	2	2
Chee et. al. (2010)	1	3	3	2	2	1		2
Dowsey et. al. (2010)	1	2	1	NI	2		2	2
Judge et. al. (2010)	2	2	NI	NI	3		2	2
Bennett et. al. (2010)	1	3	NI	2	NI	2	2	2
Andrew et. al. (2008)	1	2	NI	2	3	2	2	2
Dowsey et. al. (2008)	2	2	NI	NI	2	2		2
McLaughlin et. al. (2006)	2	2	NI	2	2	2		2
Namba et. al. (2005)	2	2	2	NI	2	1		2
Jibodh et. al. (2004)	2	2	NI	2	NI	2		2
Stickles et. al. (2001)	2	3	NI	NI	3		2	2
Werner et. al. (2016)	1	2	3	NI	NI	3		2

BMI>35[21–25]



BMI>40[8,21,26–31]



BMI>50[8,10,12–14]

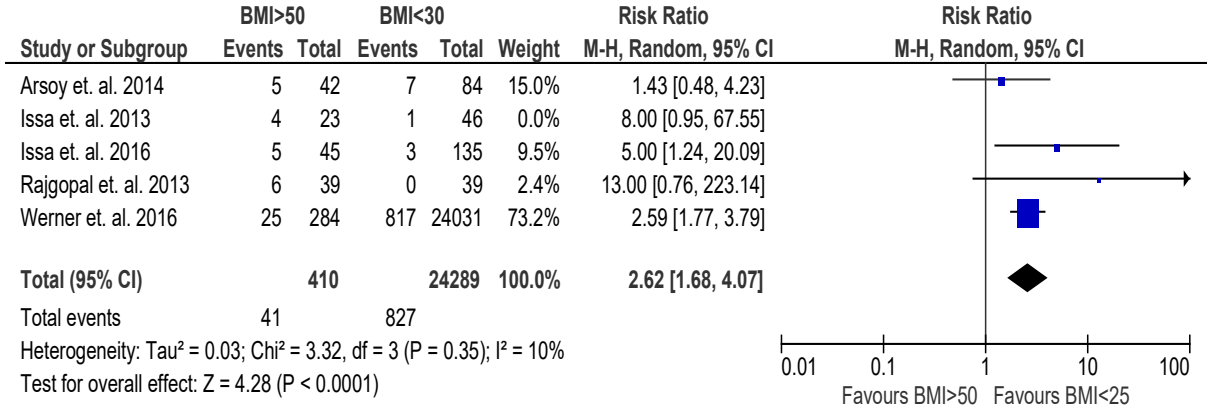
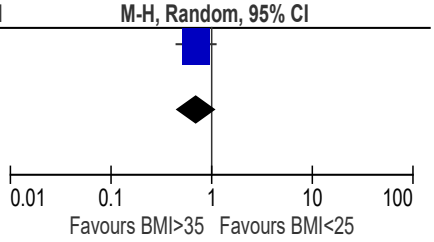


Figure 2-2: Reoperation Rates Across Severely, Morbidly, and Super-Obese Patients

BMI>35[24]

Study or Subgroup	BMI>35 Events	Total	BMI<25 Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
McLaughlin et. al. 2006	14	30	22	33	100.0%	0.70 [0.45, 1.10]
Total (95% CI)		**30**		**33**	**100.0%**	**0.70 [0.45, 1.10]**
Total events	14		22			

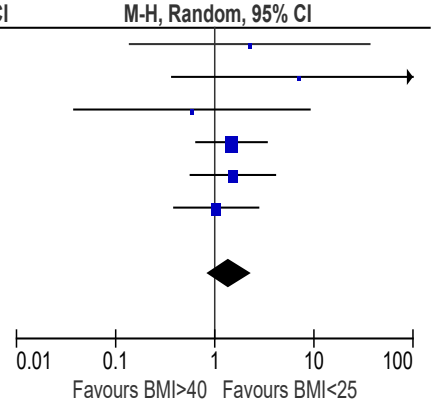
Heterogeneity: Not applicable
Test for overall effect: Z = 1.55 (P = 0.12)



BMI>40[26–31]

Study or Subgroup	BMI>40 Events	Total	BMI 18.5-25 Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
Andrew et. al. 2007	0	18	12	1069	3.3%	2.25 [0.14, 36.68]
Chee et. al. 2010	3	55	0	55	3.0%	7.00 [0.37, 132.40]
Lehman et. al. 1994	0	8	13	142	3.4%	0.59 [0.04, 9.12]
McCalden et. al. 2011	8	206	17	647	37.6%	1.48 [0.65, 3.37]
Murgatroyd et. al. 2014	5	219	17	1136	26.3%	1.53 [0.57, 4.09]
Traina et. al. 2011	4	187	126	6102	26.4%	1.04 [0.39, 2.77]
Total (95% CI)		**693**		**9151**	**100.0%**	**1.40 [0.84, 2.32]**
Total events	20		185			

Heterogeneity: Tau² = 0.00; Chi² = 2.06, df = 5 (P = 0.84); I² = 0%
Test for overall effect: Z = 1.29 (P = 0.20)



BMI>50[10,12–14]

Study or Subgroup	BMI>50 Events	Total	BMI<30 Events	Total	Weight	Risk Ratio M-H, Random, 95% CI
Arsoy et. al. 2014	4	42	6	84	56.8%	1.33 [0.40, 4.47]
Issa et. al. 2013	1	23	0	46	0.0%	5.88 [0.25, 138.84]
Issa et. al. 2016	3	45	3	135	34.0%	3.00 [0.63, 14.34]
Rajgopal et. al. 2013	2	39	0	39	9.2%	5.00 [0.25, 100.89]
Total (95% CI)		**126**		**258**	**100.0%**	**1.98 [0.80, 4.94]**
Total events	9		9			

Heterogeneity: Tau² = 0.00; Chi² = 1.05, df = 2 (P = 0.59); I² = 0%
Test for overall effect: Z = 1.47 (P = 0.14)

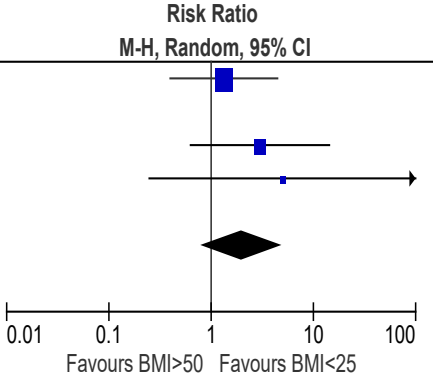
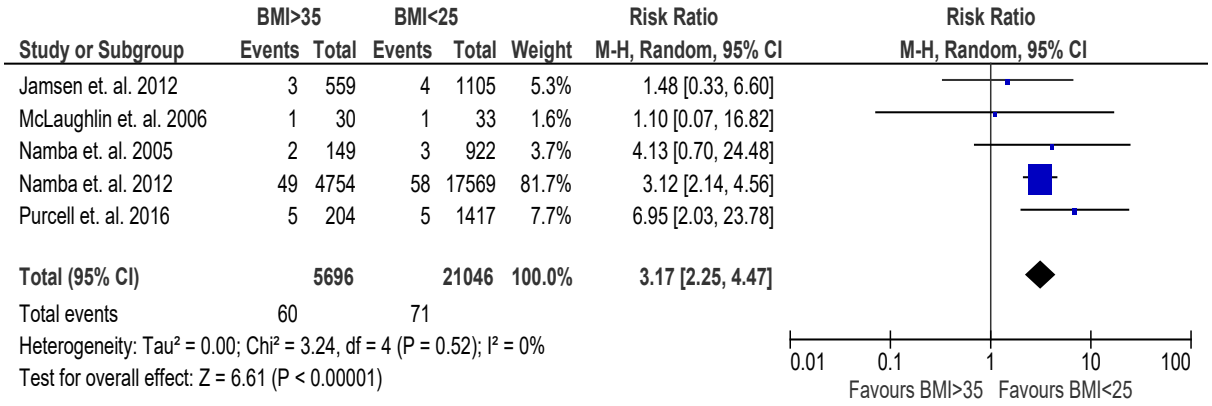
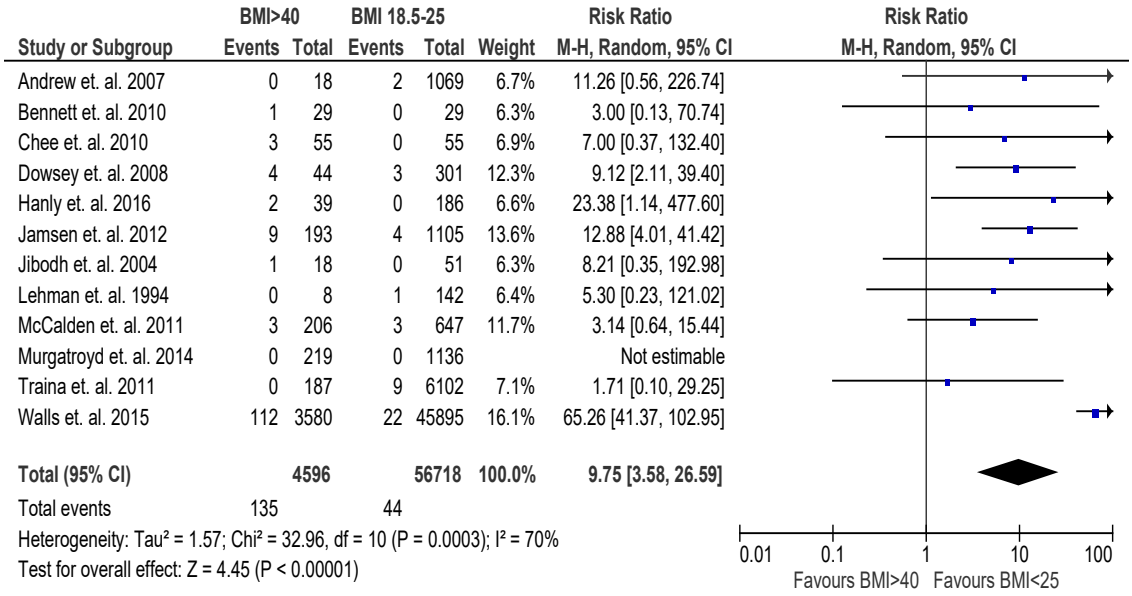


Figure 2-3: Aseptic Revisions Rates Across Severely, Morbidly, and Super-Obese Patients

BMI>35[22,24,25,32,33]



BMI>40[22,26–31,34–38]



BMI>50[10,12–14]

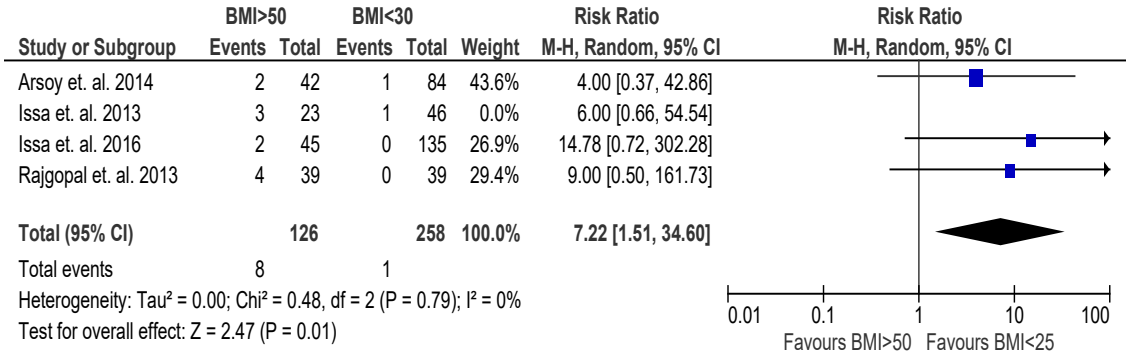
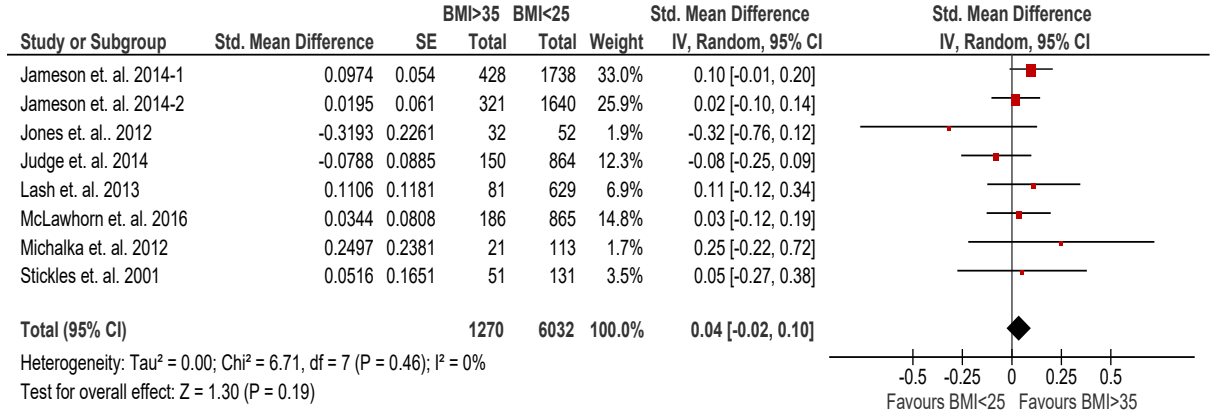


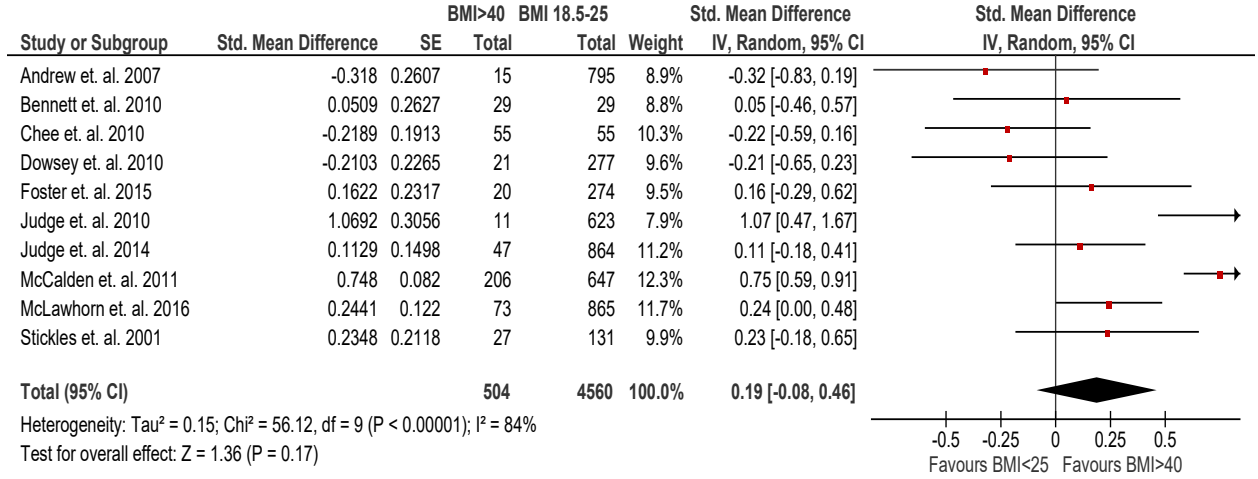
Figure 2-4: Septic Revision Rates Across Severely, Morbidly, and Super-Obese Patients.

BMI>35[5,22,39–43]

*For the super-obese analysis, an earlier study by Issa et. al. (2013)[14] is included in the table, but not used for the pooled calculations. A more recent paper on the same patient population by Issa et. al. (2016)[12] was used for pooled calculations.



BMI>40[5,26,34,35,40,43–45]



BMI>50[10,12,14]

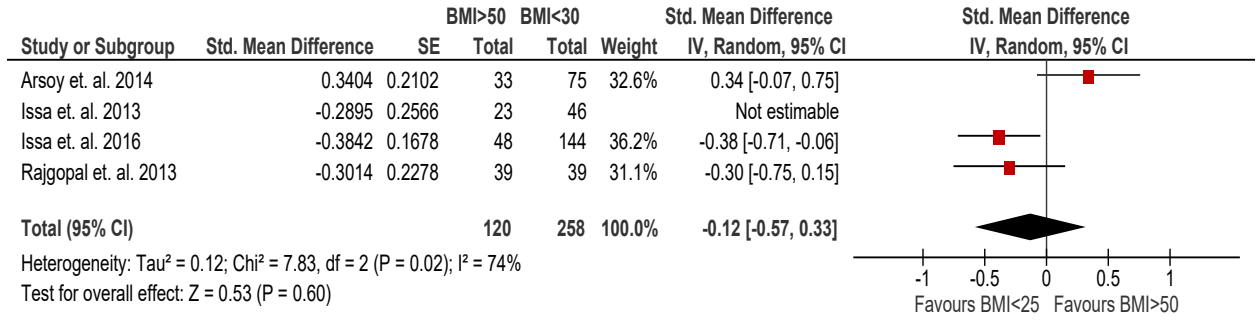


Figure 2-5: Change Scores for Outcome Across Severely, Morbidly, and Super-Obese Patients

For risk of reoperations relative to the non-obese cohort, we found that there was an increased relative risk for the morbidly (2.01, 95% CI: 1.81-2.23, p<0.01) and super-obese patients (2.62, 95% CI: 1.68-4.07, p<0.01) (Figure 2-2). The increased risk of reoperation for the severely-obese was not significant (1.40, 95% CI: 0.97-2.02, p=0.07). Exclusion of studies with short-term (less than a year) follow-up did not change the significance of the results for the severely-obese (1.24, 95% CI: 0.68-2.26, p=0.49) or super-obese (3.57, 95% CI: 1.33-9.57, p=0.01). In the case of the morbidly-obese, the increased risk was no longer significant (1.50, 95% CI: 0.93-2.41, p=0.10). Both the morbidly and super-obese patient comparisons had no heterogeneity with I^2 = 0% and 10%, respectively, the heterogeneity had minimal change with the sensitivity analysis. Between study heterogeneity was not reduced with sensitivity analysis for the severely-obese patient comparison (I^2 = 83% and I^2 = 82% for the longer follow-up studies only).

Aseptic revision was only reported in one study for the severely-obese patients (Figure 2-3). That study did not show any increased risk for the severely-obese patients (0.70, 95% CI: 0.45-1.10, p=0.12), but each group only had about 30 patients. Similarly, there was no significantly increased risk of aseptic revisions for either the morbidly (1.40, 95% CI: 0.84-2.32, p=0.20) or super-obese (1.98, 95% CI: 0.80-4.94, p=0.14) patients. All studies for both the morbidly and super-obese patients included longer follow-up so no additional sensitivity analysis was performed for this outcome. There was no heterogeneity (I^2 = 0%) for either the morbidly or super-obese analysis.

The risk of septic revisions were found to be significantly higher for severely (3.17, 95% CI: 2.25-4.47, p<0.01), morbidly (9.75, 95% CI: 3.58--26.59, p<0.01), and super-obese patients (7.22, 95% CI: 1.51-34.60, p=0.01) (Figure 2-4). Sensitivity analysis could not be performed for the severely or super-obese patients, since all included studies had follow-up of one year or greater. After removal of the studies with short follow-up in the morbidly-obese patient analysis, the risk ratio was still significantly greater at 7.49 (95% CI: 3.85-14.57, p<0.01) and the heterogeneity was reduced from 70% to 0%. There was no heterogeneity (I^2 = 0%) with the severely and super-obese analysis.

The change in functional outcome score as evaluated by standardized mean difference was not significantly different between the severely (0.04, 95% CI: -0.02-0.10, p=0.19), morbidly (0.19, 95% CI: -0.08-0.46, p=0.17), and super-obese patients (-0.12, 95% CI: -0.57-0.33 p=0.60) with then non-obese population. Sensitivity analysis focusing on longer term outcomes of 1 year or more did not alter the results for the severely (0, 95% CI: -0.10-0.09, p=0.95) or morbidly-obese (0.15, 95% CI: -0.10-0.40, p=0.23). All studies included for the super-obese analysis had longer term follow up, and two reported worse improvement and one reported better improvement for the super-obese resulting in high heterogeneity for this result (I^2 = 86%). There was no heterogeneity (I^2 = 0%) for the severely-obese analysis. Sensitivity analysis did not reduce the heterogeneity (I^2 = 84% vs. 86%) for the morbidly-obese analysis.

2.4 Discussion

Our results suggest that both morbidly and super-obese populations are at a higher risk for reoperation following THA than the non-obese population, with the super-obese at a higher relative risk than the morbidly obese. All three obese groups were at a higher risk for septic revision than the non-obese patients, and the morbidly-obese (RR 9.75, 95% CI: 3.58--26.59, p<0.01) and super-obese (RR 7.22, 95% CI: 1.51-34.60, p=0.01) had a much higher relative risk than the severely-obese (RR 3.17, 95% CI: 2.25-4.47, p<0.01) patients. The severely, morbidly, and super-obese patients did not have a significant difference in aseptic revision or change in functional outcome scores.

Our study did not find a greater risk of reoperation until the BMI reached the morbidly and super-obese groups. Wagner et al. reported similar results based on their retrospective study of their institution's outcomes.[39] They found no significantly greater risk of reoperation until a BMI greater than 40, which had a hazard ratio of 1.6 (95% CI: 1.3-2.0) relative to the non-obese. We had a comparable risk ratio of 2.01 (95% CI: 1.81-2.23) for our morbidly-obese group. For the morbidly-obese deep infection rate, we reported a greater risk ratio of 9.75 (95% CI: 3.58-26.59) versus Wagner et al.'s hazard ratio of 4.4 (95% CI: 2.8-6.9).[18] The difference in results could be partly attributed to the varying definitions in deep infection/septic revisions utilized by the studies included in the meta-analysis. Also, our sensitivity analysis examining longer term follow-up

demonstrated a slightly lower relative risk ratio that does include Wagner's hazard ratio in its confidence interval (7.49, 95% CI: 3.85-14.57).

In recent years, there has been an increased focus on preoperative optimization prior to THA and TKA. It has been controversial whether, and to what degree, obesity can be reduced, or at least optimized. Some studies have examined the impact of both nonoperative and operative means of weight loss but their influence on improving arthroplasty outcomes has not been clearly demonstrated.[46] At the same time, there is clear evidence that obese patients have increased costs of care and complications.[47] Consequently, some authors recommend BMI thresholds (35-45) above which an arthroplasty should not be offered.[11,41,48] Our study clearly demonstrates that over the long term, severely, morbidly, and super-obese patients benefit significantly by having an arthroplasty with comparable change scores as the non-obese cohorts, although they also have varying levels of increased risks for reoperation and septic revision. This leads to the question of whether obese patients should be denied a procedure that provides significant benefit, despite the additional risks. For other chronic diseases such as diabetes, we do not deny those patients an arthroplasty. Instead, physicians focus on improving their glucose management, to optimize their perioperative outcomes. Unfortunately, there are no clear obesity treatments that have been demonstrated to improve obesity's perioperative risk profile. This issue will become even more important with the combined factors of increasing number of obese individuals, increasing degree of obesity around the world, and changing health care policy.[1,47]

The limitations in this study are those common with systematic reviews and meta-analysis; the quality of results are limited by the quality of the included studies. We did perform a quality analysis and found that the predominant study design was retrospective cohort studies, with only two prospective cohort studies, resulting in a high degree of either selection or missing data bias. Another limitation included varying follow-up times that can influence the revision rates. We did account for that in our sensitivity analysis and found that in only one case did it alter the significance of our results. For the super-obese group's change score analysis, we only had three studies with one reporting a conflicting results. This warrants further research to better evaluate their outcome scores

after arthroplasty. Some studies did not have a non-obese (BMI 18.5-25) cohort for comparison, as a result the smallest BMI cohort was chosen for comparison. Since Wagner et al[18] suggested that results only dramatically change above a BMI of 40, this likely is not an important factor for reoperations since the comparison groups had a BMI less than or equal to 40 (except for one study in the super-obese group, Arsoy et. al.[10,] which used a comparison group with BMI less than 50). The results for septic revision could be underestimated due to the differences in comparison groups. For the functional outcome score comparisons, we choose the outcome measures that were most commonly reported in the included studies, but some studies only reported one outcome measure in which case that was used.

Older literature tended to categorize all patients with a BMI greater than 30 as obese, and prior systematic reviews[15–17] have used these studies to evaluate the impact of obesity. However, a more granular evaluation of obesity is warranted since the risk profile of everyone with a BMI greater than 30 is not the same. This inspired our study to focus on a systematic review and meta-analysis of the studies that consider the sub-categories of obesity. In addition, many of the studies on higher obesity categories were limited by number of patients available, and we hoped to increase the power of our study by pooling the results of multiple studies in the meta-analysis. We found that severely, morbidly, and super-obese patients have comparable functional outcome score improvements to non-obese patients, but have higher risk of reoperation and septic revision. The different obesity thresholds have dramatically different risk profiles that need to be accounted for in perioperative counseling.

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Chapter 3

3 90-Day Costs, Reoperations, and Readmissions for Primary Total Hip Arthroplasty Patients of Varying BMI Levels

3.1 Introduction

The demand for total hip arthroplasty (THA) is increasing rapidly due to a combination of an aging population as well as an increasing level of obesity in the US and Canada.[1,2] Patients with a higher BMI may be at a greater risk for perioperative length of stay, complications, infections, and revision.[3–5] Nonetheless, obese patients who undergo a THA report significant improvements in pain, function, and activity levels after the procedure.[6–8] Concurrently, in the United States several payers for health care including both government (Medicare) and private insurance are instituting bundled payment plans where physicians and hospitals will be held financially accountable for complications within 90-days of a surgery.[9] Similarly, many of the Canadian provincial healthcare systems have fixed budgets to perform a government established number of THAs. The costs of any subsequent readmission or revision as a complication of the index procedure are absorbed by the treating hospital. Additionally, metrics such as 30-day readmissions, infections and reoperation within a year are used to track hospital quality. It is conceivable that Canadian hospitals could be penalized for underperforming outcome metrics which are actually a reflection of the case acuity. When a center's quality of care is assessed, no metric to account for taking care of a greater number of high risk patients (such as obesity) is utilized. In both countries, many providers have arbitrarily chosen specific body mass index (BMI) levels ranging from 35-45, above which they will not offer arthroplasty as an option.

Health care policy incentivizes a focus on the short-term outcomes and their economic implications and does not account for the longer-term benefits. Prior studies have focused on either the costs[10] or complications[11–13], or on the functional outcomes[8] for different BMIs. We sought to more thoroughly evaluate both the risks and the benefits of arthroplasty for a wide range of BMIs, which can provide guidance for clinicians,

patients and administrators to ensure optimal care for obese and non-obese arthritic patients.

The primary purpose of this study is to compare 90-day costs and mid-term functional score improvements following total hip arthroplasty (THA) among non-obese (BMI 18.5-24.9), overweight (25-29.9), obese (30-34.9), severely-obese (35-39.9), morbidly-obese (40-44.9), and super-obese (45+) patient cohorts. We hypothesized that the 90-day costs would be higher for the super-obese patient population, but that those patients would have comparable functional score improvements relative to the other BMI groups.

3.2 Methods

We retrospectively reviewed our institutional database to identify patients who had undergone a primary THA between 2006 and 2013. Data was collected at the beginning of 2017. All patients who had a unilateral primary THA (with an underlying diagnosis of osteoarthritis, rheumatoid arthritis, post-traumatic arthritis, or osteonecrosis) were included for selection into the study. Patients who had a simultaneous bilateral arthroplasty, acute fracture or polytrauma as indication for arthroplasty, femoral shortening osteotomy, or skeletal dysplasia were excluded from the study. BMI was calculated from heights and weights measured at the preoperative assessment and recorded in the database. The patients were categorized into 6 groups based on BMI recorded in the database: <25 (non-obese), 25-29.9 (overweight), 30-34.9 (obese), 35-39.9 (severely-obese), 40-44.9 (morbidly-obese), and 45+ (super-obese). We used a sample of convenience based on the number of eligible patients in the super-obese category, as this was expected to be the least common. We identified 33 patients with a BMI categorized as super-obese and met the inclusion and exclusion criteria. Patients from the other BMI cohorts were then selected randomly from the entire THA cohort by use of a random numbers table in a 2:1 ratio relative to the super-obese cohort (66 patients in each group, total of 363 patients). Perioperative protocols were the same for all BMI cohorts except for DVT prophylaxis. Low molecular weight heparin was used for DVT prophylaxis for the morbidly and super-obese patients, and aspirin was used for the other cohorts.

3.2.1 Outcome Measures

Patient charts and electronic medical records were reviewed. We extracted demographic variables including age, sex, BMI, smoking status, Charlson comorbidity index (CCI), and American Society of Anesthesiologists (ASA) score. We also recorded all in-hospital resource use such as time in the operating room, anesthesia type, length of hospital stay, and perioperative complications (DVT/PE and superficial infection). For the first 90-days postoperative, we identified emergency room visits, reoperations, and readmissions to hospitals within the local region (most hospitals within a 100 kilometer radius of our institution). Medical records were reviewed to identify mid-term revisions rates (reoperation for any cause, aseptic, and septic revision). Costs were determined using unit costs from our institutional administrative data for all in-hospital resource utilization (Table 3-1). Costs for the index hospitalization, 90-day readmissions, and 90-day ER visits were averaged over all patients whether or not they had a readmission or ER visit. The 90-day costs were calculated by taking the sum of the index hospitalization, 90-day readmissions, and 90-day ER visits.

Table 3-1: Unit Costs from Administrative Data

Item	Costs
Inpatient	
PACU Stay	$344.10
Inpatient Costs (per hour)	$26.13/hr
Inpatient Meals (per hour)	$1.40/hr
PT cost (per hour)	$2.47/hr
OT cost	$92.22
Average Consults	$78.85
Average Transfusion	$6.84
Average Lab & Imaging	$53.12
Pelvis X-Ray	$95.13
Antibiotics & Foley	$18.73
Operating Room	
OR Time (per min)	$16.37/min
Anesthesia Equipment	$269.04
Average OR Packs	$318.59
Acetabular Socket	$500.00
Femoral Stem	$950.00
Femoral Head	$200.00
Liner	$800.00
Screw	$75.00
Luque Wire	$43.26

We also collected patient-reported outcome measures from the database. All patients treated at our institution complete the Harris Hip Score (HHS), Short-Form Health Survey (SF-12), and Western Ontario and McMaster Universities Arthritis Index (WOMAC) preoperatively and at each visit postoperatively. We used the preoperative and latest postoperative data to calculate a change score for each patient. Scores were scaled such that lower scores meant worse function and higher scores meant greater function. Missing data due to inadequate recording in the patient chart or incomplete outcome questionnaires were not included in statistical analysis. The primary outcomes of interest were 90-day costs and midterm change scores. Secondary outcomes are perioperative outcomes, 90-day complications, and midterm (3 year) revision rates.

3.2.2 Statistical Analysis

We used descriptive statistics (frequencies, means and standard deviation) to summarize the demographics, clinical characteristics, and outcomes. For continuous variables, normality was tested with the Shapiro-Wilk test. Normally distributed continuous variables were compared using analysis of variance (ANOVA) and non-normal continuous variables were compared using the nonparametric Kruskal-Wallis H test. Significance on these tests implied that there was a statistically significant difference across all six cohorts. A post-hoc Tukey's test was performed on variables that demonstrated a significant difference on ANOVA to identify the specific BMI cohort comparisons that led to the statistical difference. Categorical variables were compared with either a Chi Square analysis or Fisher’s exact test. Statistical significance was set at $p < 0.05$. Data were analyzed using Stata, Version 12, Software (Stata Corp LP, College Station, TX).

3.3 Results

3.3.1 Demographics

Table 3-2: Demographics of THA Patients by BMI Group

Variable	Body Mass Index (BMI) Group						
	18.5-24.9 Non-Obese (n = 66)	25-29.9 Overweight (n = 66)	30-34.9 Obese (n = 66)	35-39.9 Severely-Obese (n = 66)	40-44.9 Morbidly-Obese (n = 66)	45+ Super-Obese (n = 33)	p-value
Age (mean±standard deviation)	66.7±12.9	68.2±11.1	65.2±12.1	62.8±12.1	59.0±10.7	57.1±9.1	<0.01
Sex (%Female)	69.7	65.2	45.5	56.1	71.2	66.7	0.02
BMI (mean±standard deviation)	22.2±2.3	27.4±1.3	32.2±1.3	37.2±1.3	42.3±1.4	50.0±4.5	<0.01
Charlson Comorbidity Index (CCI) (%)							
0	69.7	62.1	69.7	69.7	54.5	57.6	
1	22.7	25.8	22.7	18.2	34.8	24.2	
2	4.5	3.0	7.6	7.6	10.6	6.1	0.03
3	3.0	6.1	0.0	3.0	0.0	6.1	
4	0.0	0.0	0.0	1.5	0.0	6.1	
5	0.0	3.0	0.0	0.0	0.0	0.0	
American Society of Anesthesiologists Score (ASA) (%)							
1	7.6	4.5	1.5	3.0	1.5	3.0	
2	45.5	45.5	50.0	28.8	15.2	6.1	<0.01
3	39.4	47.0	43.9	60.6	75.8	57.6	
4	7.6	3.0	4.5	7.6	7.6	33.3	
Smoking (%)	16.7	9.1	7.6	9.1	7.6	3.0	0.31

The demographics of the study participants are reported in Table 3-2. There was a statistically significant difference in age across the groups ($p < 0.01$). In particular, the morbidly and super-obese patients were significantly younger than the non-obese ($p < 0.01$ and $p < 0.01$, respectively), overweight ($p < 0.01$ and $p < 0.01$, respectively), and obese groups ($p = 0.03$ and $p = 0.02$, respectively). There were significant differences in CCI ($p = 0.03$) and ASA ($p < 0.01$) across the BMI groups. The higher BMI categories

had more patients with ASA scores of 3 and 4 than 1 and 2. No significant difference was found in smoking rates across the BMI cohorts (p = 0.31).

3.3.2 Primary Outcomes

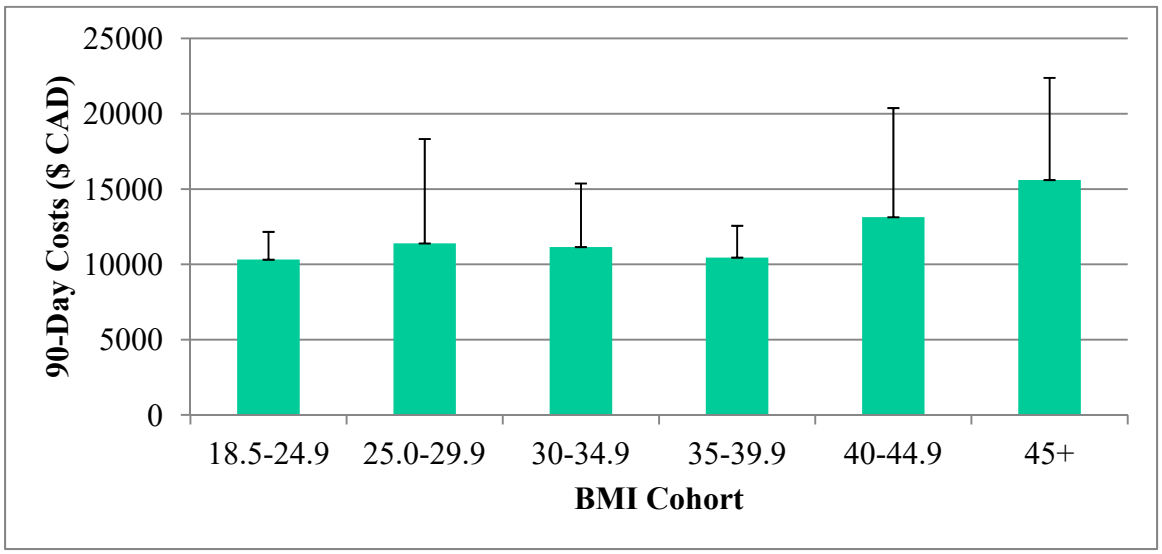

Figure 3-1: 90-Day Costs Across BMI Cohorts

At 90-days, the costs were significantly different across the BMI cohorts (p < 0.01) (Figure 3-1). The super-obese cohort had significantly greater costs than the four smallest BMI cohorts (p < 0.01 for every comparison) but not relative to the morbidly-obese (p = 0.23). The morbidly-obese cohort had significantly higher costs than the non-obese (p = 0.03) and the severely obese (p = 0.04) cohort. The inpatient costs were significantly different across the BMI cohorts (p < 0.01), and the difference in magnitude between the super-obese and the non-obese cohorts is approximately $1,700. By 90-days, the cost differential between the super-obese and the non-obese cohorts is approximately $5,300. The main three contributors to the cost differential are readmissions, index hospitalization, and treatment with fragmin for DVT prophylaxis. For HHS, SF12 MCS and PCS, and WOMAC, there were no significant differences in change scores across the BMI cohorts (p = 0.29, p = 0.47, p = 0.86, and p = 0.93, respectively).

3.3.3 Secondary Outcomes

Perioperative outcomes during the inpatient stay, 90-days, and after 3 years are reported in Table 3-3. The time in the operating room was significantly different among the BMI cohorts ($p < 0.01$). Post-hoc analysis demonstrated that the super-obese had significantly longer operative time compared to all other BMI cohorts ($p < 0.01$, $p < 0.01$, $p < 0.01$, $p = 0.01$, and $p = 0.01$, respectively for the non-obese to morbidly-obese). The severely-obese and morbidly-obese had significantly longer operative time than the non-obese cohort ($p = 0.01$ and $p = 0.01$, respectively). There was no statistically significant difference among the BMI cohorts for length of hospital stay. At 90-days, there were no significant differences in the superficial infection ($p = 0.14$), VTE ($p = 0.71$), ER visits ($p = 0.06$), or readmissions ($p = 0.05$) across all the BMI cohorts. Ninety day reoperation rates were significantly different among the BMI cohorts ($p < 0.01$) with the morbidly and super-obese patients having dramatically more reoperations of any kind.

Table 3-3: Outcomes of THA Patients by BMI Group

Variable	BMI Group						
	18.5-24.9 Non-Obese (n = 66)	25-29.9 Overweight (n = 66)	30-34.9 Obese (n = 66)	35-39.9 Severely-Obese (n = 66)	40-44.9 Morbidly-Obese (n = 66)	45+ Super-Obese (n = 33)	p-value
Outcomes During Hospitalization							
OR Time (min) (mean±standard deviation)	119±19	122±22	129±24	133±29	132±20	150±28	<0.01
Anesthesia							
Spinal	72.7%	50.0%	68.2%	62.1%	63.6%	60.6%	0.27
General	27.3%	50.0%	30.3%	36.4%	36.4%	39.4%	
Other	0.0%	0.0%	1.5%	1.5%	0.0%	0.0%	
LOS (days) (mean±standard deviation)	4.4±1.7	4.3±1.5	4.8±2.5	4.2±2.0	4.6±2.0	5.6±3.5	0.06
Discharge to Extended Care Facility	16.7%	12.1%	12.1%	13.6%	15.2%	18.2%	0.95
Inpatient Cost (mean±standard deviation)	$10,002 ±1,348	$10,000 ±1,265	$10,392 ±1,797	$10,102 ±1,772	$10,615 ±1,547	$11,704 ±2,997	<0.01
Outcomes at 90 Days							
Superficial Infection	3.0%	7.6%	3.0%	4.5%	13.6%	9.1%	0.14
VTE	0.0%	1.5%	3.0%	3.0%	3.0%	0.0%	0.71
ER Visit	12.1%	19.7%	16.7%	9.1%	16.7%	33.3%	0.06

Table 3-3 (continued): Outcomes of THA Patients by BMI Group

Readmission	4.5%	4.5%	6.1%	3.0%	7.6%	21.2%	0.05
Reoperation	0.0%	4.5%	1.5%	1.5%	6.1%	18.2%	<0.01
ER Costs (mean±standard deviation)	$83±240	$158±401	$113±286	$68±229	$128±373	$211±352	0.27
Readmission Costs (mean±standard deviation)	$226±1110	$1,230±6,610	$641±3,711	$275±1,905	$1,399±6,796	$2,697±6,018	0.15
Cost (including index hospitalization) (mean±standard deviation)	$10,315 ±1,848	$11,392 ±6,936	$11,150 ±4,225	$10,449 ±2,119	$13,134 ±7,250	$15,604 ±6,783	<0.01
Outcomes after 3 Years							
Mortality	3.0%	1.5%	7.6%	1.5%	1.5%	9.1%	0.14
Reoperation Cumulative from Index surgery	3.0%	4.5%	4.5%	4.5%	10.6%	21.2%	0.03
Aseptic Revision	1.5%	1.5%	3.0%	3.0%	1.5%	6.1%	0.74
Septic Revision	1.5%	3.0%	1.5%	1.5%	7.6%	18.2%	<0.01

Table 3-4: Functional Outcome Scores of THA Patients by BMI Group

Variable	BMI Group						
(mean±standard deviation)	18.5-24.9 Non-Obese (n = 66)	25-29.9 Overweight (n = 66)	30-34.9 Obese (n = 66)	35-39.9 Severely-Obese (n = 66)	40-44.9 Morbidly-Obese (n = 66)	45+ Super-Obese (n = 33)	p-value
HHS							
Preoperative	54±11	46±12	50±10	44±12	42±12	39±17	<0.01
Postoperative	95±7	92±10	91±12	87±16	88±12	84±14	<0.01
Change	40±12	44±15	40±16	44±20	49±14	40±17	0.29
SF12 MCS							
Preoperative	51±11	51±10	53±11	49±12	48±12	46±12	0.06
Postoperative	54±9	55±8	54±10	52±10	52±11	49±14	0.06
Change	3±13	4±8	1±12	2±12	6±13	3±14	0.47
SF12 PCS							
Preoperative	31±9	29±8	29±8	29±7	27±6	25±6	<0.01
Postoperative	43±12	40±12	41±12	39±11	37±13	35±10	0.01
Change	12±13	12±12	11±12	11±12	9±12	11±10	0.86
WOMAC							
Preoperative	43±18	40±16	42±18	39±14	36±16	35±15	0.11
Postoperative	85±18	76±23	83±18	76±22	73±22	70±23	<0.01
Change	41±23	37±23	40±24	38±25	37±25	39±24	0.93

Outcomes after 3 years demonstrated no significant difference in mortality ($p = 0.14$) or aseptic revisions across the cohorts ($p = 0.74$). Reoperation ($p = 0.03$) and septic revision ($p < 0.01$) rates were significantly different across the BMI cohorts. The super-obese had greater cumulative reoperation and septic revision rates compared to the non-obese cohort (21.2% vs 3.0%, $p = 0.01$ and 18.2% vs 1.5%, $p = 0.01$, respectively).

3.4 Discussion

Obesity is not a simple binary comorbidity that can be evaluated as being above or below a BMI of 30. The degree of obesity plays an influential role in the risk of perioperative complications and costs of care. Given that health policy in many healthcare systems in the developed world, including both the United States and Canada, focus on the short-term costs (such as 90-days), one of our primary objectives was to focus on the 90-day costs of care for various BMI cohorts. We found that in the short-term, 90-day costs were

much higher for the morbidly-obese (>25% higher) and super-obese (>50%) cohorts than the non-obese cohort. The focus on the short-term risks should not divert attention from the potential mid-term benefits and they need to be stratified by BMI as well. We found that the change scores for HHS, SF12 MCS and PCS, and WOMAC were comparable across all BMI cohorts.

Our costing analysis was based on the costs at a Canadian hospital, which generally has lower costs compared to the United States healthcare systems. Kremers et al. also reported their costs in the United States across multiple BMI cohorts and found that costs were relatively stable for BMIs ranging from 18.5 to 40, but above 40 the costs started to increase.[10] The cost of their non-obese group at 90-days postoperative was approximately $20,000. Our results for the non-obese cohort were half as much, largely owing to the lower costs of care in Canada. We also found a more dramatic increase in the costs for the morbidly-obese and super-obese of 25-50% over the non-obese, while Kremers et al.[10] had only a 5-10% premium for the same cohorts relative to the non-obese. In our study, the three main factors driving the increased costs were readmissions, index hospitalization, and DVT prophylaxis differences. Kremers et al.[10] did not report the readmission rate or differences in DVT prophylaxis for their BMI cohorts. Our study had a 90-day reoperation rate of 6.1% in the morbidly-obese and 18.2% in the super-obese cohorts. Our readmission rates are comparable to those reported in the literature. In a meta-analysis, Ramkumar et al.[17] reported a 90-day readmission rate of 7.7% after a THA. Our readmission rates were lower than that for all BMI groups with the exception of the super-obese cohort.

We also found that the degree of improvement in outcome scores were comparable across the BMI cohorts. McLawhorn et al. examined EQ-5D scores (a measure of health status utility, frequently used for cost-effectiveness) across different BMI cohorts and reported that their larger BMI cohorts had comparable or greater improvements than their non-obese cohort.[8] Other studies report that the various obesity categories (ranging from severely-obese to super-obese) have comparable outcome score improvements as non-obese cohorts.[4,6,7,14–16] The potential for greater improvement in higher obesity classes may be due to their lower preoperative scores. Surgeons may delay surgical intervention

for the morbidly and super-obese patients because of their BMI. During the time it takes for these patients to identify a surgeon willing to perform their procedure, their function may deteriorate leading to a lower preoperative score than a patient who is at a lower obesity level. Consequently, an arthroplasty may lead to a larger improvement in outcome.

Our study had a much higher risk for revision than was reported by Wagner et al.[3] They reported a hazard ratio of 1.6 for reoperation for the BMI>40 cohort versus the BMI 18.5-25 cohort, and no significant difference in risk for reoperation for other obese categories with a BMI<40. Similarly, we found no significant difference in reoperation in the overweight, obese, and severely-obese cohorts versus the non-obese cohort. Compared to the non-obese, our relative risk was greater in the morbidly-obese by over three times and for the super-obese by over seven times. This differential is likely driven by the fact that all patients with a BMI above 40 are not the same. A BMI over 45 or 50 is at a much higher risk for revision than a BMI just over 40 (Chapter 2).

Bariatric surgery and other nonoperative weight loss measures have been proposed to assist morbidly and super-obese patients to attain a lower BMI and hopefully lead to a lower risk profile and cost. Additionally, a potential benefit of weight loss is that hip arthritis symptoms may improve sufficiently that an arthroplasty may not be needed at that time. Research to date has provided conflicting evidence on the impact of bariatric surgery prior to arthroplasty with some reports suggesting no improvement,[18–20] other studies suggesting lower complication rates,[13,21] and others reporting higher complication rates for the arthroplasty.[22,23] Nonoperative weight loss treatments have not been very successful for weight loss for patients with a BMI over 40. Huffaker and Giori[24] conducted a retrospective study of a structured nonoperative weight loss program, and found that only 17% of patients with a BMI over 40 lost enough weight to bring their BMI below 40. Of the patients with a BMI over 45, less than 10% of patients reached that same goal. In addition, nonoperative weight loss options have not been shown to improve the complication profile for arthroplasty. There are also concerns that weight loss puts patients in a catabolic state leading to poorer healing and higher risk of infections and

wound complications.[25] As of yet, there are no clear pathways to improve the perioperative risk profile of morbidly and super-obese patients.

Morbidly and super-obese are at highest risk for losing access to arthroplasty despite their comparable improvements in functional outcomes. In both the US and Canadian healthcare systems, the economic incentives are to provide arthroplasty care for those who would be the cheapest to care for since there is no risk adjusted reimbursement. As well, worldwide, many hospitals are scored based on their reoperation and readmission profile, and their annual arthroplasty volumes and budget may be affected by their reported outcomes. By operating on more morbidly or super-obese patients their outcome metrics may suffer and consequently could be penalized with lower funding for arthroplasty. Concurrently, in the US, surgeons are starting to be rated based on the complication profile including one published by Propublica[26] that does not account for patient risks. US News and World Report is planning to publish an arthroplasty surgeon rating based on outcomes in the Fall of 2017. It remains to be seen whether it will account for the risk profile of patients.[27] Due to a multitude of reasons, both surgeons and hospitals are being incentivized to focus only on the short term risks regardless of the potential longer term benefits. This jeopardizes arthroplasty access for morbidly and super-obese patients when they have no clear pathway to either improve their symptoms or improve their risk profile.

One of the limitations of our study is that it is a retrospective chart review for most of the reported outcomes. We did have prospectively collected data for functional outcome scores, but other results were obtained from a review of the electronic medical records. As the regional tertiary arthroplasty center, we tend to capture most complications/revisions, but we could have underestimated events that did not get referred back to our institution. Another limitation of our study relates to the low frequency of events such as revision and VTEs, where we may have had too few patients to be powered to detect a true difference. Consequently, we were only able to detect a difference for the super-obese group. In addition, owing to the small sample sizes for each cohort, the results may be affected by outliers. Furthermore, as a study from a single

tertiary care institution in Canada, our results may not be generalizable to community institutions or those outside of Canada.

A strength of this study is that our institution is a regional tertiary referral center for arthroplasty. Nearly all readmissions, ER visits, and subsequent revisions are transferred to or taken care of at our hospital. We also have access to an electronic records sharing system, which allows us to capture any visits or readmissions to all the hospitals within our region (most hospitals within a 100 kilometer radius of our institution).

In conclusion, the morbidly-obese and super-obese total hip arthroplasty patients incur greater costs during the first 90-days than the non-obese cohort. All BMI cohorts have clinically significant improvements in function that are comparable to the non-obese cohort. Owing to the combined pressures on hospitals and surgeons in North American and many healthcare systems in the developed world, there will be a high risk that the morbidly-obese and super-obese will lose access to arthroplasty care due to their higher 90-day risks and costs. Health care policies do not account for the longer-term potential benefits of arthroplasty. Preoperative health optimization of obesity is an important topic of future research, but as of now we do not have an obvious method to achieve it. In the interim, thorough preoperative counseling of morbidly-obese and super-obese patients is warranted, but arbitrary restrictions should not be used to deny arthroplasty access since these patients have no effective alternatives and demonstrate equivalent progress to patients in lower BMI levels and have clinically significant functional improvements.

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Chapter 4

4 Cost-Effectiveness of Total Hip Arthroplasty versus Nonoperative Management in Non-obese, Overweight, Obese, Severely-Obese, Morbidly-Obese, and Super-Obese Patients

4.1 Introduction

Currently, there are about 250,000 total hip arthroplasties (THAs) performed each year in the United States. Those numbers are projected to increase to 572,000 by 2030.[1] The demand is increasing rapidly due to a combination of an aging population and an increasing level of obesity in the country.[2,3] Not all obese individuals (BMI>30) have the same risk profiles with surgery. Higher BMI (i.e. BMI>40 and BMI>50) have a greater risk for perioperative complications, infections, and revision,[4–6] which leads to higher costs of care.[7] Both the United States and Canada have healthcare policies that pay a fixed amount for taking care of an arthroplasty patient, which typically does not account for the increased risks and costs of patients with comorbidities. In addition to the financial risks, both providers and hospitals are commonly evaluated on quality metrics that frequently do not account for the risk profile of their patients. In the metrics that do account for risk profile, they likely do not adequately adjust for the risk.[8,9] Physicians and hospitals may be penalized by caring for higher risk patients such as extremely obese individuals. As a result many providers have arbitrarily chosen specific BMI levels (ranging from 35-45) at which they will not offer arthroplasty. These thresholds do not account for the long-term benefits of arthroplasty over the expected lifetime of the implant. Patients at all obesity levels have been shown to have significant improvements in pain, function, and activity levels after an arthroplasty.[10–12] The alternative nonoperative options for hip arthritis can mitigate symptoms, but do not correct the underlying pathology which can further progress.[13] The question arises whether THA is cost-effective relative to nonoperative management over a longer time horizon after accounting for the risks and benefits related to BMI.

The purpose of our study is to estimate the cost-effectiveness of performing a THA versus nonoperative management (NM) for non-obese (BMI 18.5-24.9), overweight (25-29.9), obese (30-34.9), severely-obese (35-39.9), morbidly-obese (40-49.9), and super-obese (50+) cohorts. We hypothesize that although the higher BMI cohorts will experience greater costs, the additional expense would be justified by significant improvements in quality of life compared to nonoperative care.

4.2 Methods

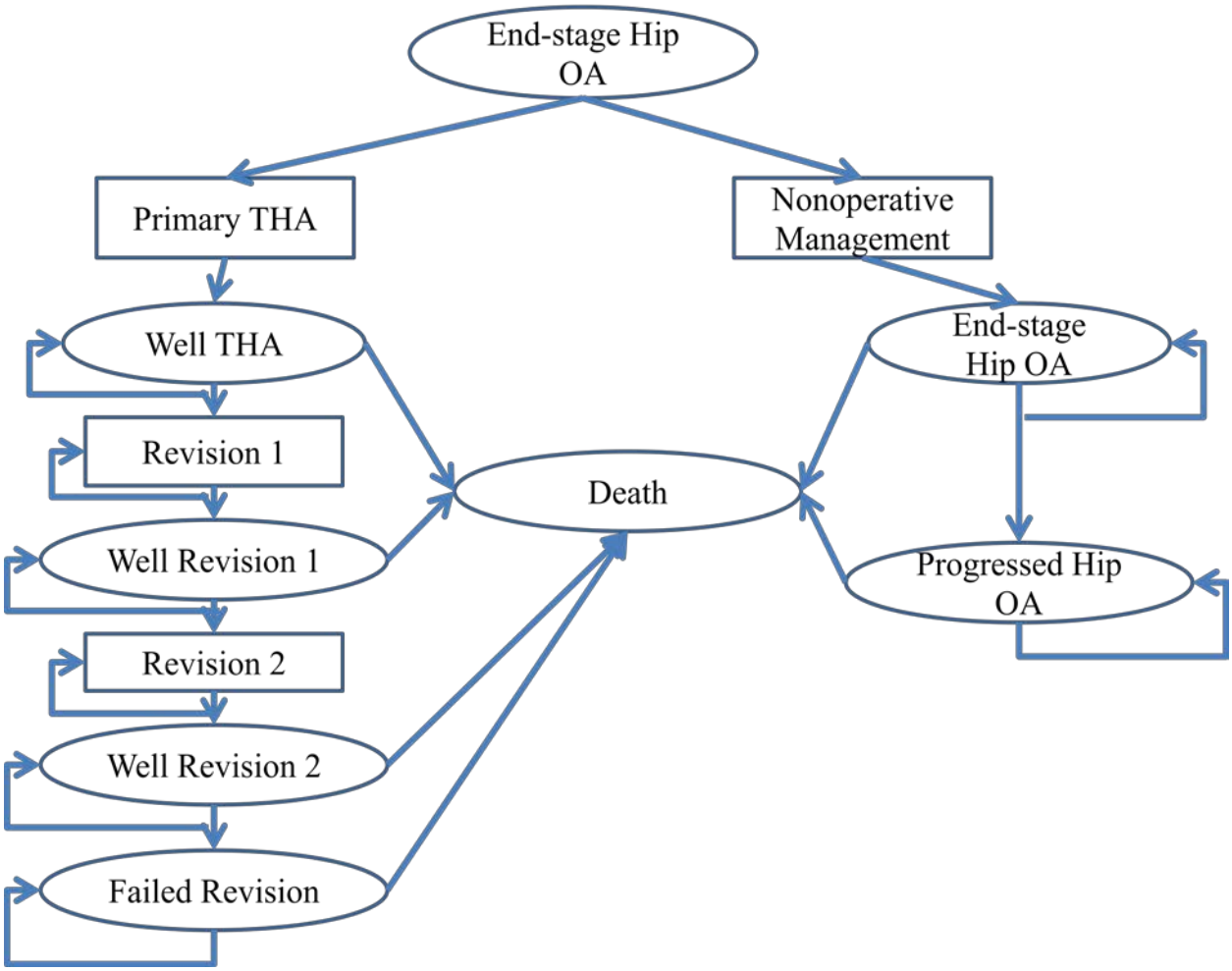

Figure 4-1: Markov decision model

We constructed a Markov model (Figure 4-1) with Excel 2007 to compare the costs and quality-adjusted life years (QALYs) of NM and THA for six BMI cohorts (non-obese (BMI 18.5-24.9), overweight (25-29.9), obese (30-34.9), severely-obese (35-39.9),

morbidly-obese (40-49.9), and super-obese (50+)). Patients entering the model were assumed to have maximized nonoperative management and would be candidates for a THA. Consequently, those that entered the NM treatment arm would continue at the same functional level until the natural history of hip arthritis progressed to a worse state or they died. The THA treatment arm assumed the patient either does well following surgery, or has a complication requiring a revision. The patient can have up to two revisions prior to transitioning to a chronically failed arthroplasty state. Transition probabilities, health-related quality of life weights, and costs for each health state in each BMI cohort were obtained from the literature (Table 4-1 to 4-4). Given the differences in prices in the US and Canada, we conducted separate analyses for the US and Canadian cost data. An annual discount rate of 3% was applied to all costs and utilities.

4.2.1 Transition Probabilities

The base-case annualized probabilities for conversion of a primary to revision 1 state and revision 1 state to revision 2 state were calculated from the 2016 Australian Registry, which reported an 8% risk for revision at 15 years for primary THA and 20% risk at 10 years for the first revision.[14] There were no published estimates for the probability of a chronically failed revision, and we assumed a 1.5% greater absolute annualized risk than revision 1 to revision 2. The relative risks were scaled up for the higher BMI cohorts based on the results of our meta-analysis (Chapter 2) and Wagner et. al.[15] The 2007 Australian Registry reported a hazard ratio of 1.383 for increased risk of mortality with a revision[18] which we used to calculate the mortality for revision 2 and a failed arthroplasty. The same mortality rates were used across all BMI cohorts. The literature suggests that obese patients undergo arthroplasty at a younger age than a non-obese individual, but generally have more comorbidities that balances out their lower mortality risk from younger age.[19–21] Prior studies of nonoperative arthritis management reported a risk for arthritis progression of 3.33%[16]-6%.[17] Arthritis in higher BMI categories likely progresses faster than the lower BMI categories. Since literature comparing the rate of progression across BMI levels was not identified, we used the conservative 3.33% parameter for our model for all BMI cohorts, which would favor the NM treatment.

Table 4-1: Transition Probabilities for Surgical and Nonoperative Model

Health State	Base Case Probability						Reference
	Non-Obese	Overweight	Obese	Severely-Obese	Morbidly-Obese	Super-Obese	
Primary to Revision 1	0.51%	0.51%	0.51%	0.72%	1.03%	2.00%	2016 Australian Registry,[14] Wagner et. al.,[15] meta-analysis, assumption
Revision 1 to Revision 2	1.84%	1.84%	1.84%	2.58%	3.70%	5.06%	2016 Australian Registry,[14] Wagner et. al.,[15] meta-analysis, assumption
Revision 2 to Failure	3.34%	3.34%	3.34%	4.68%	6.71%	9.18%	Assumption
Progression of Hip Arthritis	3.33%						Chang et. al.[16], Mota et. al.[17]
Mortality of Primary THA	2.35%						2016 Australian Registry[14]
Mortality of Revision 1	3.33%						2007 Australian Registry[18]
Mortality of Revision 2	4.60%						Assumption
Mortality of Failed	6.36%						Assumption

4.2.2 Utilities

McLawhorn et. al. reported the preoperative and postoperative utility scores for hip arthritis across a range of BMI classes that corresponded to our BMI cohorts.[10] They did not have a super-obese group, nor did any from our systematic review that measured utility scores. We therefore extrapolated the trend found in McLawhorn et. al.'s study[10] for this cohort based on the trend across their BMI cohorts. Utility scores after a revision were obtained from Postler et. al.[22], which we used as the non-obese utility score. For the

other BMI cohorts' post revision utility score, we assumed a similar decrease in utility as was reported for the primary utility scores in McLawhorn et. al.[10] We assumed revision 2 resulted in 90% the utility of revision 1.[23] We assumed that arthritis that has progressed would have the same percentage decrease from preoperative utility as reported in the literature for all patients in general (not specified by BMI).[16,17] Larger BMI cohorts likely would have a greater worsening in utility scores than the non-obese cohorts, but due to a lack of literature on the topic we used the conservative assumption that they had the same degree of worsening.

Table 4-2: Utility Values for Surgical and Nonoperative Model

Health State	Base Case Utility						Reference
	Non-Obese	Overweight	Obese	Severely-Obese	Morbidly-Obese	Super-Obese	
Preoperative	0.66	0.66	0.62	0.58	0.54	0.5	McLawhorn et. al.[10]
Arthritis Progression	0.36	0.36	0.33	0.31	0.29	0.27	Mota et. al.,[17] Chang et. al.[16]
Primary THA	0.9	0.89	0.87	0.84	0.85	0.83	McLawhorn et. al.[10]
Revision 1	0.8	0.79	0.77	0.74	0.75	0.73	Postler et. al.,[22] Assumption
Revision 2	0.72	0.71	0.69	0.67	0.68	0.66	McLawhorn et. al.,[23] Assumption
Failed	0.5	0.49	0.47	0.44	0.45	0.43	Postler et. al.,[22] Assumption

4.2.3 Costs

US Costs for primary THA and revision 1 were obtained from Kremers et. al. 90-day cost of care for different BMI levels, which are in 2010 US dollars.[7] The Canadian costs for a primary THA were based on our retrospective costing study looking at 90-day costs at our institution, which was calculated in 2017 Canadian dollars (Chapter 3). Since we did not have costing data for super-obese (BMI>50) patients and revisions by BMI category, we assumed a similar scaling in costs relative to the other groups reported in Kremers et. al.[7] For revision 2 in both the US and Canadian costs, we assumed that it cost 10% more

than revision 1[23] Based on US literature, we estimated annual cost of follow up for arthroplasty care of $581 in 2012 US dollars, as reported in Bedair et. al.[25] This was converted to 2017 Canadian dollars by using purchasing power parities and adjusting for inflation. It has been reported that the costs of nonoperative arthritis care in the quarter prior to an arthroplasty can be US$2,094-3,100,[24] while another study reported a median annual cost of $1,630 in 2002 Canadian dollars.[26] For the US base-case annual NM cost, we used the value of $1,733 (converting the median annual cost in Canadian dollars to US dollars with purchasing power parities and then accounting for inflation for 2017 US dollars), and tested a wider distribution in sensitivity analyses. Gupta et. al.[26] reported the annual direct medical costs hip arthritis in Canadian dollars, which was used for the Canadian costs after adjusting for inflation. Only the direct costs of medical care for an arthritic hip were accounted for in the model. All costs were inflation adjusted for 2017 values. Indirect costs were not included.

Table 4-3: US Costs for Surgical and Nonoperative Model

Health State	Base Case Cost						Reference
	Non-Obese	Overweight	Obese	Severely-Obese	Morbidly-Obese	Super-Obese	
Primary THA	$22,672 ±1,386	$21,509 ±5,202	$21,220 ±3,169	$22,590 ±1,589	$24,069 ±5,438	$25,190 ±5,699	Kremers et. al.[7]
Revision 1	$30,750 ±1,880	$30,070 ±7,273	$30,579 ±4,566	$32,253 ±2,269	$30,710 ±6,947	$40,748 ±9,218	Kremers et. al.[7]
Revision 2	$33,825 ±2,068	$33,077 ±8,000	$33,638 ±5,023	$35,479 ±2,496	$33,781 ±7,643	$44,823 ±10,140	McLawhorn et. al.[23]
Annual Nonoperative Care	$2,128±1,000						Chang et. al.,[16] Berger et. al.,[24] Gupta et. al.[26]
Annual follow up of primary and revision arthroplasties	$622 ±400						Chang et. al.[16], Bedair et. al.[25]

Table 4-4: Canadian Costs for Surgical and Nonoperative Model

Health State	Base Case Cost						Reference
	Non-Obese	Overweight	Obese	Severely-Obese	Morbidly-Obese	Super-Obese	
Primary THA	$10,315 ±1,848	$11,392 ±6,936	$11,150 ±4,225	$10,449 ±2,119	$13,134 ±7,250	$13,765 ±7,598	Chapter 3
Revision 1	$13,990 ±2,506	$15,926 ±9.697	$16,068 ±6,088	$14,919 ±3,025	$16,781 ±9,263	$22,267 ±12,291	Chapter 3, Kremers et. al.[7]
Revision 2	$15,389 ±2,757	$17,519 ±10,666	$17,674 ±6,697	$16,411 ±3,328	$18,460 ±10,190	$24,493 ±13,520	McLawhorn et. al.[23]
Annual Nonoperative Care	$1,733±1,000						Chang et. al.,[16] Berger et. al.,[24] Gupta et. al.[26]
Annual follow up of primary and revision arthroplasties	$798 ±400						Chang et. al.[16], Bedair et. al.[25]

4.2.4 Analysis

The model was simulated for a 15 year time period with each cycle lasting one year. A 15 year time period was chosen in order to have the longest time period for which reliable parameter data was available. We calculated the incremental cost-effectiveness ratio (ICER) for THA versus NM for each of the six BMI cohorts in both a US and Canadian system. To determine model robustness with the base-case parameters, one-way threshold sensitivity analyses were performed to determine the point at which the ICER exceeded the willingness to pay threshold of $25,000/QALY (USD) for the US analysis and $10,000/QALY (CAD) for the Canadian analysis. These values were chosen since the current average payment for the US Medicare bundled payment system is $25,565 (USD) and approximately $10,000 (CAD) in Canada.[27] In addition, a Monte Carlo probabilistic sensitivity analysis was performed with the upper and lower bounds reported in Tables 4-1 to 4-4. We ran 10,000 iterations for the sensitivity analysis. For the costs a gamma distribution was used and for transition probabilities and utilities a beta distribution was used. Distribution parameters were calculated using the method of moments.[23,28]

4.3 Results

4.3.1 US Cost Analysis

Table 4-5: US Base Case Results

BMI Group	Nonoperative Cost	Nonoperative QALY	Incremental Cost	Incremental QALY	ICER
Non-Obese	$21,390	6.00	$18,096	2.99	$6,043
Overweight	$21,390	6.00	$16,699	2.89	$5,770
Obese	$21,390	5.64	$16,585	3.06	$5,425
Severely-Obese	$21,390	5.27	$22,866	3.10	$7,382
Morbidly-Obese	$21,390	4.91	$29,408	3.53	$8,338
Super-Obese	$21,390	4.55	$59,705	3.59	$16,651

With the US base case all BMI cohorts had ICERs less than $17,000/QALY (Table 4-5). The super-obese had the highest ICER of $16,651/QALY, while the obese had the lowest ICER of $5,425/QALY. All the other BMI cohorts had ICERs from $5,700 to $8,400 for the base-case.

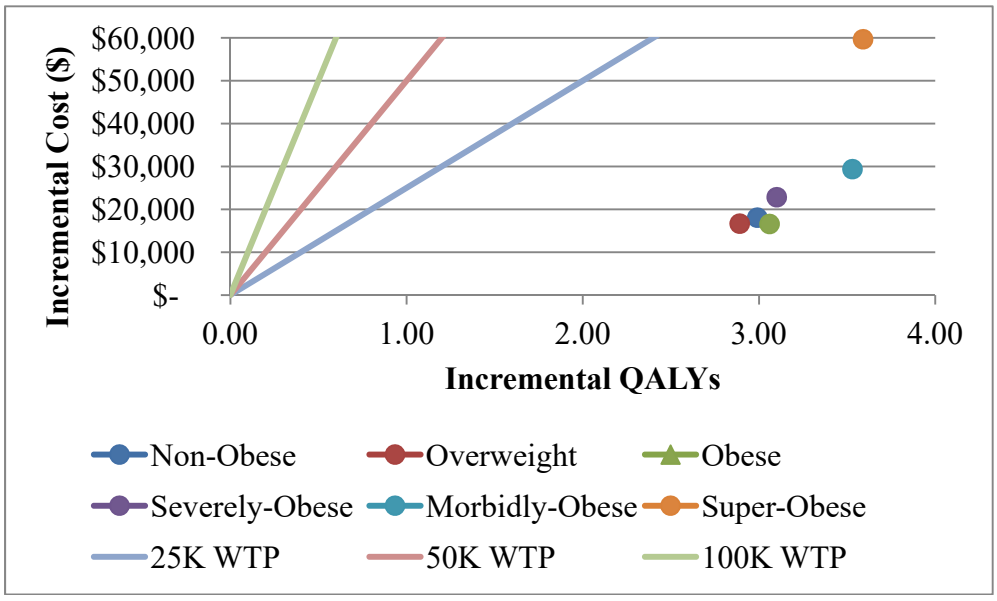

Figure 4-2: US Incremental Costs vs Incremental QALYs for THA over Nonoperative Management for Different BMI Cohorts

Table 4-6: US One-Way Sensitivity Threshold Analysis for ICER>$25,000, base case values are in parenthesis

	BMI Category					
Parameter	Non-Obese	Overweight	Obese	Severely-Obese	Morbidly-Obese	Super-Obese
Transition Probabilities						
Primary to Revision 1	>3.33% (0.51%)	>3.33% (0.51%)	>3.52% (0.51%)	>3.36% (0.72%)	>4.16% (1.03%)	>3.26% (2.00%)
Revision 1 to Revision 2	-	-	-	-	-	-
Revision 2 to Failed Arthroplasty	-	-	-	-	-	-
Primary Mortality	>22.19% (2.35%)	>22.62% (2.35%)	>23.90% (2.35%)	>21.53% (2.35%)	>21.92% (2.35%)	>12.45% (2.35%)
Revision 1 Mortality	-	-	-	-	-	-
Revision 2 Mortality	-	-	-	-	-	-
Failed Arthroplasty Mortality	-	-	-	-	-	-
Arthritis Progression	-	-	-	-	-	-
Utilities						
Primary Arthroplasty	<0.67 (0.90)	<0.66 (0.89)	<0.62 (0.87)	<0.61 (0.84)	<0.60 (0.85)	<0.69 (0.83)
Revision 1	-	-	-	-	-	-
Revision 2	-	-	-	-	-	-
Failed Arthroplasty	-	-	-	-	-	-
Preoperative Arthritis	>0.91 (0.66)	>0.90 (0.66)	>0.88 (0.62)	>0.82 (0.58)	>0.80 (0.54)	>0.63 (0.50)
Costs						
Primary	>$79,436 ($22,672)	>$77,161 ($21,509)	>$81,060 ($21,220)	>$77,165 ($22,590)	>$82,832 ($24,069)	>$55,125 ($25,190)
Revision 1	>$208,725 ($30,750)	>$204,558 ($30,070)	>$218,198 ($30,579)	>$158,437 ($32,253)	>$131,551	>$69,949 ($40,748

					($30,710)	)
Revision 2	>$2,546,707 ($33,825)	>$2,496,728 ($33,077)	>$2,682,693 ($33,638)	>$1,344,363 ($35,479)	>$796,438 ($33,781)	>$214,144 ($44,823)
Annual Arthroplasty Follow-up	>$6,278 ($622)	>$6,168 ($622)	>$6,58 ($622)	>$6,064 ($622)	>$6,488 ($622)	>$3,620 ($622)
Annual Nonoperative Care	-	-	-	-	-	-

Our model was sensitive to the following parameters (the threshold was exceeded with a transition or utility number between 0 and 1, or any non-negative cost value): transition from primary to revision 1, mortality of primary THA, utility scores for primary THA, utility scores for preoperative arthritis, and costs of primary, revision 1, revision 2, and annual arthroplasty follow-up (Table 4-6). The sensitivity analysis demonstrated that the model was stable to a wide-range of parameters. The most critical parameter in the model is the probability of transition from primary to revision 1. The one-way sensitivity analysis threshold for the super-obese was 3.26% which is close to the 2% base case predicted for the super-obese group's annualized revision rate. This means that the results for the super-obese are extremely dependent on their risk of revision. Another important parameter is the preoperative utility score of a super-obese patient. If their preoperative utility is greater than 0.63, then a THA would not be cost-effective at a $25,000/QALY threshold. In order to significantly change our conclusions, the other parameters identified by the sensitivity analysis would require values dramatically different from the base case that would not be realistic. For example, the mortality rate would need to be ten times that reported in the literature.

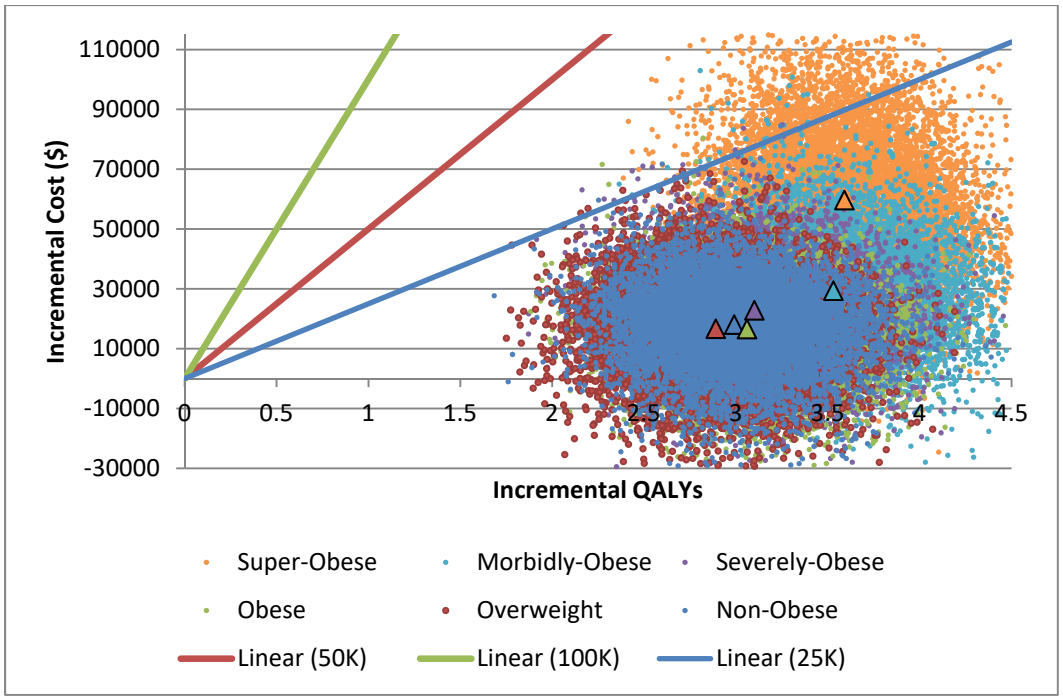

Figure 4-3: Plot of US Monte Carlo Simulation of Incremental Costs and QALYs

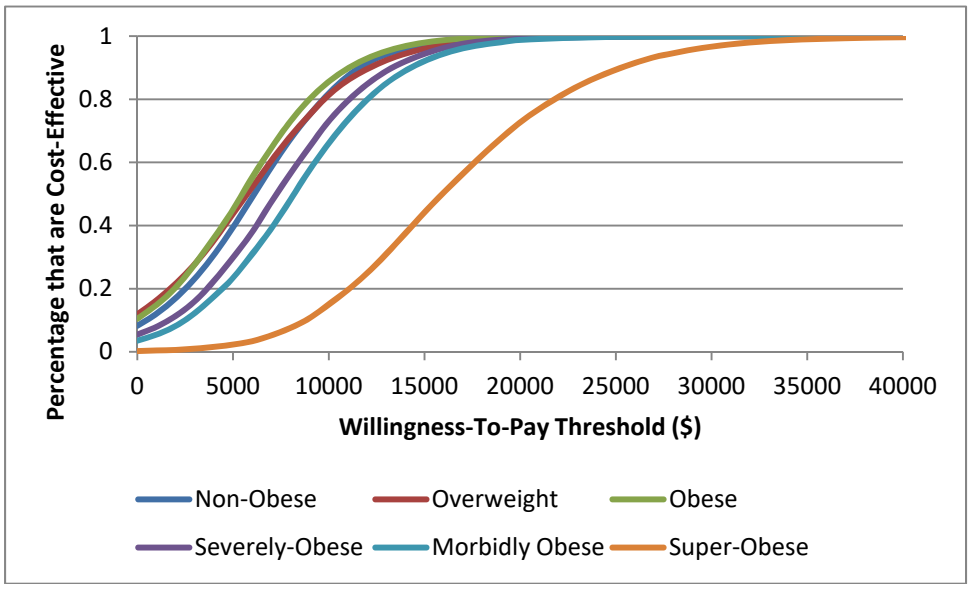

Figure 4-4: Percentage of Cases that Are Cost-Effective by Willingness-to-Pay Threshold in US Monte Carlo Simulation

Our probabilistic sensitivity analysis demonstrated that, in the vast majority of simulations, performing a THA would be cost-effective at a willingness-to-pay threshold of $30,000/QALY (Figure 4-3 & 4-4). We used a broad range of parameter values (based

on the gamma and beta distributions as noted in the methods) for our simulations to demonstrate the robustness of the results of our model, and they show with a willingness-to-pay threshold of $30,000/QALY, THA is cost-effective across all BMI groups. At that threshold, the model found THA cost-effective in comparison to NM for 100% of the non-obese, overweight, annd severely-obese simulations, 99.99% of obese simulations, 99.96% of morbidly-obese simulations, and 96.65% of super-obese simulations.

4.3.2 Canadian Cost Analysis

Table 4-7: Canadian Base Case Results

BMI Group	Nonoperative Cost	Nonoperative QALY	Incremental Cost	Incremental QALY	ICER
Non-Obese	$17,420	6.00	$5,713	2.99	$1,908
Overweight	$17,420	6.00	$7,456	2.89	$2,576
Obese	$17,420	5.64	$7,263	3.06	$2,376
Severely-Obese	$17,420	5.27	$8,169	3.10	$2,637
Morbidly-Obese	$17,420	4.91	$14,909	3.53	$4,227
Super-Obese	$17,420	4.55	$31,468	3.59	$8,776

The base-case Canadian model found that all BMI cohorts had an ICER below $10,000/QALY (Table 4-7). The super-obese cohort had the largest ICER for THA over NM of $8,776/QALY, while the other cohorts had an ICER ranging from $1,900-4,300/QALY.

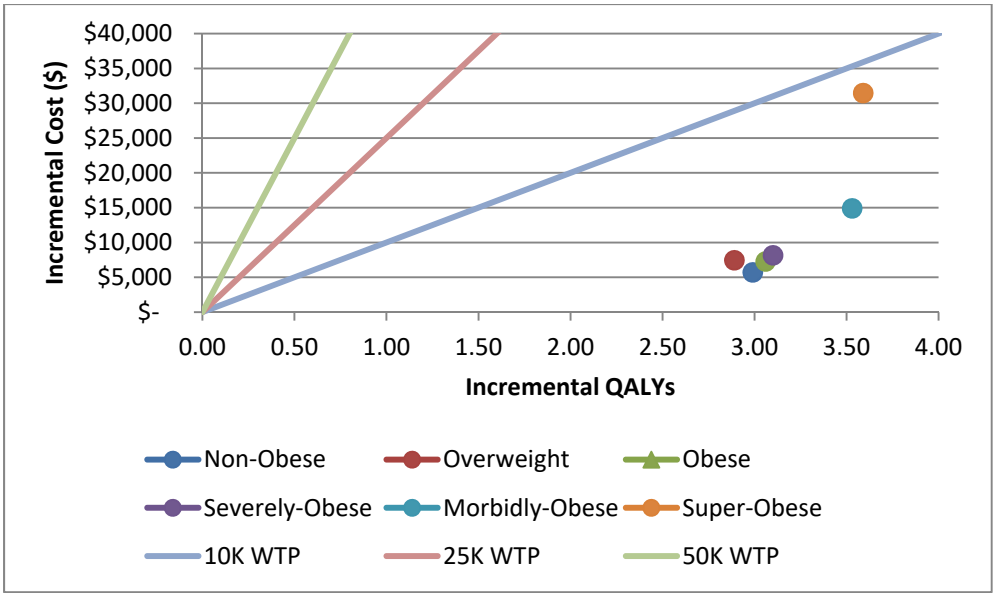

Figure 4-5: Canadian Incremental Costs vs Incremental QALYs for THA over Nonoperative Management for Different BMI Cohorts

Table 4-8:Canadian One-Way Sensitivity Threshold Analysis for ICER>$10,000

	BMI Category					
Parameter	Non-Obese	Overweight	Obese	Severely-Obese	Morbidly-Obese	Super-Obese
Transition Probabilities						
Primary to Revision 1	>3.18% (0.51%)	>2.56% (0.51%)	>2.73% (0.51%)	>3.12% (0.72%)	>2.98% (1.03%)	>2.33% (2.00%)
Revision 1 to Revision 2	-	-	-	-	-	-
Revision 2 to Failed Arthroplasty	-	-	-	-	-	-
Primary Mortality	>21.13% (2.35%)	>18.20% (2.35%)	>19.46% (2.35%)	>19.89% (2.35%)	>15.74% (2.35%)	>5.20% (2.35%)
Revision 1 Mortality	-	-	-	-	-	-
Revision 2 Mortality	-	-	-	-	-	-
Failed Arthroplasty Mortality	-	-	-	-	-	-
Arthritis Progression	-	-	-	-	-	-
Utilities						

Primary Arthroplasty	<0.65 (0.90)	<0.67 (0.89)	<0.63 (0.87)	<0.60 (0.84)	<0.63 (0.85)	<0.78 (0.83)
Revision 1	-	-	-	-	-	-
Revision 2	-	-	-	-	-	-
Failed Arthroplasty	-	-	-	-	-	
Preoperative Arthritis	>0.93 (0.66)	>0.90 (0.66)	>0.88 (0.62)	>0.83 (0.58)	>0.76 (0.54)	>0.55 (0.50)
Costs						
Primary	>$34,546 ($10,315)	>$32,877 ($11,392)	>$34,457 ($11,150)	>$33,257 ($10,449)	>$33,493 ($13,134)	>$18,153 ($13,765)
Revision 1	>$89,961 ($13,990)	>$83,287 ($15,926)	>$89,144 ($16,068)	>$67,654 ($14,919)	>$51,719 ($16,781)	>$26,547 ($22,267)
Revision 2	>$1,088,049 ($15,389)	>$968,611 ($17,519)	>$1,049,462 ($17,674)	>$563,417 ($16,411)	>$282,695 ($18,460)	>$49,313 ($24,493)
Annual Arthroplasty Follow-up	>$3,212 ($798)	>$2,939 ($798)	>$3,120 ($798)	>$3,072 ($798)	>$2,830 ($798)	>$1,238 ($798)
Annual Nonoperative Care	-	-	-	-	-	<$1,296 ($1,733)

Our one-way sensitivity analysis for the Canadian costs identified the following parameters as critical to the model: transition from primary to revision 1, mortality of primary THA, utility scores for primary THA, utility scores for preoperative arthritis, and costs of primary, revision 1, revision 2, and annual arthroplasty follow-up (Table 4-8). Given the lower ICER threshold used for this analysis, the results of the super-obese group analysis was most sensitive to the primary to revision 1 transition, preoperative and primary arthroplasty utility, and costs for primary, revision 1, annual arthroplasty follow-up and annual nonoperative care. Our base case for the primary to revision 1 transition was 2%, and the sensitivity analysis identified 2.33% as the transition for an ICER of $10,000/QALY. Also, if a super-obese patient has a preoperative utility greater than 0.55 (base estimate 0.5), then it would be more cost-effective to do NM. The base case utility of a primary arthroplasty was 0.78, and the sensitivity analysis identified 0.83 as the threshold. The cost parameters identified earlier are also close to the base case. The other BMI group's parameters identified by the sensitivity analysis would require values dramatically different from the base case and would be extremely unlikely to reach those levels.

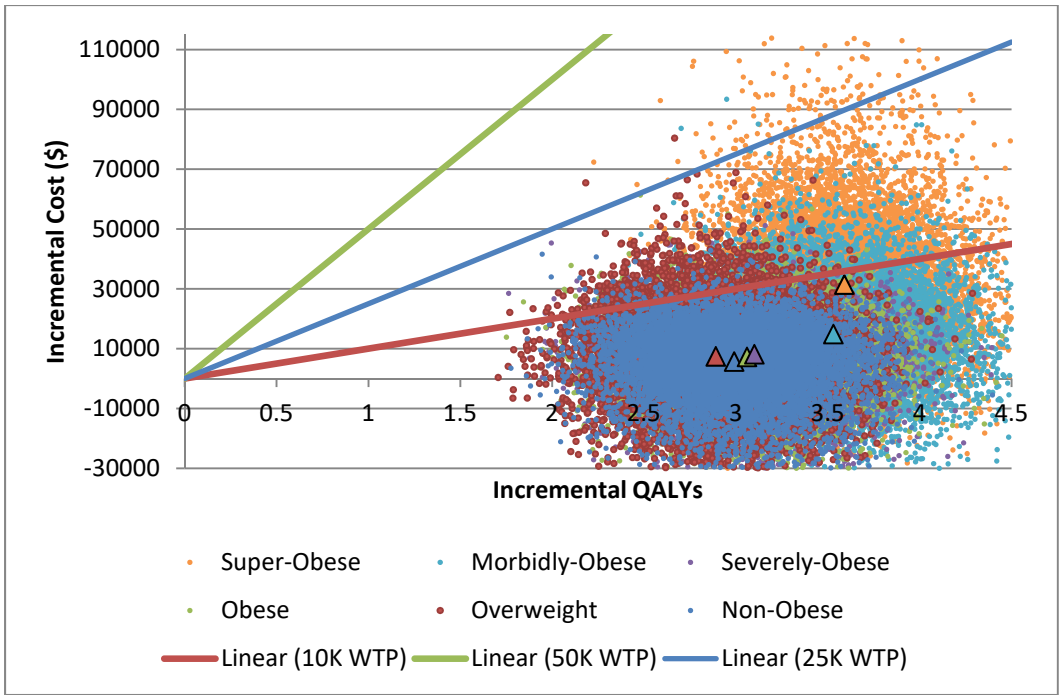

Figure 4-6: Plot of Canadian Monte Carlo Simulation of Incremental Costs and QALYs

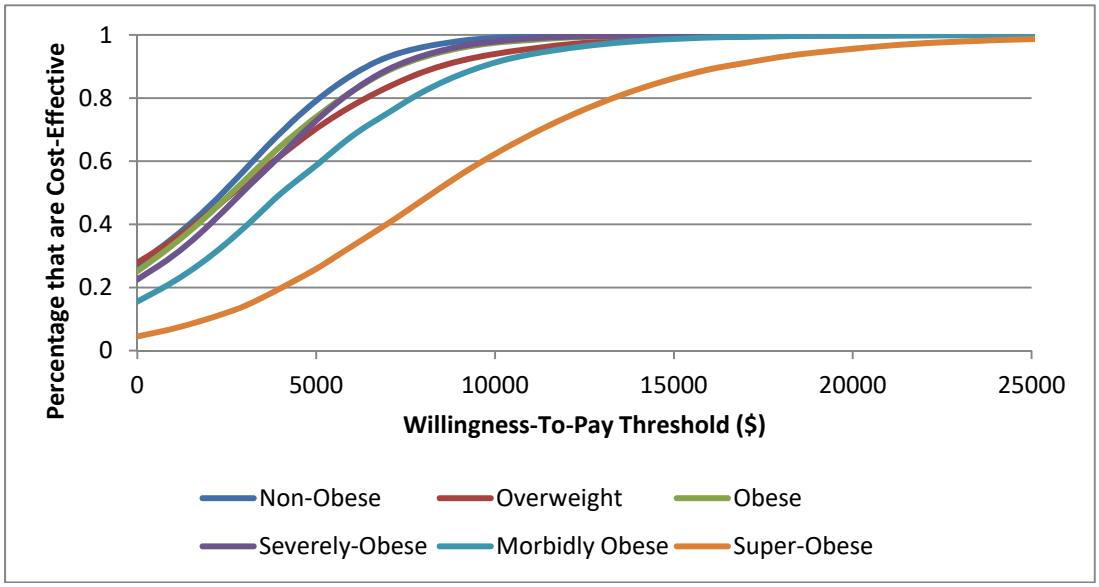

Figure 4-7: Percentage of Cases that Are Cost-Effective by Willingness-to-Pay Threshold in Canadian Monte Carlo Simulation

The probabilistic analysis of the ICERs with the Canadian costing data demonstrated that in the vast majority of the simulations THA would be cost-effective compared to NM at a

willingness-pay-threshold of $20,000/QALY (Figures 4-6 & 4-7). A wide range of simulation parameters (based on the beta and gamma distributions) were used to demonstrate the robustness of the model. At a willingness-to-pay threshold of $20,000/QALY, THA was cost-effective relative to NM for 99.99% of non-obese, obese, and severely-obese, 99.87% of overweight, 99.83% of morbidly-obese, and 95.60% of super-obese.

4.4 Discussion

Our study results suggest that in the vast majority of cases THA would be cost-effective for all BMI cohorts in both the US (at a willingness-to-pay threshold of $30,000/QALY) and Canadian cost structures (at a willingness-to-pay threshold of $20,000/QALY). This raises the issue that BMI cut-offs for THA may lead to unnecessary loss of healthcare access.

The expanding prevalence of obesity in the United States, Canada, and other developed countries is driving greater arthroplasty utilization rates.[2] However, because of greater risks and complication rates with higher obesity levels, some surgeons are utilizing BMI thresholds to determine eligibility for arthroplasty.[4,5] There is a greater push in this direction due to the bundled payments for arthroplasty in both the US and Canada. These bundled payments are not risk-stratified for patients.[29] Morbidly-obese and super-obese patients have been shown to have greater costs of care than patients of lower obesity levels.[7] In addition, surgeons and hospitals are being rated on and may be penalized due to their complication profile in both the US and Canada.[8,9] As a result, there is pressure on clinicians to not offer arthroplasty to the morbidly and super-obese patients due to the higher 90-day costs of care. Our model suggests that at a reasonable cost, THA would lead to substantial improvements in quality of life for morbidly-obese and super-obese patients compared to NM over a 15 year time period. Healthcare economics and other healthcare drivers are emphasizing a focus on the short-term results and do not account for the long-term benefits of THA. As a result, there may be a loss of access to arthroplasty care for the morbidly and super-obese despite having the potential to benefit substantially with surgery over the longer term.

Bundled payment models in the US are designed such that the hospital and providers will need to use that fixed payment to cover all the costs of care within 90 days after surgery. As a result, hospitals that have an excessive number of readmissions and reoperations within that time window would have increased expenses without any additional reimbursement. This can place them at a higher risk for spending more money than they collect. Due to this longer time window of coverage after surgery, there has been an increased emphasis on perioperative management and medical optimization prior to surgery. For example, more surgeons are now requiring patients to quit smoking prior to an arthroplasty. New York University has shown improved smoking cessation results prior to arthroplasty with a smoking counseling program that led to improved postoperative complication rates.[30] In the case of obesity, the major question is whether and to what degree obesity can be optimized prior to surgery. Some have suggested bariatric surgery and other weight loss measures to lower BMI level might lead to a lower perioperative risk profile and cost. However, there is conflicting evidence on the impact of bariatric surgery prior to arthroplasty. For complication rates, some suggest no improvement,[31–33] other studies found lower complication rates,[34,35] and others report higher complication rates.[36,37] Another option is nonoperative weight loss programs. Unfortunately, they have not demonstrated dramatic success in weight reduction for morbidly or super-obese patients. Huffaker and Giori[38] presented their work that showed only 17% of those starting above a BMI greater than 40 would reduce their BMI below 40 in a structured weight loss program. For those patients starting at a BMI greater than 45, less than 10% achieved the same threshold. At the same time, it is unclear if the patient achieved a BMI reduction below 40, whether that would lead to substantial improvements in their risk profile.[39] In fact, one study suggests that weight loss in the year prior to arthroplasty had a higher risk for deep surgical site infections.[33] It is thought that the catabolic state induced by weight loss can negatively affect wound healing and may explain those results. Future work examining the relationship between nutrition and obesity with weight loss and bariatric surgery will be critical in improving the preoperative risk profile for obese patients prior to an arthroplasty.[40] Unfortunately to date, there are no protocols that have clearly demonstrated the ability to shift obese patients from a higher risk profile to a lower risk profile. However, for some patients,

weight loss alone may be sufficient to improve the symptoms of arthritis enough that an arthroplasty may not be needed.

A major limitation in generalizing the results of this study is the availability of utility scores for patients prior to an arthroplasty. We utilized data published from a retrospective study of an institutional database reporting preoperative EQ-5D utility scores across different BMI levels.[10] As a retrospective study, it is possible that patients with a higher BMI may have had a longer wait time for surgery, and consequently, lower preoperative EQ-5D scores than lower BMI patients. They found that the morbidly-obese had greater improvement after THA than the non-obese. Our one-way sensitivity analysis also identified preoperative utility as a significant parameter influencing the results of the model. The analysis suggested that the super-obese needed a pre-operative utility score of less than 0.63 to achieve an ICER value less than $25,000/QALY in the US model. We could not identify a utility score in the literature for the preoperative and postoperative utility score for the super-obese group. We used the literature on super-obese patients to guide an assumption of the utility scores for these patients. Our study is also limited in that we do not account for the associated comorbidities of higher BMI levels such as metabolic syndrome and cardiac risks. Certain comorbidities such as diabetes can be optimized preoperatively to improve outcomes after an arthroplasty. Also, this study only evaluated the direct medical costs of hip arthritis care and did not consider the indirect societal costs, which can be sizeable due to time off from work.

The strength of our study is that it evaluates the utility of THA versus NM for a wide range of BMI cohorts based on the best available literature from a systematic review and meta-analysis, and institutional chart review. A cost-effectiveness study comparing THA versus NM for different BMI cohorts has not been performed previously, and this study adds valuable information in better balancing the long-term risks and benefits of an arthroplasty. Prior literature has placed too much emphasis on the short-term results, and we hope our results draw attention to the impact over a longer time span.

In conclusion, THA is a very effective procedure to improve quality of life for patients of all BMI levels. In the vast majority of scenarios for both US and Canadian costs, we

found that THA was likely to be cost-effective compared to nonoperative care among all BMI cohorts. Currently, there are no clear ways to improve the risk profile of obese patients. As we continue to evaluate options to optimize the health of the morbidly and super-obese, these patients should not be denied a THA, since the procedure can dramatically improve their quality of life.

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Chapter 5

5 Conclusion

5.1 Rationale for Study

Healthcare payers in Canada, and an increasing percentage of the United States, provide funding for arthroplasty surgeries with a simple bundled payment for an episode of care, with no risk stratification. Concurrently, both hospitals and surgeons are increasingly rated on their short-term arthroplasty complication rates along with other quality metrics. If a hospital or surgeon is reported to have higher complications, there is the potential to be penalized with lower funding levels and fewer patient visits. These factors are incentivizing surgeons to avoid operating on patients who may be at higher risk of perioperative complications and/or have a higher cost of care. This situation can lead to certain populations, who may have significant long term benefit from arthroplasty, losing access to care because they have higher short-term costs and complications.

One population that is being affected by this situation are obese patients. Patients with a BMI higher than 40 undergoing hip and knee arthroplasty have higher costs of care and complications compared to non-obese patients, with the risk increasing as BMI increases. Because of this, some surgeons in Canada, the US, and Europe, have established BMI thresholds ranging from 35-45, above which they will not offer arthroplasty as a treatment option. Nonetheless, at mid-term follow up, patients at all BMI levels have comparable improvements in function with arthroplasty. This begs the important question as to whether we are unfairly discriminating against patients at higher BMI levels by denying them surgery on the basis of their weight.

We decided to approach this study by performing a cost-effectiveness analysis to better weigh the risks and benefits of a THA versus nonoperative care for patients of all BMI levels over a 15-year time period. To determine the parameters for our model we performed a systematic review and meta-analysis (Chapter 2) and an institutional chart review (Chapter 3). We used this information to construct an economic model (Chapter

4) and determine the incremental cost-effectiveness ratio of THA versus nonoperative care.

5.2 Summary of Findings

In Chapter 2 and 3, we found similar results between the literature and our institutional registry. At a BMI threshold of 40, the risk for revision surgery increases exponentially, while the BMI levels lower than that have a comparable risk of revision. The costs also increase dramatically at a BMI level of 40 and above. Despite this, all the BMI cohorts demonstrated comparable improvements in their function as measured by clinical outcome scores.

We applied the risks and benefits that were quantified in Chapter 2 and 3 to an economic model comparing THA versus nonoperative management in Chapter 4. We applied the BMI specific parameters from our systematic review and institution's registry and chart review for the analysis. The results were analyzed with both US and Canadian costs over a 15 year time period. We found that in both health care systems that performing a THA would be cost-effective relative to nonoperative management for all BMI cohorts

5.3 Challenges

There were several challenges that were encountered during the course of the study. One of the major limitations of the systematic review and meta-analysis was the dearth of high quality studies on the topic. We identified only 2 prospective studies that met our inclusion criteria, and 31 retrospective studies. The small number of internally valid studies has the potential to limit the quality of the results. Further, several studies combined the results for both THA and TKA. Since the impact of obesity on THA and TKA can differ owing to the differential fat distribution between the hip and the knee, we elected to exclude those studies that did not provide separate results for THAs. Some studies reported results only in a graph. The corresponding authors were contacted for detailed information from the graph. If the information, was not provided, the numbers were approximated from the graphs in the paper. Another common way of reporting results was using a linear regression to determine the degree of association between BMI

and complications. However, the relationship between BMI and complications is not a linear relationship as we demonstrated in Chapter 2 and 3. Below a BMI of 40, there generally is not much change in the risk profiles for THA patients. However, above a BMI of 40, the risks rise rapidly. Consequently, we elected to include those studies that divided BMI into categories and provided the event rates for reoperations, aseptic, and septic revisions rather than odds ratios for these complications.

In Chapter 3, we examined our institutional database to obtain the 90-day costs of care categorized by BMI for our model. We aimed to include a cohort with a BMI greater than 50, but our database had too few patients meeting this criteria. As a result, we adjusted our largest BMI cohort to be greater than 45, this allowed for the inclusion of 33 patients in that cohort.

With our economic model (Chapter 4), our model may overly simplify the care and outcomes of a patient with hip arthritis. Our nonoperative model does not account for pharmaceutical, weight loss, physical therapy, and other options. However, most patients would have attempted one if not more of these options prior to being considered for a THA. As a result, our model assumed that these options were maximized prior to entering the decision tree. The operative side of the model simplifies the possible states to assuming that they have a well functioning arthroplasty or they undergo a revision. There are many cases where a patient has a suboptimal improvement with the arthroplasty, but they do not undergo a revision.

5.4 Future Studies

Our study highlights that the benefits of an arthroplasty outweigh the risks over a 15-year time period for all BMI cohorts. However, it is clear that the risks rise significantly for those patients with a BMI greater than 40. A prospective well-designed study could account for any biases in selection and improve the confidence in our results.

It will be important in the future to focus on identifying techniques to improve the perioperative risk profile of patients with a BMI greater than 40. As we noted in prior chapters, current attempts at bariatric surgery and weight loss have not clearly

demonstrated improvement of the risks. Nonetheless, we should continue to focus on improving the risk profile. Perioperative optimization of morbid or super-obesity could decrease the risk, and future cost-effectiveness analysis could help quantify the value gained from these interventions for optimization.

5.5 Clinical Implications

The results of this study will hopefully be applied to realign the incentives in arthroplasty care in both Canada and the US. The current system in both countries places an inordinate emphasis on the short-term outcomes and costs of an arthroplasty. This could lead to an unnecessary loss of arthroplasty access for patients who have a BMI greater than 40. Our study highlights that the longer-term benefits of an arthroplasty outweigh the short-term risks and costs. It is our hope that policy makers use this information to adjust incentives around arthroplasty such that patients are not denied access to care.

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Curriculum Vitae

Name: Karthikeyan Ponnusamy

Post-secondary Education and Degrees:

Johns Hopkins University
Baltimore, MD, USA
2003-2006 B.S. Biomedical Engineering

Johns Hopkins University
Baltimore, MD, USA
2006-2007 M.S.E. Biomedical Engineering

Stanford University
Stanford, CA, USA
2007-2011 M.D.

Related Work Experience:

Orthopedic Surgery Resident
Johns Hopkins University
2011-2016

Adult Reconstruction Fellow
University of Western University
2016-2017

Publications:

1) Thomas TJ, **Ponnusamy KE**, Chang NM, Galmore K, Minteer SD. Effects of annealing on mixture-cast membranes of Nafion and quaternary ammonium bromide salts. Journal of Membrane Science: 2003 March 1;213:55-66.
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