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The Effect of Obesity on Revision Total Knee Arthroplasty: Functional Outcome, Ninety-Day Costs, Reoperations, Readmissions and Cost-Effectiveness

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Abstract

The demand for revision total knee arthroplasty (RTKA) is increasing due to obesity and an aging population. The purpose of this study is to evaluate the effect of different body mass index (BMI) categories on RTKA using a retrospective cohort analysis. The first part was to assess patients' functionality post-RTKA. The second part was to determine the survival of RTKA and re-revision rate. The third part was to explore the complication and readmission rates, and to estimate the 90-day costs of RTKA. We found the most common indication for RTKA in super obese patients is infection, unlike other BMI categories, whose most common indication is aseptic loosening. The improvement after RTKA is comparable across all BMI cohorts. Our analysis showed that a BMI ≥45 kg/m^2 increases the risk of infection and re-revision, but only super obese patients are at an increased risk of readmissions and therefore have higher 90-day costs.

Keywords

Revision total knee arthroplasty, obesity, costs, complications, quality of life

Summary for Lay Audience

The prevalence of obesity is increasing worldwide. Its hazardous effect on people's health has led to investigations of its impact on arthroplasty. The literature documents an increased complication rate of primary and revision total knee arthroplasty (RTKA) due to obesity, which consequently has caused many surgeons to avoid operating on patients whose body mass index (BMI) is above a certain threshold, in order to avoid harming their and the hospitals' reputation. Therefore, many patients are prohibited from the benefits of RTKA due to perceived higher risks and costs based on an arbitrary threshold. This study investigates the effect of obesity on RTKA by classifying it into several categories and looking into its influence on gain in quality of life (QoL), RTKA survival, complication rate, re-revision rate, readmission rate and costs within 90 days of operation. The six weight categories used in the study are in an ascending manner: normal weight, overweight, obesity, severe obesity, morbid obesity and super obesity. It was found that RTKA improves QoL similarly across all BMI classes. Morbid and super obese patients, however, present at a younger age for RTKA, are at an increased risk of postoperative infection and the survival of their RTKA is less, necessitating more re-revision. Super obese patients are also at an increased risk for readmission, which in turn boosts their total 90-day costs by 25%. Thus, only patients whose BMI is ≥45 kg/m^2 are at increased risk of complications and may need further evaluation prior to RTKA, while those below this threshold must be operated on for the benefits of RTKA and the similar risk profile to patients with normal weight.

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Table of Contents

List of Tables

List of Figures

List of Appendices

1. Introduction

1.1. Obesity

Obesity is a multifactorial disease that is defined as excess body weight for height, associated with metabolically active visceral adiposity, and complicated with a multitude of comorbid conditions.[1] It is measured using the body mass index (BMI), which is derived by dividing a body's mass in kilograms (kg) by the square of a body's height in meters (m) and is expressed in kg/m^2.[2] Although BMI does not differentiate between muscle mass and fat, nor does it consider the distribution of fat in the body, the World Health Organization (WHO) uses it as a system of measurement to define obesity and classify body weight. Accordingly, the WHO's classes of weight are underweight, normal weight, overweight, obesity class I, obesity class II and obesity class III (Table 1.1).[3] The medical literature, however, has pushed for further categorization of obesity due to the observed clinical differences within obese patients in various fields. Hence obesity is stratified into severe obesity, morbid obesity, and super obesity (Table 1.1).[4]

Obesity is a worldwide pandemic.[5] Its prevalence in the United States (US) was estimated to be 36.5% in 2014, which is a significant rise compared to 2000, when the prevalence was 30%.[6] In Canada, obesity's prevalence doubled from 13.8% in 1978 to 26.4% in 2013 and is expected to rise further over the next two decades.[7] A similar trend has been documented across Europe too, where obesity increased in France and United Kingdom (UK) from 6.3% and 6% in 1980s to 13.1% and 19.2% in 2014 respectively (Figure 1.1).[8-10] The pervasive pattern of obesity has grabbed the medical community's attention, especially since it precipitates a spectrum of health hazards.

Obesity is an independent risk factor for mortality. It reduces survival by 2 to 10 years depending on the magnitude of the elevated BMI.[11] Moreover, it is a risk factor for numerous health conditions, such as cardiovascular disease (CVD), diabetes mellitus type 2 (DM-2), infections, malignancies, and arthritis.[12-17] Consequently, obesity increases healthcare costs and indirect costs related to decreased productivity. It is estimated that the direct and indirect costs of obesity in Canada ranges between $4.6 and $7.1 billion.[7]

Table 1.1 WHO and Medical Literature Classification of Body Weight Based on BMI. [3,4]

WHO Classification	BMI (kg/m^2)	Medical Literature Classification	BMI (kg/m^2)
Underweight	<18.5	Underweight	<18.5
Normal Weight	18.5 – 24.9	Normal Weight	18.5 – 24.9
Overweight	25 – 29.9	Overweight	25 – 29.9
Obesity		Obesity	30 – 34.9
Class I	30 – 34.9	Severe Obesity	35 – 39.9
Class II	35 – 39.9	Morbid Obesity	40 – 49.9
Class III	>40	Super Obesity	>50

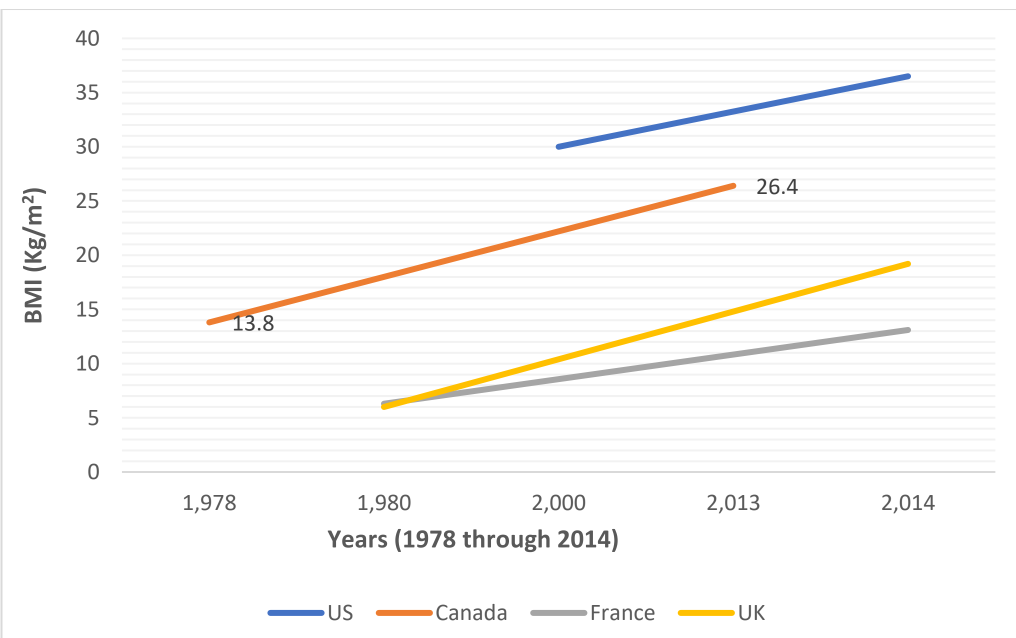

Figure 1.1 Prevalence of Obesity over the Decades

1.2. Osteoarthritis

Osteoarthritis (OA) is a disorder that develops in response to repetitive strain on mobile synovial joints, causing cartilage degradation, bone remodeling, osteophyte formation, joint inflammation, and loss of function.[18] It commonly compromises the joints of the spine, hand, hip and knee.[19] Its hallmark presentation is a dull, aching joint pain of insidious onset that is precipitated by activity in early disease and occurs at rest at an advanced stage.[20] This chronic pain is associated with acute, unpredictable, and debilitating episodes of severe joint pain, in addition to a range of symptoms that involve the affected joint and include crepitus, decreased range of motion (ROM), deformity, instability, short-lived stiffness and swelling.[20,21] The persistent nature of these symptoms reduces patients' functionality, interrupts their sleep, and keeps them in psychological distress; hence OA is labeled as one of the ten most disabling ailments by the WHO.[20-22]

OA is a common condition that is expected to increase with time.[23] The Global Burden of Disease Study 2017 (GBD 2017) estimates the global prevalence of knee OA as 260 million cases, while the Framingham OA study estimates the prevalence of symptomatic knee OA in the US as 7%.[24,25] This high prevalence of OA is attributed to its multitude of risk factors, such as age, sex and body weight.[26]

The incidence of knee OA increases with age and is amplified after the age of 50, reaching a plateau by 70 to 80 years of age.[25-27] Similarly, female sex and obesity are risk factors for knee OA. [25] In the Framingham study, obesity increases the risk of knee OA by 1.5- to 2-fold.[28] A similar observation was made in a meta-analysis of 85 studies by Blagojevic et al., in which obesity increases the odds ratio (OR) of knee OA by 2.63.[29] Moreover, obesity promotes progression of OA in knees with neutral or valgus alignment and contributes to its symptoms; weight loss improves pain and functionality according to the Arthritis, Diet, and Activity Promotion Trial (ADAPT), Intensive Diet and Exercise for Arthritis (IDEA) trial and meta-analysis by Christensen et al., hence its inclusion in the treatment regimen of OA.[30-33]

The treatment regimen of knee OA includes four therapeutic modalities, which are summarized in Table 1.2.[34-37] These modalities are used in an ascending manner, starting with the least invasive. The first modality is nonpharmacologic treatment, like weight loss and exercise, which tackles obesity and strengthens periarticular muscles. This modality has been shown to improve OA symptoms in the ADAPT and IDEA trials.[31,32] The second modality is pharmacologic treatment, whose backbone is non-steroidal anti-inflammatory drugs (NSAIDs). The third modality is minimally invasive procedures, such as intraarticular steroid injections (IASI) and intraarticular hyaluronic acid (IAHA) injections, both of which have been shown to be effective in reducing pain and improving ROM, although IAHA is yet to be recommended by the American Academy of Orthopedic Surgeons (AAOS).[38-40] Finally, the fourth modality is total knee arthroplasty (TKA), which is utilized when other options have failed, and the patient has debilitating symptoms.

1.3. Total Knee Arthroplasty

Total knee arthroplasty (TKA) is a surgical procedure in which a damaged knee is replaced with a prosthesis that is composed of femoral, tibial, and patellar components, and polyethylene spacer.[41] It was first performed in the 1960s and has since been growing in popularity.[42] The Centers for Disease Control and Prevention (CDC) conducted a study among Medicare enrollees, which showed a growth of 58% from 2000 to 2006 in hospitalization for TKA.[43] The Swedish Register demonstrated a similar growth of TKA incidence over a period of 20 years, while the National Inpatient Sample (NIS) dataset highlighted, in a subset analysis, that the incidence of TKA increased more in the youngest age group of 45 to 49 years.[44-46] This pattern can be explained by the increasing prevalence of obesity, which has been shown to be an independent risk factor for TKA at a younger age.

Table 1.2 Summary of knee OA treatment as per the guidelines of the American Academy of Orthopedic Surgeons (AAOS), American College of Rheumatology (ACR) & Osteoarthritis Research Society International (OARSI).

Treatment of Knee OA	Examples
Nonpharmacologic	Weight loss, exercise
Pharmacologic	Topical NSAID, oral NSAID
Minimally invasive procedure	IASI, IAHA
Surgery	TKA

TKA is indicated in patients with severe pain caused by arthritis and refractory to alternative treatments, in the absence of septic arthritis or other sources of infection. [41] It is an effective treatment option that improves both pain and functionality. In a meta-analysis of 63 studies, Lutzner et al. concluded that TKA improves patients' long-term functional outcome, measured by Knee Society Score (KSS), by 30 to 50%.[47] Nonetheless, TKA can result in a series of complications (Table 1.3), many of which necessitate revision TKA (RTKA).[41] The rate of complications is affected by several factors, such as age, sex, and comorbid conditions.

The risk of TKA failure declines as patients grow older, with a significant decrease in failure observed every 10 years.[48-50] The reason behind this inverse relationship is the mechanism of most TKA complications, which is wear and tear. Older patients have a shorter life expectancy and are less mobile than their younger counterparts, thus their use of the prosthetic joint is less, resulting in lower rate of complications. The association between sex and TKA complications has yet to be established. Multiple studies, including an analysis of a large database by Blum et al., have presented female sex as a protective factor against TKA complications.[48,49,51] This notion, however, is challenged by Stiehl et al., whose multi-center survivorship analysis show that female sex increases the risk of RTKA by 50%.[52] A third risk factor for TKA complications is comorbidity. In a population study in Ontario, Kreder et al. conclude that comorbid diseases amplify the risk of joint infection and postoperative complications.[53] Jamsen et al. conducted a nationwide study of 53 thousand TKAs; its results reveal an increased likelihood of RTKA in patients with conditions like cancer, Cardiovascular Disease (CVD), Diabetes Mellitus type 2

(DM-2), hypertension (HTN) and psychotic disorders.[54] This intricate relationship between comorbid diseases and TKA, in addition to the soaring prevalence of obesity and its association with OA, has led to investigations of the direct effect of obesity on TKA.

Many patients are denied access to TKA due to their high BMI, citing the increased risk of infection and RTKA, as well as increased costs.[55,56] In a retrospective review of an institutional database, however, the outcome change scores for KSS, SF-12 Health Composite Score and Western Ontario and McMaster Universities Arthritis Index (WOMAC) are comparable across all BMI cohorts (Table 1.1).[44] A similar result is demonstrated in a meta-analysis by Chaudhry et al., albeit super obese patients scored marginally lower, demonstrating that TKA relieves pain and improves quality of life regardless of body mass index.[57] Furthermore, the risk of aseptic RTKA is similar across all BMI groups.[44,57-60] This is in contrast to septic revision, which increases in an ascending manner as BMI increases, reaching up to a 12-fold jump in the cohort of Werner et al..[44,57,61,62] Accordingly, the 90-day costs for TKA are significantly higher in the morbid and super obesity groups only, mainly due to hospital readmissions.[44] Despite the increased expense, TKA has been proven through a Markov model to be cost-effective in all simulations of patients with a BMI <50 kg/m^2 and 99.16 percent of super obese simulations, refuting the notion that is reasonable to withhold care from patients who are from higher BMI cohorts.[63]

Table 1.3 List of complications of TKA

Complications
Arterial compromise
Arthrofibrosis
Component malpositioning
Extensor mechanism rupture
Infection
Instability
Patellar clunk syndrome

Patellar maltracking
Periprosthetic fracture
Peroneal nerve palsy
Polyethylene wear
Venous thromboembolism

1.4. Revision Total Knee Arthroplasty

Revision total knee arthroplasty (RTKA) is a reoperation in which TKA components are retrieved followed by knee reconstruction.[41] There are two main indications for RTKA: septic and aseptic loosening. Septic loosening is the failure of TKA secondary to an infection, while aseptic loosening refers to failure that excludes infection or mechanical etiology.

There are two methods of RTKA practiced in our institution in the setting of septic loosening: a 2-stage RTKA and 1.5-stage RTKA. A 2-stage RTKA is composed of two stages; the first one involves the removal of infected components, debridement of tissues and implantation of antibiotic-impregnated cement spacer which is usually static in nature; the second stage is final knee reconstruction after a period of antibiotics administration with clinical and serological evidence of infection clearance.[64,65] A 1.5-stage RTKA is a unique intervention in which a surgeon uses antibiotic-impregnated cement along with polyethylene spacer to replace the tibial component, along with a regular femoral component. A 1.5-stage acts as a step toward second stage if infection is yet to be cleared, or as a final stage if the patient is satisfied with the outcome along with clearance of infection. This intervention provides reasonable range of motion around the knee joint.

Aseptic loosening, on the other hand, is fixed with a single-stage RTKA. It includes both component retrieval and final reconstruction within the same operation. It involves one or all knee components: femur, tibia, and polyethylene spacer. RTKA includes further procedures that are designed in response to patient's presentation; these interventions are summarized in Table 4.

The incidence of RTKA is on the rise despite increasing efficacy of primary TKA.[66] Although it can be explained with the growing elderly population and the concomitant rise of TKA, the medical literature has been shedding light on the inevitable impact of obesity on RTKA as one of the causes too. Using the Nationwide Inpatient Sample (NIS), Odum et al. analyzed more than 450,000 RTKA cases over a decade.[67] Their work shows that obesity among RTKA patients has increased by more than 4-folds, with 1 out of 4 patients undergoing RTKA being obese. Moreover, obesity in RTKA patients is associated with female sex and, alarmingly, younger patients whose age is between 45 and 64 years.

The epidemiologic increase of obesity amongst RTKA patients is met with investigations of its effect on RTKA. In a 10-year retrospective comparative study of 154 RTKA procedures, obesity increased the rate of postoperative orthopaedic and medical complications, although the latter did not reach statistical significance due to low power.[68] Carter et al. further investigated the difference in early outcome between morbidly obese and non-obese RTKA patients. They highlighted that morbidly obese patients present for RTKA at a significantly younger age compared to their non-obese counterparts. They also found that morbidly obese patients are more likely to develop early complications, especially delayed wound healing.[69] The consequences of morbid obesity on RTKA were further investigated by Sisko et al., who compared the long-term clinical outcomes of RTKA between two small, matched groups of morbidly obese and non-morbidly obese patients.[70] The morbidly obese group has a higher rate of reoperation and re-revision, with lower 10-year survivorship for both, particularly in the aseptic subgroup. Additionally, the morbidly obese group has lower clinical outcome, evident by the lower final WOMAC score and smaller gain in KSS and SF-12 Mental Component (MC) compared to the non-morbidly obese. As a result, the value of RTKA in morbid and super obese patients is questioned by practitioners, especially as there are no studies evaluating the cost-effectiveness of RTKA in these groups either.

1.5. Rationale for Study

Obesity is a growing phenomenon that is leaving an impact across all medical fields, including arthroplasty. While many studies have clarified the effect of obesity on TKA clinically and economically, displaying results in favor of operating on obese patients, the literature lacks sufficient data on the relationship between obesity and RTKA. This void contrasts the increasing incidence of RTKA and growing volume of obese patients among RTKA population. The current papers, in addition to their scarcity, include small numbers of patients, address obesity as one group rather than dealing with the four categories of obesity separately, and are deficient in economic analysis. Therefore, there is a need to evaluate the magnitude of the benefits, risks, and economic implications of RTKA for a sufficient number of patients with varying BMI levels, including those at the end of the spectrum.

1.6. Study Objectives

1. To compare the change in functional outcome scores, survivorship and re-revision rate in patients undergoing RTKA across the BMI spectrum.
2. To evaluate the 90-day complication and readmission rate of RTKA across the BMI spectrum.
3. To assess 90-days costs of RTKA among the different BMI groups.

Table 1.4 Types of revision total knee arthroplasty procedures.

RTKA Procedure	
Single-stage	Component retrieval & reconstruction are done in one operation. Used in aseptic component loosening.
All	All components retrieved.
Femoral	Femoral component retrieved only.
Tibial	Tibial component retrieved only.
Two-stage	Component retrieval (stage 1) & reconstruction (stage 2) are done in two separate operations. Used in septic component loosening.

1.5-stage	Femoral component, polyethylene spacer and cement as half-step toward stage 2 or as final step.
Amputation	Above knee amputation (AKA) for life-threatening, incurable infections.
Arthrodesis	Also called knee fusion. The femur and tibia are joined together to eliminate knee joint. Used as last resort for refractory pain.
Bone grafting	Used in aseptic loosening of femoral or tibial component to avoid full revision.
Distal femur replacement (DFR)	Distal femur is replaced with endoprosthesis. Used in severe loosening or periprosthetic fracture due to lack of femoral bone stock or poor bone quality.
Extensor mechanism reconstruction	Repair, reconstruct or reinforce quadriceps tendon and/ or patellar tendon in the setting of extensive mechanism disruption.
Conversion to Hinge	Usually used in cases of collateral ligament deficiency gross flexion-extension gap imbalance, and in cases of severe bone loss. It provides stability at the expense of ROM.
Reduction of hinge dislocation	Urgent open reduction and possible revision of hinge TKA due to high risk of neurovascular compromise.
Incision & drainage with polyethylene exchange (I&D w/ poly)	Polyethylene component is removed followed by tissue debridement. Used in acute infection with no evidence of septic component loosening.
Manipulation under anesthesia	Used in arthrofibrosis, where under muscle relaxation and anesthesia the joint is manipulated until fibrosis is broken.
Open reduction & internal fixation (ORIF) of distal femur	Used in periprosthetic fracture in which the femoral component is stable.
Patellar resurfacing	The articular surface of the patella is replaced with polyethylene dome. Used in anterior knee pain, patellar loosening and patellar maltracking.
Polyethylene component exchange	It is exchanged with bigger size for instability, smaller size for stiffness and similar size if the component is fractured.
Release of adhesions	Used in arthrofibrosis, where the joint is surgically opened, and adhesions are excised.

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2. Retrospective Analysis of Functional Outcome Scores for Revision Total Knee Arthroplasty Patients with Varying BMI Categories

2.1. Introduction

The demand for revision total knee arthroplasty (RTKA) is rising due to a growing elderly population and increasing obesity.[1,2] There is reluctance, however, in operating on patients at the higher end of the body mass index (BMI) spectrum because obesity is a risk factor for postoperative complications, is associated with a number of comorbid conditions that increase the risk of surgery, and the degree of benefit of arthroplasty for these patients is debatable.[3,4]

In a retrospective review by Ponnusamy et al., morbid and super obese patients undergoing primary total knee arthroplasty (TKA) had higher Charlson comorbidity index (CCI) and American Society of Anesthesiologists (ASA) score.[5] Nevertheless, the functional outcome change scores were similar across all BMI categories for Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Knee Society Score (KSS) and Short Form-12 (SF-12) Mental Component Summary (MCS). Only SF-12 Physical Component Summary (PCS) was markedly better in overweight and severely obese patients compared to obese patients. Chaudhry et al. yielded comparable results in their systematic review, which analyzed functional outcome scores before and after primary TKA.[6] The scores measured were WOMAC, KSS, Oxford Knee Score (OKS), EuroQol-5D (EQ-5D), and SF12-PCS. They reported that functional outcome change scores in patients with severe and morbid obesity were similar relative to patients with normal BMI, but 0.52 lower in patients with super obesity.

The clinical benefit of primary TKA for most obese patients is not as established in RTKA due to the scarcity of such studies. Sisko et al., however, have compared two small groups of patients whose BMI is either ≥40 kg/m^2 or lower.[7] Their work showed that morbidly obese patients had lower postoperative WOMAC score, and small score change in KSS and SF-12 MCS, suggesting a smaller degree of benefit of RTKA for patients with advanced obesity. Nonetheless, the current literature on RTKA involves a small number of patients and lacks distinct differentiation of the multiple obesity classes. Hence the aim of this study is to investigate the effect of the various classes of obesity on the benefit of RTKA using several functional outcome scores.

2.2. Methods

Our institutional clinical database was retrospectively reviewed for patients who had undergone RTKA from Dec 2005 to Jan 2020. Patients who had undergone first-stage only were excluded because the majority of them had a static spacer, which prevented them from moving their joint, limiting the functional outcome scores that can be measured. Body Mass Index (BMI) was calculated using patients' height and weight that were measured preoperatively. Accordingly, the patients were categorized into 6 groups: normal weight (BMI <25 kg/m^2), overweight (BMI 25-29.9 kg/m^2), obesity (BMI 30-34.9 kg/m^2), severe obesity (BMI 35-39.9 kg/m^2), morbid obesity (BMI 40-49.9 kg/m^2) and super obesity (BMI ≥50 kg/m^2).[4]

Since the super obese group was expected to be the smallest, we used a sample of convenience based on the number of eligible super obese patients. Patients from the other BMI groups were then randomly selected by a random number generator from the entire RTKA cohort in a 2:1 ratio for each BMI category relative to the super obese group. Perioperative protocols were the same for all cohorts, except for deep venous thrombosis (DVT) prophylaxis, which was aspirin for those with BMI <40 and low-molecular weight heparin (LMWH) for morbid and super obese patients.

2.3. Outcome Measures

Patient charts and electronic medical records were reviewed. The demographic variables that were extracted were age, sex, BMI, smoking status, years of follow-up, Charlson comorbidity index (CCI) and the American Society of Anesthesiologists (ASA) class. CCI predicts 10-year survival in patients with multiple comorbidities; as the score increases, survival rate declines

(Table 2.1).[8] ASA classification system, on the other hand, categorizes patients prior to surgery based on their preoperative health (Table 2.2).[9]

Medical records were reviewed to identify patients who required re-revisions and the date of re-revision and reason for re-revision were collected. The institutional database was reviewed to collect preoperative and latest available postoperative patient-reported functional outcome scores. These included the 12-Item Short Form Health Survey (SF-12), Knee Society Score (KSS) and the Western Ontario and McMaster Universities Arthritis Index (WOMAC). The SF-12 measures quality of life (QoL) by assessing the impact of health on a patient's life physically and mentally.[10] KSS is a clinician rated scoring system that rates the knee and patient's functionality before and after arthroplasty.[11] WOMAC is an index that evaluates OA based on pain, stiffness, and physical function.[12] All scores were scaled such that a higher score indicates a better outcome.

Table 2.1 CCI score and corresponding 10-year survival rate.

CCI Score	10-year survival rate (%)
0	98
1	96
2	90
3	77
4	53
5	21
≥6	0

Table 2.2 ASA classification system.

ASA Class	Description
1	Normal health
2	Mild systemic disease

3	Severe systemic disease
4	Severe systemic disease that is constant threat to life
5	Moribund not expected to survive without operation
6	Declared brain dead

2.4. Statistical Analysis

Demographics, clinical characteristics, and outcomes were summarized using descriptive statistics: frequencies, proportions, means and standard deviation. Categorical variables were compared using either a Chi-squared test or Fisher's exact test. Z-test was used to identify the subsets of BMI categories that differ significantly from each other. For continuous variables normality was assessed using Shapiro-Wilk test. Normally distributed continuous variables were compared using analysis of variance (ANOVA) and Welch's ANOVA if the assumption of homogeneity of variance was violated as per Levene's test. Non-normally distributed continuous variables were compared using Kruskal-Wallis test. A post-hoc Tukey's and Games-Howell test were performed for variables that showed statistical significance on ANOVA and Welch's ANOVA respectively to identify the specific BMI group comparisons that caused the significance. The means of the preoperative and postoperative functional outcome scores of each BMI group were compared using dependent t-test to evaluate if the score change is significant. Statistical significance was set at $p < 0.05$. Data was analyzed using IBM SPSS Statistics 26.

2.5. Results

The cohort consists of 50 super obese patients and 100 patients in each of the other BMI groups, resulting in a total of 550 patients. The demographics of the participants are reported in Table 2.3. There is a statistically significant difference in age among the BMI groups. In particular, morbidly and super obese patients are significantly younger compared to patients who are nonobese (p= 0.01 and 0.01 respectively), overweight (p= 0.003 and 0.001) and obese (0.004 and 0.001). The distribution of female patients is comparable across all BMI groups, although overweight patients are predominantly males, but this difference is not statistically significant (p= 0.102). The majority of patients has a CCI score of 3 or above, with no statistical difference between the BMI groups (p= 0.217). The majority of patients were nonsmokers, but the super obese group has a statistically higher percentage of smokers compared to the rest of the groups (p= 0.01). Similarly, a significant difference is observed in ASA classification between super obese patients and remaining BMI groups, who are mostly class IV compared to class III in the remaining cohorts (p= 0.01).

The indications for RTKA in the sample are shown in Figure 2.1. The most common indication is aseptic loosening, except for super obese patients, whose most common reason for RTKA is infection (58%). This observed difference is statistically significant (p= 0.048).

Table 2.3 Demographics of RTKA patients per BMI group.

Variable	BMI Group						
	Normal Weight (100)	Overweight (100)	Obesity (100)	Severe Obesity (100)	Morbid Obesity (100)	Super Obesity (50)	p-value
Age (mean ± standard deviation)	73 ± 12	72 ± 11	71 ± 11	68 ± 8	66 ± 10	65 ± 7	0.01
Female (%)	61	45	56	61	62	64	0.103
Smoking (%)	9	7	7	11	17	32*	0.01
BMI (mean ± standard deviation)	22.74 ± 1.79	27.84 ± 1.34	32.15 ± 1.51	37.43 ± 1.44	44.96 ± 2.89	55.16 ± 4.54	0.01
CCI (%)							0.248
0	0	3	3	1	1	2	
1	4	9	4	3	6	2	

2	5	10	12	16	10	8	
3	15	19	16	20	24	20	
4	25	23	19	19	20	16	
5	30	12	15	17	15	26	
≥6	21	24	31	24	24	26	
ASA (%)							0.01
1	1	1	0	0	0	0	
2	23	24	28	16	2*	2*	
3	61	62	60	78	73	38*	
4	15	13	12	6	25	60*	

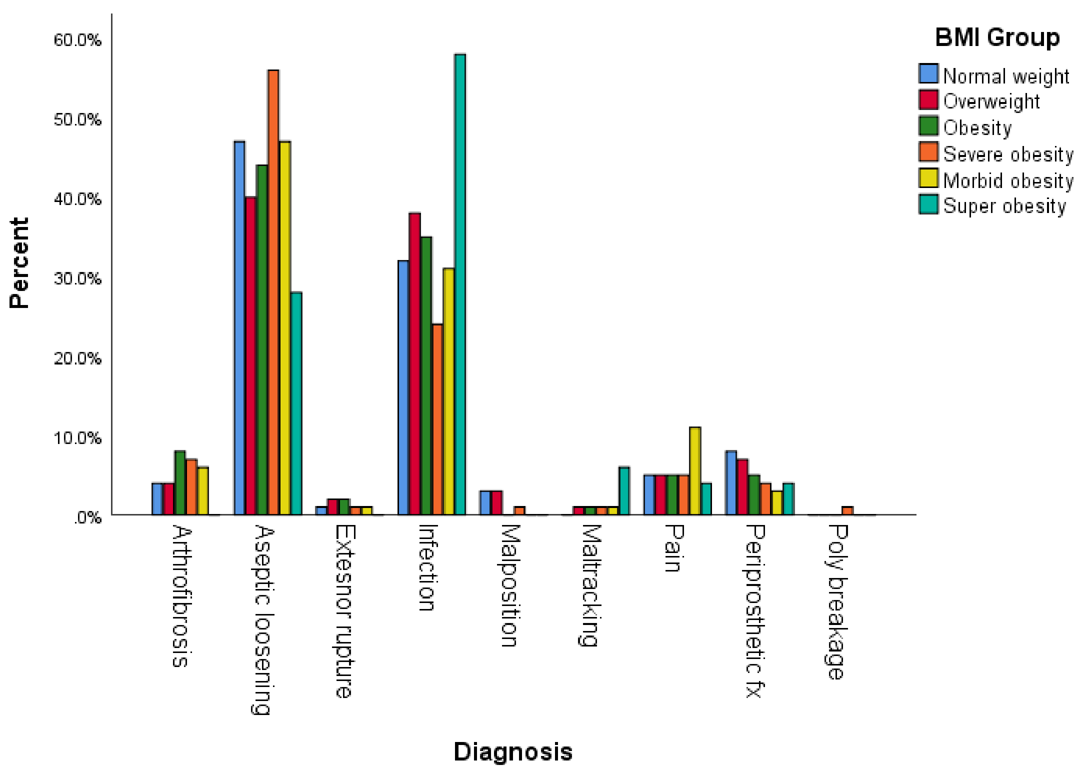

Figure 2.1 Indications for RTKA across BMI groups.

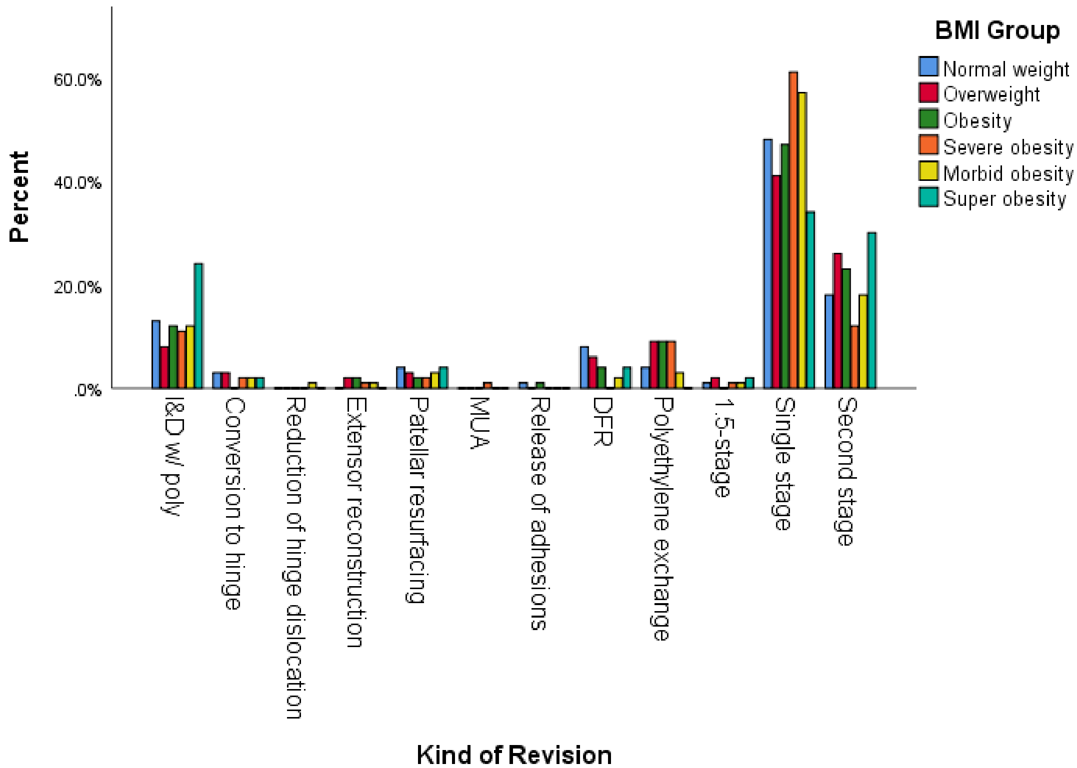

Figure 2.2 Type of RTKA performed across the BMI groups.

The types of RTKA performed within the sample are displayed in Figure 2.2. Thirteen types were identified. The most common RTKA performed is single-stage for aseptic loosening, except in super obese cohort, in which both single- and second-stage RTKA are approximately the same (34 and 30% respectively) for aseptic and septic loosening respectively. Furthermore, the percentage of I&D within the super obese group was twice as common compared to the other BMI groups (24%). These differences observed are also statistically significant (p= 0.026).

The preoperative and postoperative functional outcome scores, in addition to the difference between the two, are listed in Table 2.4. The functional scores available for analysis varied between the cohorts. Table 2.5 lists the availability of each score in the cohort. The number of reported scores was variable between the different functional scores and between the BMI groups. Patients who had both preoperative and postoperative scores were included in the calculations, and their mean proportion was 30%. There was a wide range of duration between preoperative and postoperative scores (3 months to 13 years). The postoperative scores of SF-12

PCS, KSS and WOMAC are higher than their preoperative counterparts across all BMI groups (p= 0.01), but the postoperative SF-12 MCS is relatively similar to its preoperative score (p= 0.713). The change scores from postoperative to preoperative were not statistically significant between all BMI groups (p-values=0.051, 0.766, 0.513, 0.124). The difference between postoperative scores were not statistically significant except in SF-12 PCS, which demonstrated significance between normal weight and overweight, and morbid and super obesity (p= 0.013).

Table 2.4 Functional outcome scores of RTKA patients across BMI groups.

Variable (mean ± standard deviation)	BMI Group						
	Normal Weight	Overweight	Obesity	Severe Obesity	Morbid Obesity	Super Obesity	p-value
SF-12 PCS	N=40	N=41	N=29	N=38	N=30	N=12	
Preoperative	30.57 ±9.06	32.06 ± 8.14	31.25 ± 7.84	29.14 ± 6.78	28.36 ± 6.86	27.68 ± 5.82	0.133
Postoperative	36.3 ± 11.27	37.87 ± 10.71	33.4 ± 9.76	32.69 ± 8.39	29.53 ± 7.44	30.39 ± 6.62	0.01
Change	+2.75 ± 9.12	+3.02 ± 7.58	+0.79 ± 5.28	+1.7 ± 6	+0.48 ± 5.69	+0.98 ± 4.77	0.051
SF-12 MCS	N=40	N=40	N=30	N=37	N=29	N=12	
Preoperative	49.84 ± 11.45	50.38 ± 10.58	47.61 ± 11.5	50.64 ± 11.16	49.82 ± 13.27	48.45 ± 10.14	0.832
Postoperative	51.37 ± 10.62	49.51 ± 10.48	48.02 ± 10.46	51.61 ± 10.3	48.91 ± 12.3	48.66 ± 13.21	0.61
Change	+0.73 ± 7.93	-0.45 ± 6.68	+0.15 ± 4.85	+0.46 ± 7.3	-0.38 ± 5	+0.07 ± 6.27	0.766
KSS	N=19	N=18	N=13	N=13	N=13	N=9	
Preoperative	86.42 ± 34.17	95.94 ± 27.72	74.31 ± 29.03	93.92 ± 23.88	77.85 ± 30.01	87.67 ± 30.32	0.319
Postoperative	159.16 ± 32.13	146.39 ± 37.71	140.92 ± 33.79	142.38 ± 43.28	135.77 ± 52.36	152.56 ± 28.68	0.704

Change	+13.82 ± 35.08	+9.08 ± 25.1	+8.66 ± 28.41	+6.3 ± 20.4	+7.53 ± 25.74	+11.68 ± 27.51	0.513
WOMAC	N=36	N=38	N=28	N=42	N=29	N=10	
Preoperative	47.28 ± 24.41	51.86 ± 18.22	46.93 ± 18.23	43.48 ± 18.55	42.81 ± 20.7	54.48 ± 15.02	0.269
Postoperative	67.73 ± 26.5	70.84 ± 21.93	64.02 ± 21.66	63.41 ± 23.22	60.17 ± 24.37	64.45 ± 26.21	0.422
Change	+7.36 ± 18.87	+7.21 ± 16.1	+4.79 ± 12.01	8.37 ± 15.91	5.21 ± 16.17	+2.19 ± 12.85	0.124

Table 2.5 List of functional outcomes scores and their percentage of availability in the cohort.

Functional Outcome Score	Percentage of Availability in Cohort (%)
Preoperative SF12 MCS	48
Preoperative SF12 PCS	48
Postoperative SF12 MCS	68
Postoperative SF12 PCS	68
Preoperative KSS	29
Postoperative KSS	46
Preoperative WOMAC	49
Postoperative WOMAC	66

2.6. Discussion

Our findings demonstrate that morbid and super obese patients present for RTKA at a younger age compared to the remaining BMI groups. Moreover, super obese patients present with higher ASA score, and their most common indication for RTKA is infection, unlike other BMI classes, whose most common indication for RTKA is aseptic loosening. Consequently, single-stage RTKA is the most common procedure in all BMI categories, except in super obesity, which has single-stage and second-stage RTKA as most common, in addition to higher proportion of incision and drainage procedures relative to other BMI cohorts. In terms of benefit, the functional outcome change scores were similar across all BMI groups, but the postoperative SF12-PCS was significantly higher in normal weight and overweight patients relative to morbid and super obese patients.

In general, our results agree with the current literature, albeit they are more specific. The studies of Odum et al. and Carter et al. showed respectively that obese and morbidly obese patients present for RTKA at a younger age compared to average, which was an effect of morbid and super obesity in our study.[2,13] Our super obese cohort had poorer health status prior to RTKA, which was a finding of Ponnusamy et al. in their analysis of primary TKA.[5] Additionally, super obese patients had more septic RTKA, which is consistent with very high BMI being a risk factor for septic revision. Our results differ, however, with those of Sisko et al., as we found no significant difference in the benefit of RTKA between the different BMI groups, while Sisko et al. found lower functional outcome change scores in morbidly obese patients.[7] Interestingly though, these results reflect the findings of Ponnusamy et al., who also did not find significant difference in the functional outcome change scores in primary TKA.[5]

This study carries a number of limitations, which are mostly inherent from the study's nature as a retrospective review. For example, only a third of our cohort had valid functional outcome scores, which increased score variability and undermined their accuracy. Moreover, the time difference between the preoperative and postoperative scores ranged between few months and more than 10 years, which is a shortcoming, as short- and long-term benefits could be different in each BMI category. Thus, a prospective study would allow more accurate documentation of functional scores and permit a standardized duration between preoperative and postoperative scores.

Nevertheless, this study remains the largest series in the literature to address the effect of obesity on RTKA and to identify the different classes of obesity rather than treating it as a single entity. This allows both patients and clinicians to better predict and understand the outcomes of RTKA in patients with varying BMI.

In conclusion, morbidly and super obese patients present for RTKA at an earlier age. It is vital to take note that super obese patients are at higher risk for infection after their primary TKA, which will require more RTKA procedures like incision and drainage, and second-stage RTKA. The benefit of RTKA for obese patients, especially those whose BMI at the higher extreme, is undeniable, given their improvement in functionality after RTKA that is comparable to those of normal weight. Thus, the clinical gain of RTKA should not be questioned when the decision to operate is being made.

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3. Complication Rate, Re-revision Rate and Survivorship of Revision Total Knee Arthroplasty in Patients with Varying BMI Categories

3.1. Introduction

Twenty-five percent of patients undergoing revision total knee arthroplasty (RTKA) are obese.[1] Obesity carries a hazardous effect on operations due to the associated comorbid conditions, that are known to be risk factors for postoperative complications and mortality. These conditions include cardiovascular disease (CVD) and diabetes mellitus type 2 (DM-2).[2] Yet obesity is an independent risk factor for postoperative complications in arthroplasty. Obesity is known to increase the probability of postoperative prosthetic infection, resulting in septic RTKA.[3,4] Indeed, the relationship between septic RTKA and body mass index (BMI) has been shown to be proportional, as the rate of septic RTKA increases as BMI increases, reaching up to a 12-fold increase in some studies.[5-8] This is in contrast to aseptic RTKA, whose rate remains similar across all BMI cohorts.[5,6,9-11] Although there are numerous studies on the relationship between obesity and primary TKA, the effect of obesity on RTKA has not been studied as extensively.

Obesity increases the risk of orthopaedic and medical complications post-RTKA.[12] In the early postoperative period, morbid obesity is associated with delayed wound healing, while in the late period, morbid obesity has been shown to reduce the survivorship of RTKA and boost the rate of re-revision.[13,14] Nevertheless, the available studies have their shortcomings.

The current literature consists of small cohorts with low statistical power. Moreover, obesity has been treated in a dichotomous fashion instead of addressing it as a spectrum, masking variabilities amongst its categories. Thus, the aim of this study is to look into the complication rate, re-revision, and survivorship of RTKA in a larger cohort with more variable BMI categories than the studies available in the literature.

3.2. Methods

We retrospectively reviewed our institutional database for patients who had undergone RTKA from Dec 2005 to Jan 2020. Patients who had undergone first-stage only were excluded because the majority of them had a static spacer, which prevented them from moving their joint, limiting the functional outcome scores that can be measured. Body Mass Index (BMI) was calculated using patients' height and weight that were measured preoperatively. Accordingly, the patients were categorized into 6 groups: normal weight (BMI <25 kg/m^2), overweight (BMI 25-29.9 kg/m^2), obesity (BMI 30-34.9 kg/m^2), severe obesity (BMI 35-39.9 kg/m^2), morbid obesity (BMI 40-49.9 kg/m^2) and super obesity (BMI ≥50 kg/m^2). Since the morbid obesity group has the largest range of BMIs compared to the other categories, we elected to classify it further into type I (BMI 40-44.9 kg/m^2) and type II (BMI 45-49.9 kg/m^2) for sub-analysis.

We used a sample of convenience based on the number of eligible super obese patients. Patients from the other BMI groups were then randomly selected by a random number generator from the entire RTKA cohort in a 2:1 ratio for each BMI category relative to the super obese group. Perioperative protocols were the same for all cohorts, except for deep venous thrombosis (DVT) prophylaxis, which was aspirin for those with BMI <40 and low-molecular weight heparin (LMWH) for morbid and super obese patients.

3.3. Outcome Measures

Patient charts were reviewed, and electronic medical records were used to identify patients who had postoperative mortality, venous thromboembolism (VTE), prosthetic infection and re-revision. The type of operation performed in re-revision, reason for re-revision and any subsequent revisions were recorded. Charts were reviewed to determine discharge status of patients and in particular those who were discharged to extended care facility (ECF) were identified.

3.4. Statistical Analysis

Follow-up time was compared between the different BMI cohorts. Normality was assessed using Shapiro-Wilk test, followed by Kruskal-Wallis test as the normality assumption was violated.

Mortality rate, ECF rate, VTE rate, infection rate and re-revision rate were summarized using frequencies and proportions were calculated. Chi-squared analysis or Fisher's exact test were performed to determine if these rates differed between the varying BMI categories. Z-test was used to identify the subsets of BMI categories that differ significantly from each other.

Survival time of the revisions were calculated by subtracting the date of surgery from either last date of follow-up or re-revision date. Kaplan Meier survival analysis was performed with revision for any reason as the endpoint. Censored subjects are those who were lost to follow-up or did not meet the endpoint after 10 years, including those who died. A log rank test was run to determine if there were differences in the survival distribution of the 6 BMI groups.

Statistical significance was set at $p < 0.05$. Data was analyzed using IBM SPSS Statistics 26.

3.5. Results

The cohort consists of 50 super obese patients and 100 patients in each of the other BMI groups, resulting in a total of 550 patients. The demographics of the patients, which have been discussed thoroughly in Chapter 2, are displayed in Table 3.1. The mean follow-up duration was 3.44 ± 3.12 years, while the maximum and minimum duration of follow-up were 14.76 years and 1 week respectively. All BMI categories had a similar follow-up duration ($p = 0.513$).

The overall mortality rate was 13%. The difference in mortality rate among the different BMI categories was statistically significant (Table 3.2, $p = 0.008$). Patients whose BMI was at the extreme ends of the spectrum, that is, less than 25 or more than 50, had a mortality rate of 21% and 20% respectively, which was higher than that of the other cohorts.

The overall rate of patients who were discharged to an ECF was 16%. Similar to mortality, those patients that were normal weight or super obese had higher rates of discharge to ECF (p= 0.004).

The overall rates of VTE, superficial infection and deep infection were 3%, 16% and 11% respectively. There was no statistical difference between the different cohorts in VTE rate. Superficial and deep infection rates, on the other hand, had statistically significant differences between the BMI categories (p= 0.006 and p= 0.001 respectively). Super obese patients were twice as likely to develop superficial infection and three times as likely to develop deep prosthetic infection compared to other groups (Table 3.2).

Subgroup analysis of morbid obesity showed that there was a significant difference (p= 0.007) in mortality rate between the two subsets; morbid obesity type 1(BMI 40 to 45) had a mortality rate of 8%, while morbid obesity type 2's (BMI 45 to 50) mortality rate was 18%, comparable to that of normal weight and super obese cohorts. Similarly, a statistical difference was observed between the two groups in superficial and deep infection rate (p= 0.005 and p= 0.001), where type 2 had a rate comparable to the super obese cohort's (22% and 18% respectively). Although the ECF rate of morbidly obese patients differed between the two subsets (8% versus 16%), the difference was not statistically significant (p=0.248). As for VTE rate, morbid obesity type 2 had a higher VTE rate compared to type 1, but it was not statistically significant p=0.065).

The overall rate of re-revision was 17%. The morbid and super obese BMI groups had the highest rate of re-revision, reaching 25% and 33% respectively. The rates observed in these two groups compared to the remaining four cohorts were statistically significant (p= 0.001). Six percent and 1.6% of patients had to undergo a third and fourth revision respectively, but there was no statistical significance between the six cohorts (Table 3.3, p=0.146 and 0.657). Subgroup analysis of the morbid obesity group did not change the results, including the re-revision rate, which was comparable in both subgroups (22% and 28%).

Table 3.1 Demographics of RTKA patients per BMI group.

Variable	BMI Group					
	Normal Weight (100)	Overweight (100)	Obesity (100)	Severe Obesity (100)	Morbid Obesity (100)	Super Obesity (50)	p-value
Age (mean ± standard deviation)	73 ± 12	72 ± 11	71 ± 11	68 ± 8	66 ± 10	65 ± 7	0.01
Female (%)	61	45	56	61	62	64	0.103
Smoking (%)	9	7	7	11	17	32*	0.01
BMI (mean ± standard deviation)	22.74 ± 1.79*	27.84 ± 1.34*	32.15 ± 1.51*	37.43 ± 1.44*	44.96 ± 2.89*	55.16 ± 4.54*	0.01
CCI (%)							0.248
0	0	3	3	1	1	2	
1	4	9	4	3	6	2	
2	5	10	12	16	10	8	
3	15	19	16	20	24	20	
4	25	23	19	19	20	16	
5	30	12	15	17	15	26	
≥6	21	24	31	24	24	26	
ASA (%)							0.01
1	1	1	0	0	0	0	
2	23	24	28	16	2*	2*	
3	61	62	60	78	73	38*	
4	15	13	12	6	25	60*	

* indicates which value is significantly different from the others.

Table 3.2 Rate of mortality, VTE and prosthetic infection in RTKA patients.

Variable	BMI Group						
	Normal Weight (100)	Overweight (100)	Obesity (100)	Severe Obesity (100)	Morbid Obesity (100)	Super Obesity (50)	p-value
Mortality (%)	21*	6	7	13	13	20*	0.008
ECF (%)	26*	16	12	10	12	28*	0.004
VTE (%)	1	6	4	2	4	0	0.233
Superficial Infection (%)	10	13	18	13	17	34*	0.006
Deep Infection (%)	9	9	10	4	15	30*	0.001

* indicates which value is significantly different from the others.

Table 3.3 Re-revision rate and follow-up years in RTKA patients across BMI groups.

Variable	BMI Group						
	Normal Weight (100)	Overweight (100)	Obesity (100)	Severe Obesity (100)	Morbid Obesity (100)	Super Obesity (50)	p-value
Follow-up Duration in years (mean ± s.d.)	3.57 ± 3.15	3.7 ± 3.54	3.3 ± 3.9	3.57 ± 3.17	3.01 ± 3.06	3.6 ± 2.63	0.513
Re-revision (%)	12	17	12	11	25*	33*	0.001
Third Revision (%)	4	5	8	2	8	11	0.146
Fourth Revision (%)	3	1	2	0	2	2	0.657

* indicates which value is significantly different from the others.

A wide variety of procedures were performed in the subsequent revisions after the first RTKA. Figures 3.1, 3.2 and 3.3 display these procedures across the six BMI cohorts. The total number of re-revisions, third revisions and fourth revisions are 94, 34 and 9 operations respectively. Patients underwent 14 different types of re-revision, 9 types of third revision and 3 types of fourth revision. The most common re-revision procedure was incision and drainage. Second-stage procedure, on the other hand, was the most common operation in third and fourth revisions. No significant difference was observed across the BMI categories (p=0.281, 0.308 and 0.484).

The 10-year cumulative survival of RTKA in our cohort is presented in Figure 3.4. The probability of survival in normal weight, overweight, obese, and severely obese patients does not drop below 90% over a 10-year span. The probability of RTKA survival in morbidly obese patients, however, drops to 80% after 4 years and reaches down to 70% in 10 years. On the other hand, the probability of survival of RTKA in super obese patients drops to 80% after 2 years and continues to decrease to 60% after 10 years. The difference in survival distribution between super obesity, morbid obesity and the remaining 4 groups is significant (p=0.001). The subclassification of morbid obesity to type 1 (BMI 40-44.9 kg/m^2) and type 2 (BMI 45-49.9 kg/m^2) changes the survival distribution significantly (p=0.001). The probability of RTKA survival in morbid obesity type 1 is 80% after 10 years, similar to the preceding 4 BMI groups. The probability of RTKA survival in morbid obesity type 2, however, drops to 60% after 8 years, sharing a similar cumulative survival with super obesity. This suggests a point of inflection or 'watershed' point where a BMI greater than 45 indicates poor survivorship.

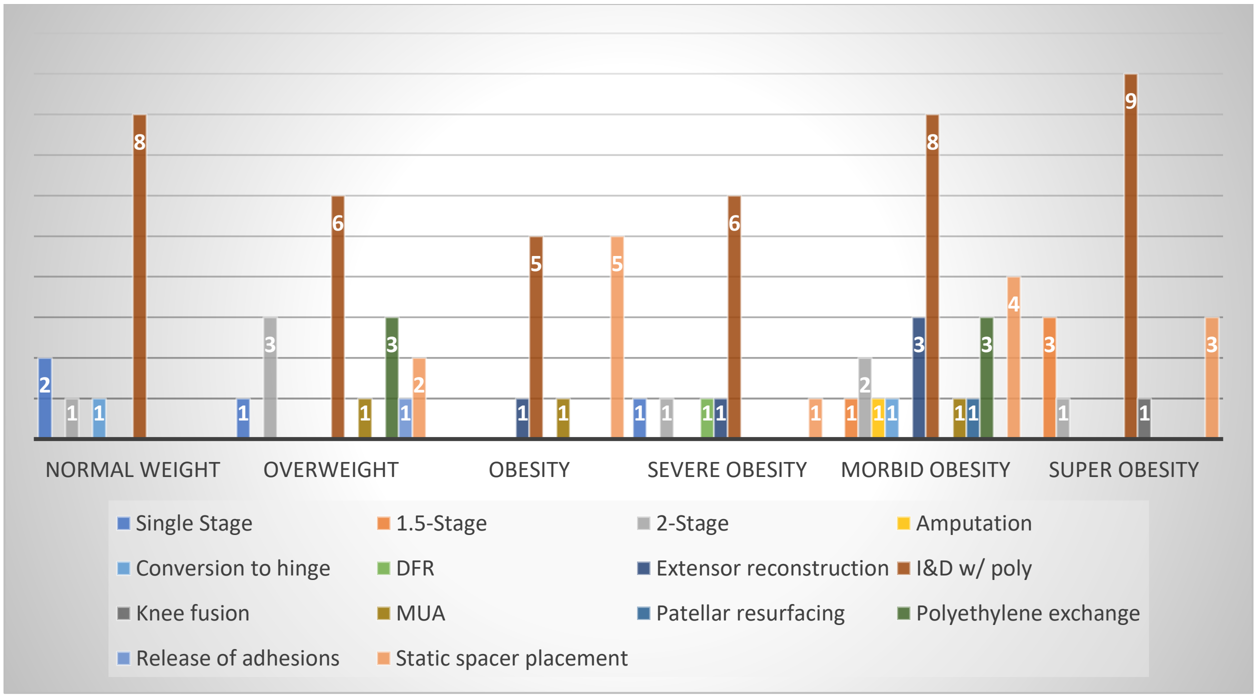

Figure 3.1 Distribution of Re-revision Across BMI Groups

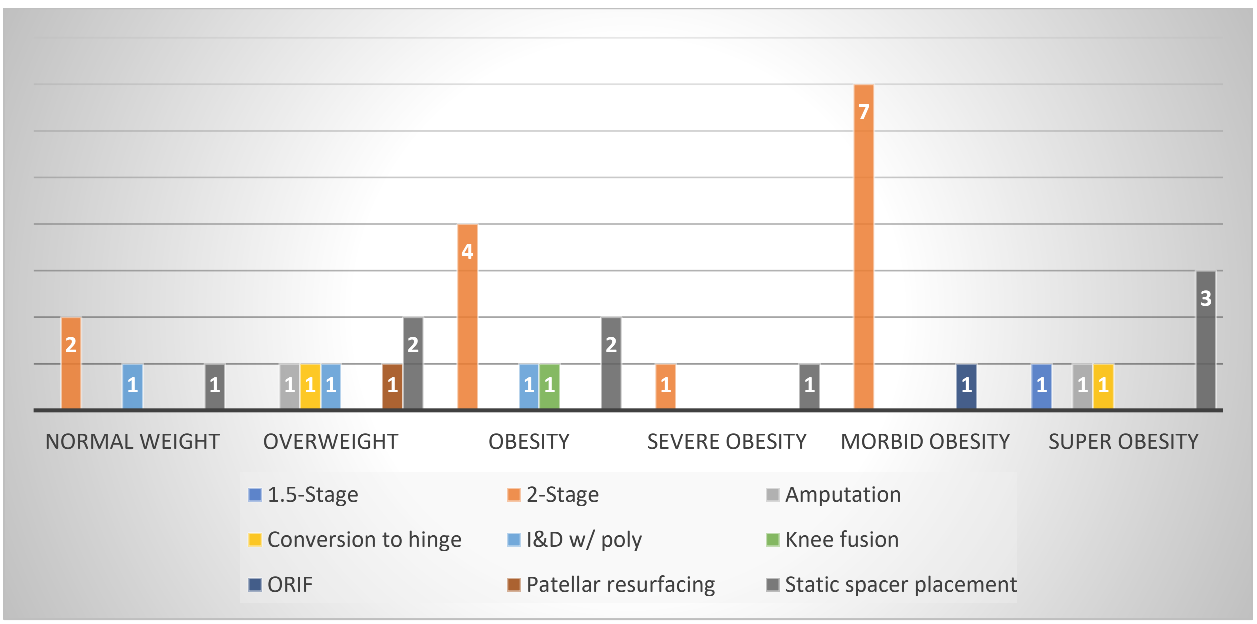

Figure 3.2 Distribution of 3rd Revision Across BMI Groups

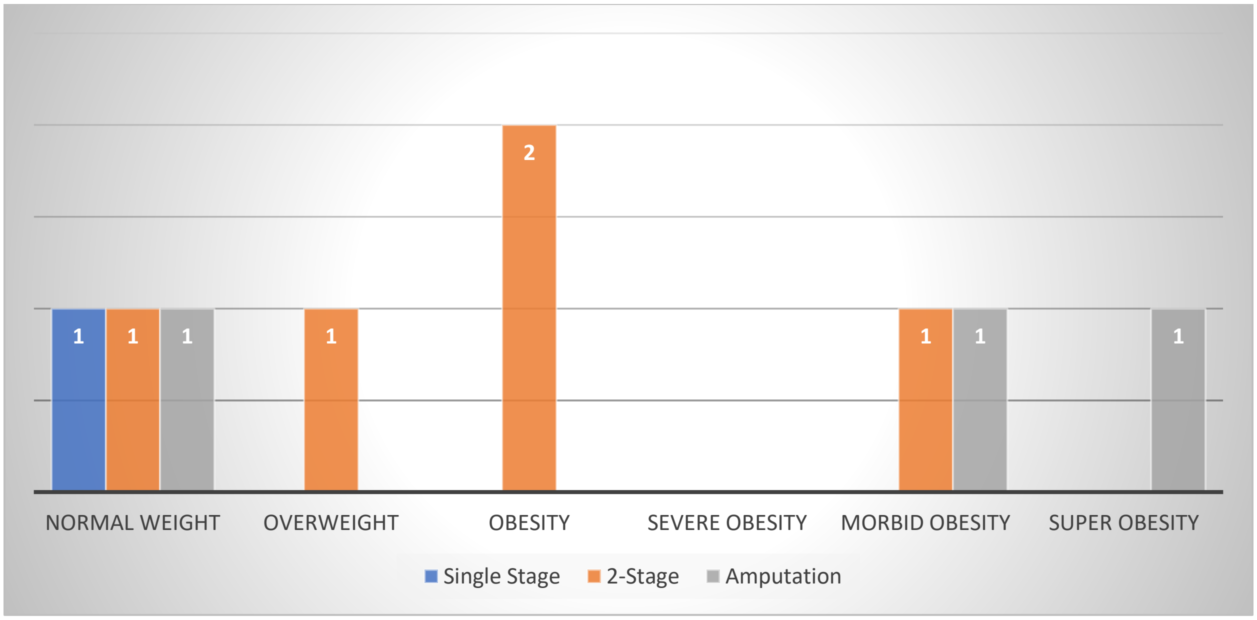

Figure 3.3 Distribution of 4th Revision Across BMI cohorts.

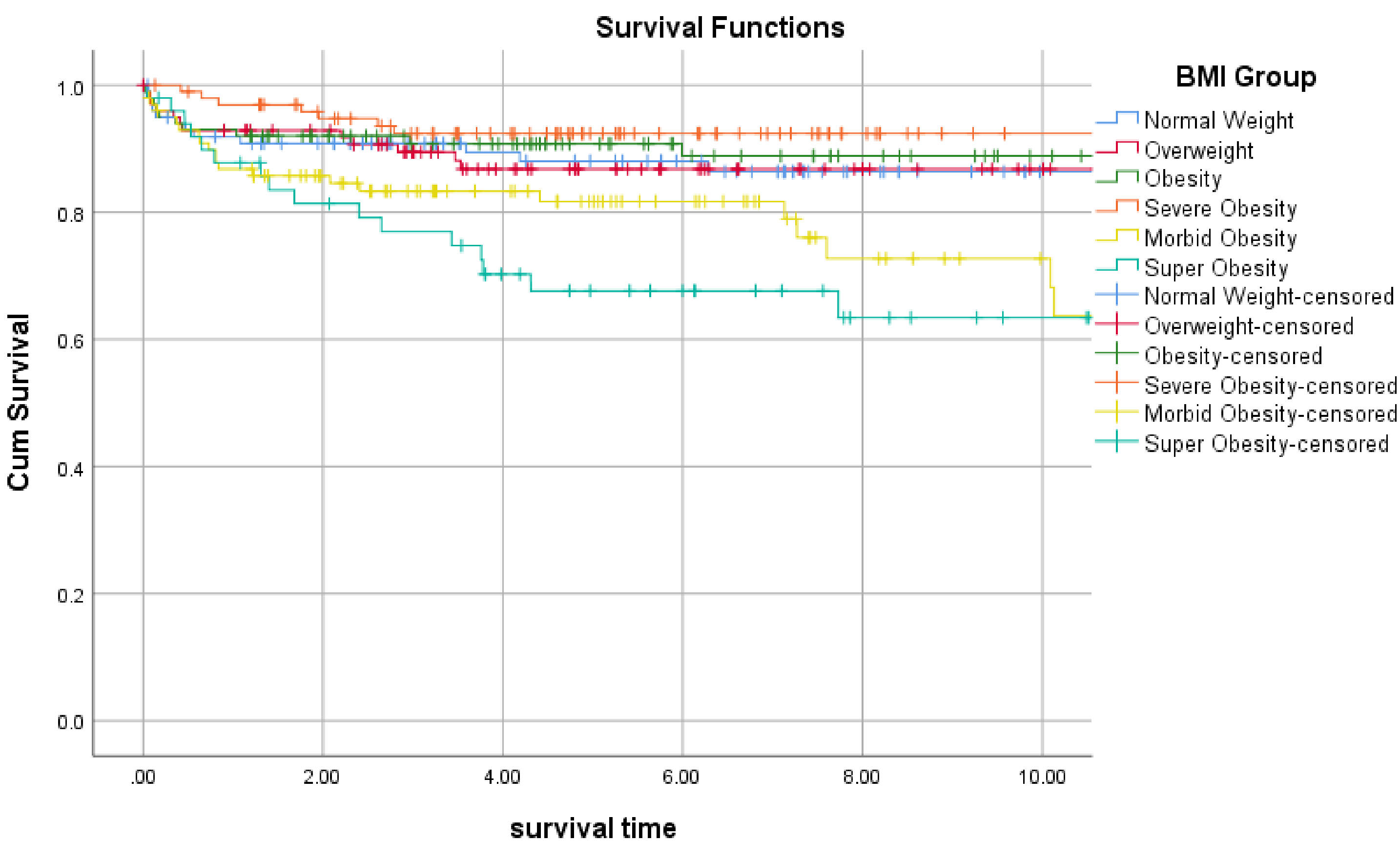

Figure 3.4 Kaplan-Meier Cumulative Survival Curve of the Six BMI Groups

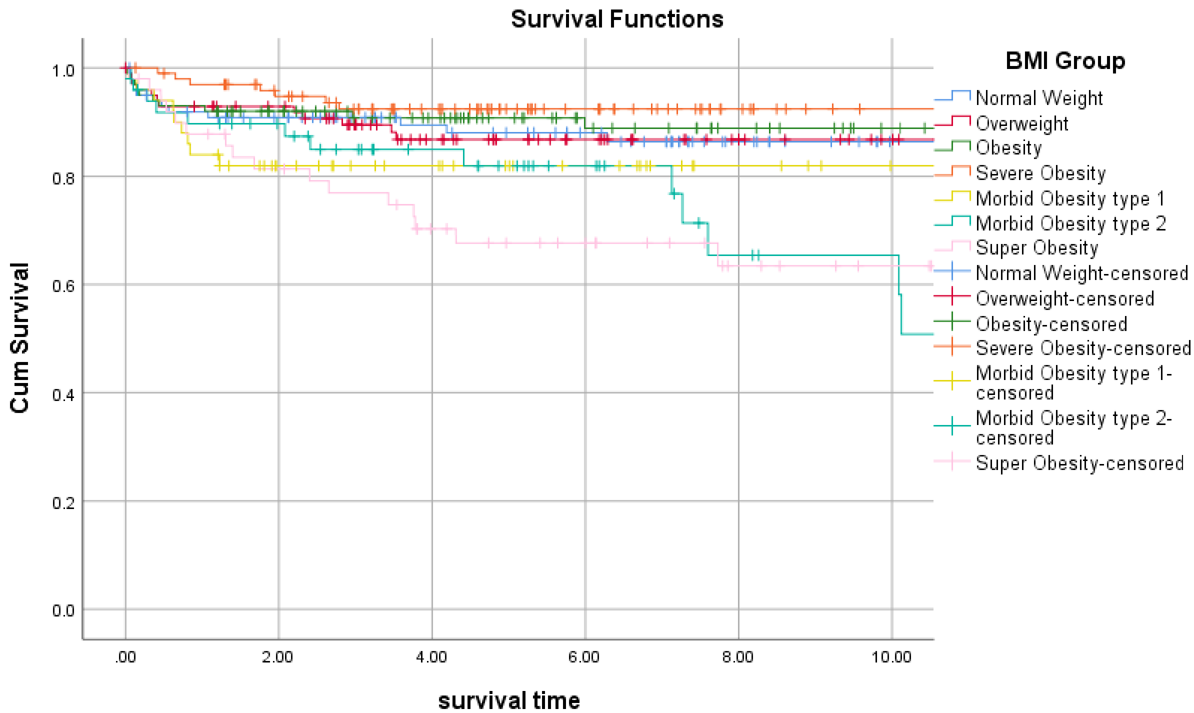

Figure 3.5 Kaplan-Meier Cumulative Survival Curve of the Six BMI Groups with Morbid Obesity Subclassification

3.6. Discussion

Obesity plays a pivotal role in the outcome of RTKA. Treating obesity in a dichotomous fashion, however, is a systematic error, as its effect on RTKA changes across the spectrum of obesity. This is proven in the results displayed above, where the mortality rate and discharge to extended-care facility (ECF) rate are twice as high in super obese patients compared to other patients with less severe obesity. Although it is expected given the worse health status of these patients as shown in the previous chapter (higher ASA class), it remains an alarming result, especially that super obese patients are significantly younger when they present for RTKA. Interestingly, a higher mortality and ECF rate are observed in the normal weight group despite similar age, comorbidity index and health status to other groups. This, perhaps, can be explained by an increase in their frailty, an aging related syndrome of physiological decline. In a systematic review by Schmucker et al., frailty in older adults undergoing TKA was associated with higher-rates of adverse events and lower clinical outcome.[15] Additionally, a prospective observational study by Wang et al. showed that frailty in adults undergoing arthroplasty increases length of stay and the probability of discharge to an extended care facility.[16] Thus, frailty can be considered a variable to be accounted for in future research.

The three postoperative complications that were studied are VTE, superficial infection and deep infection. The rate of VTE is comparable across all BMI cohorts mainly due to the increased dosage of prophylaxis as BMI increases. On the other hand, infection rate is significantly high in super obese patients, confirming the results of Jean et al. and Carter et al.; a third of super obese patients from our cohort developed superficial infection and another third developed deep infection.[12,13] This is reflected on second revision rate, which a third of super obese patients undergo mainly for incision and drainage. Second revision rate is high in morbid obesity too, which 25% undergo for incision and drainage. Although some patients underwent third and fourth revisions, mainly for second-stage procedure or amputation, statistical significance could not be reached between the different cohorts likely due to the low rates of these secondary complications. Consequently, the cumulative survival rate of RTKA among the different BMI cohorts is affected by the extreme higher end of obesity; it is significantly reduced in patients whose BMI ≥45 kg/m^2 to 60% after 8 years, while the cumulative survival of RTKA drops to 80% after 10 years in those whose BMI is <45 kg/m^2, which coincides with the findings of Sisko et al. who reported that morbid obesity increases the rate of re-revision.[14] The fact that super obese patients present at a younger age, in addition to their lower survivorship, puts their overall outcome of RTKA under the spotlight and questions its value.

Subcategorizing morbid obesity to two classes, BMI <45 kg/m^2 and BMI ≥45 kg/m^2, sheds light on the fluidity of obesity's effect on RTKA. We divided this cohort because it had the largest range of BMI compared to other groups and we were interested in identifying another BMI threshold where there is a shift in complication rate. The data suggests that a point of inflection or 'watershed' point exists where morbid obese patients whose BMI ≥45 kg/m^2 have a higher mortality rate, superficial infection rate and deep infection rate, all of which are comparable to the findings of super obese group. The subclassification, however, does not alter the re-revision rate, which remains high in both subsets (22% and 28%), but it affects the survival distribution, aligning morbid obesity type 2 with super obesity.

The limitations of this study stem from its retrospective nature and the inherent limitations that come with this type of study. The outcomes of interest, such as postoperative complications and re-revision could have been attended to in a different institution, which would underestimate our results. Moreover, the variability in follow-up, which is evident by the large number of censored events in the Kaplan-Meier curve, affects the precision of the cumulative survival rates.

Nevertheless, our study remains the first to include a large cohort and subcategorize obesity into its different classes prior to investigating obesity's effect on RTKA. Further, since our institution is the main tertiary center for arthroplasty in our region, the probability of patients presenting with major complications to other institutions is low. Nonetheless, a prospective cohort or randomized trial with predetermined follow-up duration would yield more robust results. Additionally, frailty is a factor that needs to be considered in future investigations.

In conclusion, morbid obesity type 2 and super obesity are risk factors for postoperative infection and mortality and reduce cumulative survival of RTKA to 60% in 10 years. Morbid and super obesity are risk factors for re-revision too. Consequently, patients whose BMI is ≥45 kg/m^2 should be counseled that their RTKA is at risk failure earlier than usual and may require re-revision, mostly as incision and drainage.

3.7. References

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4. Emergency Department Visits, Readmissions, and 90-Day Costs for Revision Total Knee Arthroplasty in Patients with Varying BMI Levels

4.1. Introduction

The concurrent growth of obesity prevalence and demand for revision total knee arthroplasty (RTKA) have pushed for several investigations into the nature of the relationship between them.[1,2] The current estimation is that 25% percent of patients undergoing RTKA are obese, which is at least 4-times more than the proportion of obese patients a decade ago.[3] Additionally, obesity has been shown to be a risk factor for earlier presentation of RTKA, which is a finding that we demonstrated in Chapter 2 among patients whose body mass index (BMI) is ≥40 kg/m^2.[3]

Obesity affects RTKA beyond demographic distribution. It increases the risk of postoperative complications and the rate of re-revision, especially in those whose BMI is ≥40 kg/m^2.[4,5] Moreover, the functional gain post-RTKA is less in morbidly obese patients compared to patients of lower BMI statuses.[6] Our findings in Chapters 2 and 3 show, however, that only morbid and super obesity augment the risk of postoperative prosthetic infection and re-revision rate and reduce the cumulative survival of RTKA. Furthermore, the functional gain post-RTKA was similar across the BMI spectrum, suggesting that RTKA is effective in all patients, regardless of their BMI.

Nevertheless, these results are insufficient to direct healthcare, as many hospitals and surgeons establish a BMI threshold beyond which they do not operate due to the perceived increased costs and the metrics that could damage a hospital's quality profile, such as emergency department (ED) visits and readmissions within 90 days of arthroplasty.[7] Our aim is to explore the effect of the varying obesity classifications on readmissions, ED visits and costs within 90 days of RTKA, as these are factors that contribute to the synthesis of a healthcare policy on RTKA in obese patients.

4.2. Methods

We retrospectively reviewed our institutional database for patients who had undergone RTKA from Dec 2005 to Jan 2020. Patients who had undergone first-stage only were excluded because the majority of them had a static spacer, which prevented them from moving their joint, limiting the functional outcome scores that can be measured. Body Mass Index (BMI) was calculated using patients' height and weight measured preoperatively. Accordingly, the patients were categorized into 6 groups: normal weight (BMI <25 kg/m^2), overweight (BMI 25-29.9 kg/m^2), obesity (BMI 30-34.9 kg/m^2), severe obesity (BMI 35-39.9 kg/m^2), morbid obesity (BMI 40-49.9 kg/m^2) and super obesity (BMI ≥50 kg/m^2). Since the morbid obesity group has the biggest range of BMI among all the categories, we elected to subcategorize it to type I (BMI 40-44.9 kg/m^2) and type II (BMI 45-49.9 kg/m^2) for subgroup-analysis.

We used a sample of convenience based on the number of eligible super obese patients. Fifty super obese patients were identified, while patients from other BMI groups were randomly selected from the entire RTKA cohort in a 2:1 ratio relative to the super obese group. Thus, we had 100 patients in these latter groups and 550 patients in total. Perioperative protocols were the same for all cohorts, except for deep venous thrombosis (DVT) prophylaxis, which was aspirin for those with BMI <40 and low-molecular weight heparin (LMWH) for morbid and super obese patients.

4.3. Outcome Measures

We reviewed patient charts over a 90-day period following their date of surgery. We recorded the surgeon who operated on the patient, equipment needed to setup the operating room (OR) and for anesthesia, American Society of Anesthesiologists (ASA) physical status classification, consignments used in each operation, operating time, medication used to prevent DVT, length of stay (LOS), follow-up visits to the clinic, ED visits and radiography used, readmissions and reoperations. Costs for operating room, length of stay and anesthesia equipment were obtained in 2015 Canadian dollars (CAD) and inflated to 2021 CAD.[8] All other costs were obtained in 2021 CAD. Appendix A lists the costs used in our study.

Ninety-day costs were calculated by summing the costs of first admission for RTKA and any ED visit or readmission within 90 days. The first admission cost was a combination of the costs of consignments, OR setup and use, surgeon charges and follow-up clinic fees, assistant and anesthesia charges, hospital admission, and DVT prophylaxis. ED costs were the summation of ED and x-ray charges, and readmission costs included in-patient charges and reoperation fees similar to those of the first admission.

4.4. Statistical Analysis

The LOS, OR time, rate of ED visits and their costs, rate of readmissions and their costs, first admission costs and 90-day costs were all summarized using the following descriptive statistics: frequencies, modes, means and standard deviation. Categorical variables were compared using either a Chi-squared test or Fisher's exact test. The normality assumption for continuous variables was tested using Shapiro-Wilk test. Normally distributed continuous variables were compared using analysis of variance (ANOVA) and Welch's ANOVA if the assumption of homogeneity of variance was violated as per Levene's test. Non-normally distributed continuous variables were compared using Kruskal-Wallis test. A post-hoc Tukey's and Games-Howell test were performed for variables that showed statistical significance on ANOVA and Welch's ANOVA respectively to identify the specific BMI group comparisons that caused the significance. Statistical significance was set at $p < 0.05$. Data was analyzed using IBM SPSS Statistics 26.

4.5. Results

The average RTKA operating time was 122 ± 42 minutes. The distribution of mean operating time across all BMI cohorts was the same (p=0.114). Table 4.1 describes the types of RTKA that were included in this study. Conversion to hinge was the most time consuming procedure (155 ± 26 minutes), while patellar resurfacing was the least with a mean duration of 61 ± 17 minutes (Figure 4.1). Figure 4.2 displays the distribution of operating time for each type of RTKA across all BMI categories. Among patients whose BMI is <25 kg/m^2, release of adhesions had the shortest duration (55 minutes), and 1.5-stage had the longest (183 minutes). Patellar resurfacing was the shortest procedure for overweight, obese, severely obese, and super obese patients. Polyethylene component exchange and extensor mechanism reconstruction were the shortest procedures for morbidly obese type 1 and type 2 patients respectively. On the other hand, conversion to hinge was the longest procedure for overweight, severely obese, and morbidly obese type 1 patients. Distal femoral reconstruction (DFR), however, consumed time the most in patients with obesity, morbid obesity type 2 and super obesity.

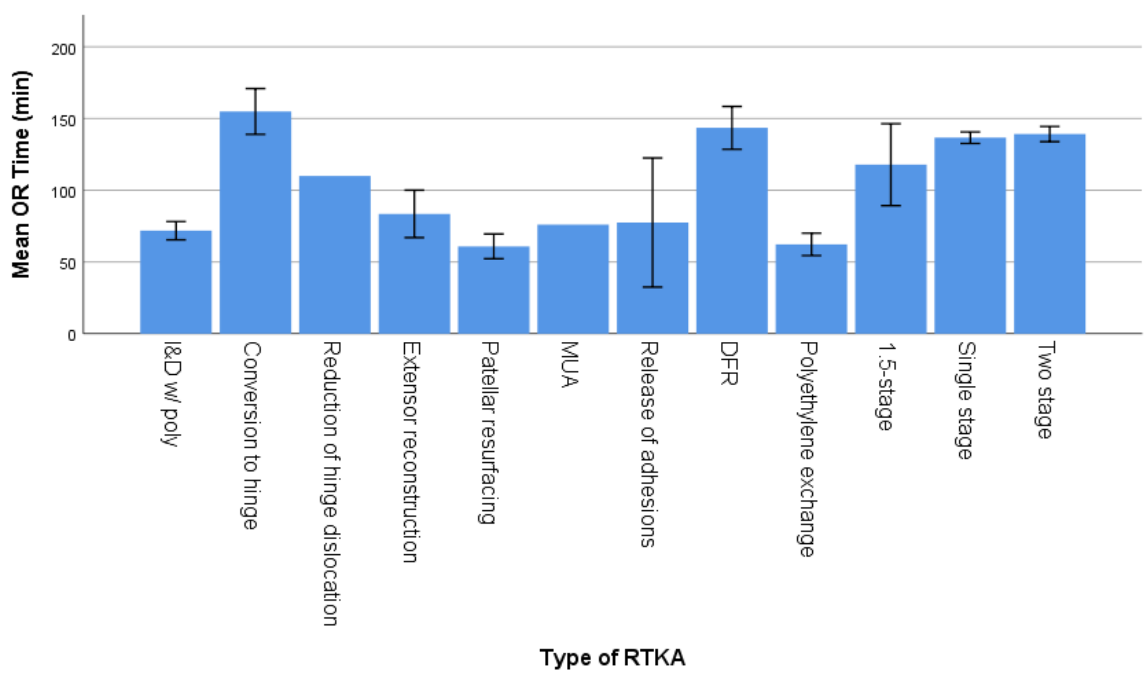

Figure 4.1 Mean OR time for each type of RTKA.

Table 4.1 Types of revision total knee arthroplasty procedures.

RTKA Procedure	
Single-stage	Component retrieval & reconstruction are done in one operation. Used in aseptic component loosening.
All	All components retrieved.
Femoral	Femoral component retrieved only.
Tibial	Tibial component retrieved only.
Two-stage	Component retrieval (stage 1) & reconstruction (stage 2) are done in two separate operations. Used in septic component loosening.
1.5-stage	Femoral component, polyethylene spacer and cement as half-step toward stage 2 or as final step.
Amputation	Above knee amputation (AKA) for life-threatening, incurable infections.
Arthrodesis	Also called knee fusion. The femur and tibia are joined together to eliminate knee joint. Used as last resort for refractory pain.
Bone grafting	Used in aseptic loosening of femoral or tibial component to avoid full revision.
Distal femur replacement (DFR)	Distal femur is replaced with endoprosthesis. Used in severe loosening or periprosthetic fracture due to lack of femoral bone stock or poor bone quality.
Extensor mechanism reconstruction	Repair, reconstruct or reinforce quadriceps tendon and/ or patellar tendon in the setting of extensive mechanism disruption.
Conversion to Hinge	Usually used in cases of collateral ligament deficiency gross flexion-extension gap imbalance, and in cases of severe bone loss. It provides stability at the expense of ROM.
Reduction of hinge dislocation	Urgent open reduction and possible revision of hinge TKA due to high risk of neurovascular compromise.
Incision & drainage with polyethylene exchange (I&D w/ poly)	Polyethylene component is removed followed by tissue debridement. Used in acute infection with no evidence of septic component loosening.

Manipulation under anesthesia	Used in arthrofibrosis, where under muscle relaxation and anesthesia the joint is manipulated until fibrosis is broken.
Open reduction & internal fixation (ORIF) of distal femur	Used in periprosthetic fracture in which the femoral component is stable.
Patellar resurfacing	The articular surface of the patella is replaced with polyethylene dome. Used in anterior knee pain, patellar loosening and patellar maltracking.
Polyethylene component exchange	It is exchanged with bigger size for instability, smaller size for stiffness and similar size if the component is fractured.
Release of adhesions	Used in arthrofibrosis, where the joint is surgically opened, and adhesions are excised.

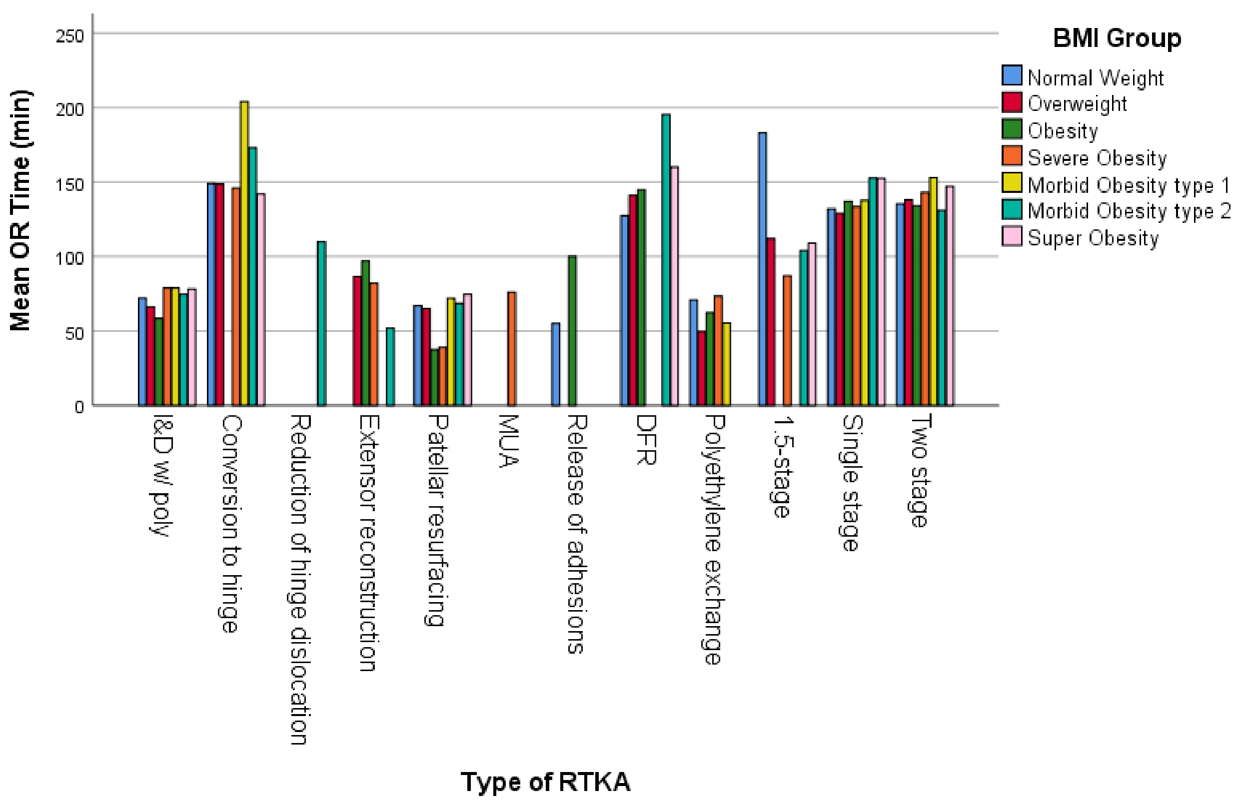

Figure 4.2 The distribution of mean OR time for each type of RTKA categorized by BMI groups.

The average LOS was 4 days. The distribution of LOS across all BMI cohorts had no significant difference (p=0.094). DFR and reduction of hinge dislocation required hospitalization the most (17 and 16 days respectively), while manipulation under anesthesia (MUA) and patellar resurfacing required hospitalization the least (2 and 3 days respectively, Figure 4.3). DFR resulted in the longest LOS in patients who had normal weight, overweight, obesity and super obesity. Extensor mechanism reconstruction caused the longest LOS in patients who were overweight, severely obese, and morbidly obese type 2, while patients who had morbid obesity type 1 were hospitalized the longest after incision and drainage with polyethylene exchange. On the other hand, the procedures that caused the shortest LOS across BMI cohorts were release of adhesions in normal weight patients, polyethylene exchange in morbid obesity type 1, single-stage and second-stage procedures in morbid obesity type 2, and patellar resurfacing in overweight, obese, severely obese, and super obese patients (Figure 4.4).

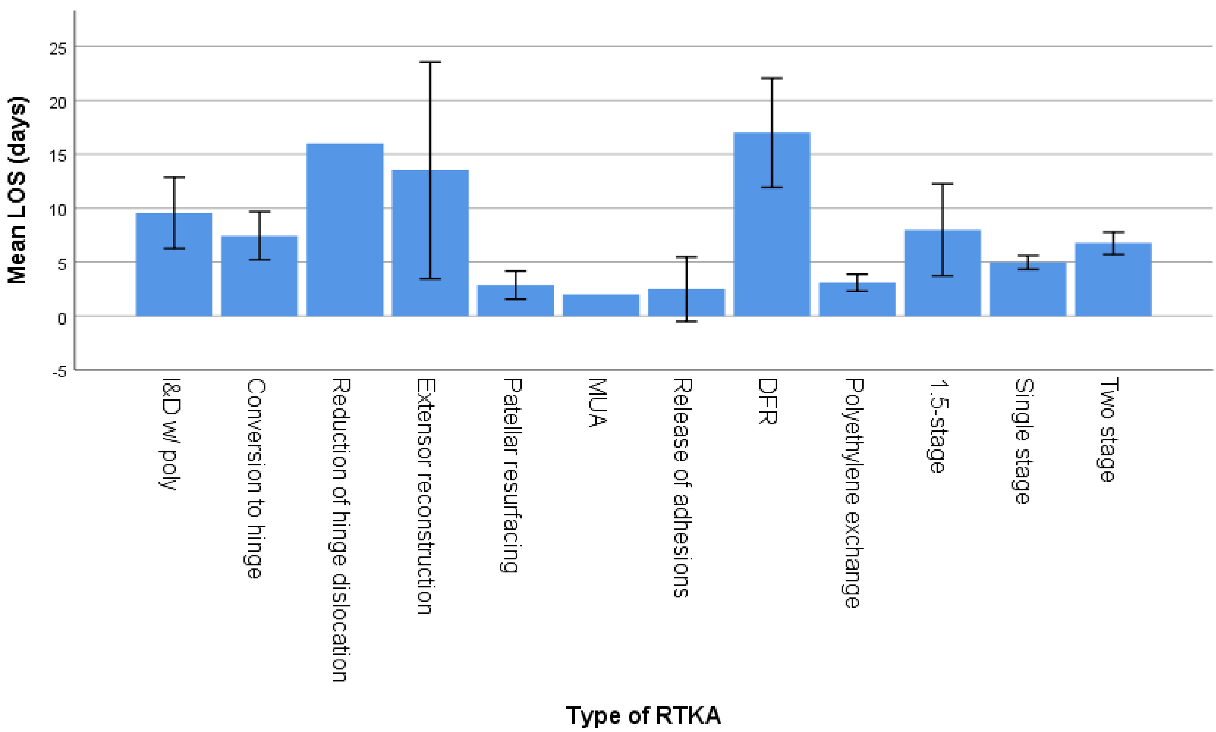

Figure 4.3 Mean LOS for each type of RTKA.

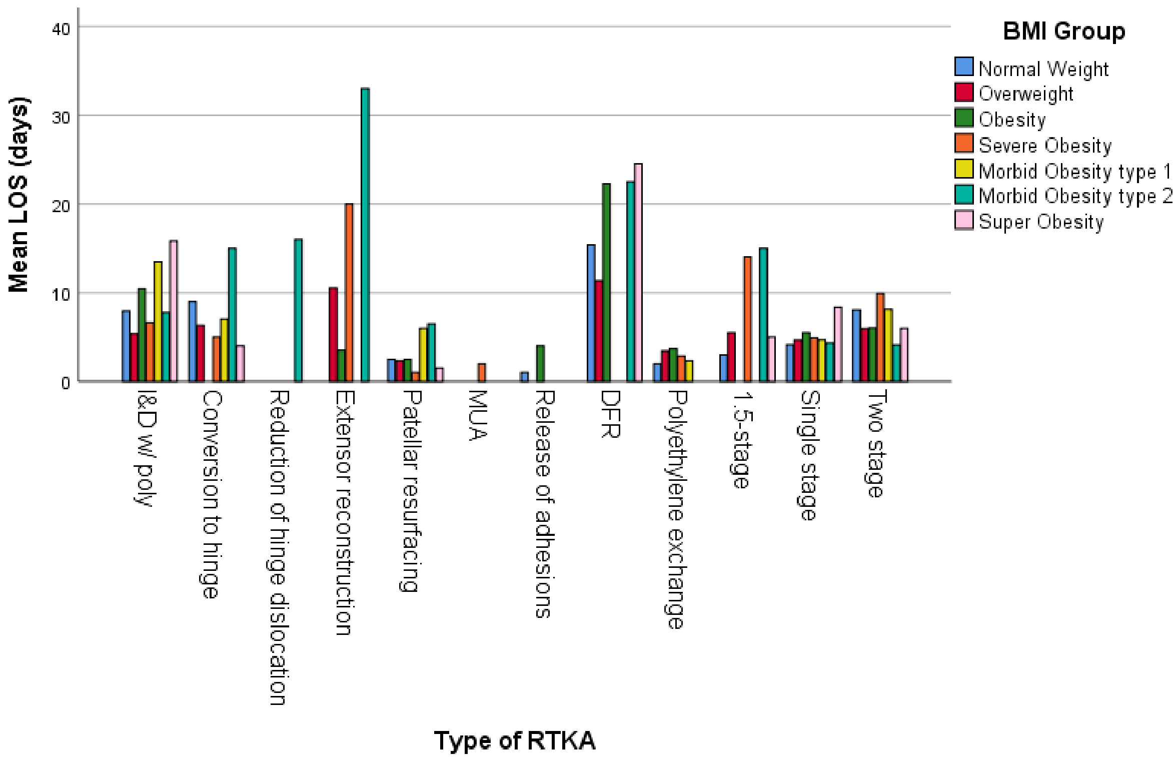

Figure 4.4 The distribution of mean LOS for each type of RTKA categorized by BMI groups.

Nineteen percent of our cohort visited the ED at least once within 90 days of operation. Although super obese patients visited the ED more than average (26%), the difference observed between the six BMI groups was not statistically significant (p= 0.609). Subclassifying morbid obesity into its two subsets did not change the statistical significance. As for readmissions within 90 days of operation, 9% of the cohort was readmitted. The difference in distribution of readmissions across the BMI categories was statistically significant (p= 0.029). Super obese patients were noted to have a higher proportion of readmissions (22%) compared to the remaining cohorts. Subgroup analysis of morbid obesity did not change the difference in distribution between BMI cohorts.

The mean average costs of first admission, ED visit and readmission were CAD 15708 ± 6895, 99 ± 225 and 1003 ± 4492, while the mean 90-day cost was CAD 16810 ± 8735. The mean surgical consignment cost was CAD 4585 ± 2724. The major contributor to the 90-day cost was the first admission cost. Figure 4.5 presents the distribution of these two costs across the six BMI categories. The differences observed among the BMI cohorts in surgical consignment costs, first admission costs, ED costs and readmission costs were not statistically significant (p=0.261, 0.063, 0.855 and 0.163 respectively). However, we demonstrated a difference in the 90-day costs of the six BMI cohorts (p=0.011, Table 4.2).

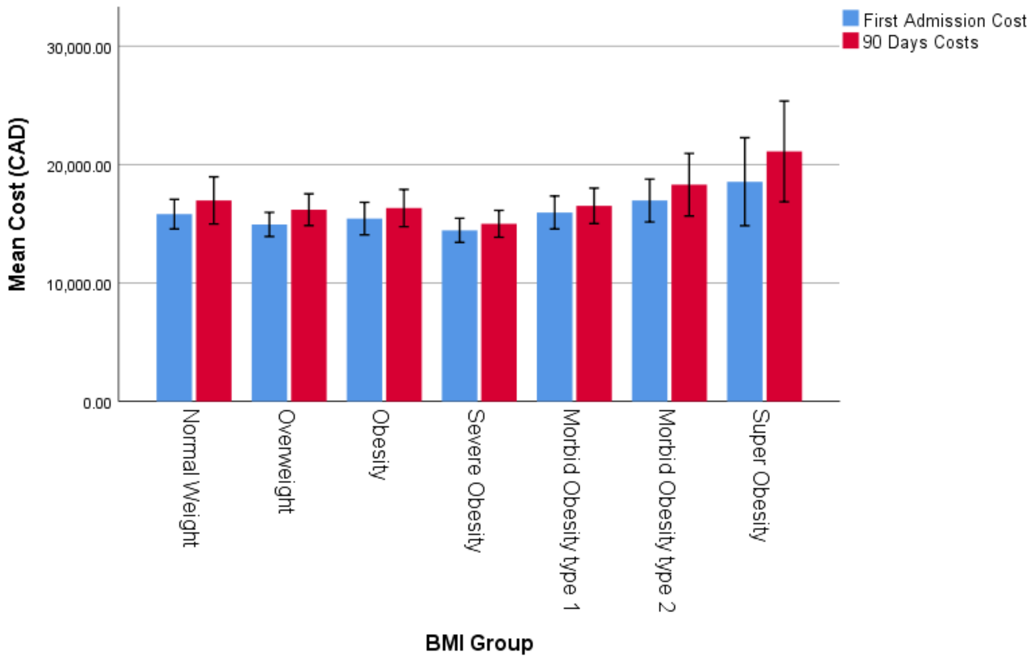

Figure 4.5 Distribution of first admission costs and 90-day costs across BMI categories.

The 90-day costs of the super obese cohort were significantly different from the costs of normal weight, overweight, obese, and severely obese (p-values=0.022, 0.038, 0.018 and 0.001 respectively). The 90-day costs of the morbid obesity cohort were significantly different from the costs of severe obesity only (p= 0.006). Subgroup analysis of morbid obesity did not change the significance observed.

Table 4.2 90-day costs of RTKA across BMI categories.

BMI Group	90-Day Cost (CAD)
Mean	*16,810 ± 8735*
Normal weight	16973 ± 10019
Overweight	16190 ± 6744

Obesity	16327 ± 7913
Severe Obesity	14998 ± 5717
Morbid Obesity	17408 ± 7570
BMI <45 kg/m^2	16517 ± 5261
BMI ≥45 kg/m^2	18300 ± 9299
Super Obesity	21113 ± 14974

4.6. Discussion

The relationship between obesity and RTKA transcends clinical outcome and leaves an imprint on health economics, healthcare policy and quality control of the medical industry. This is due to the effect of obesity on RTKA costs and metrics that are used to assess a hospital or surgeon's quality, such as postoperative ED visits and readmissions. The outcome of these assist in shaping healthcare and insurance policies regarding RTKA; some patients may not be offered RTKA or get covered financially beyond a certain BMI if it proves disadvantageous to stakeholders excluding the patient. The aim of this study was to evaluate this complex field in an evidence-based approach.

The average operating time and LOS after RTKA was similar across all BMI cohorts, which suggests that patients of higher BMI have a similar operative profile to those at the lower end of the spectrum. This is further suggested in the similar surgical consignment cost across all BMI cohorts, which imply that the surgical complexity did not differ between the patients. The similarity continues post discharge, where 1 out of 5 RTKA patients is expected to visit the ED at least once within 90 days of procedure regardless of their BMI. The similarity in these results is highlighted by the lack of significant difference in the first admission costs, which include those of the operation, and ED costs among the multiple BMI cohorts. Readmission, on the other hand, is at least twice as much in super obese patients compared to other cohorts, which is expected considering the increased risk of postoperative complications and reoperation in this group as proven in Chapter 3. Consequently, the increased readmission rate drives the increased total costs of RTKA in super obese patients, despite a similar fiscal profile in the initial admission.

Our results differ from those obtained by Kremers et al., whose study showed persistently growing RTKA costs in patients with BMI beyond 30 kg/m^2; every 5-unit increase in BMI was associated with USD 600 to 650 higher hospitalization costs.[9] Interestingly, our findings mirror the work of Ponnusamy et al., whose study on primary TKA showed increased costs in super obese patients driven by readmissions.[10] Our results differ, however, in the morbidly obese group; we found no difference between morbid obesity and other groups of lower BMI, while Ponnusamy et al. found statistically significant difference in total costs of primary TKA between morbid obesity and other categories.

Our study has shown that super obesity increases the rate of readmissions and subsequently 90-day costs by 25%. The limitations of our results are those of any retrospective study, in which the outcomes measured could have been missed or lost to follow-up. However, since our institution is the regional tertiary arthroplasty center, the impact of this limitation remains minimal. Nevertheless, a prospective study of larger sample size can yield more robust results. Despite these shortcomings, our study is the largest so far to look into the costs of RTKA while evaluating the subcategories of obesity. It is vital to highlight that our findings are not sufficient to build a policy yet; although the costs of RTKA in super obese patients are higher, a prospective study is needed in which the cost-effectiveness of RTKA is assessed against conservative management across the subclasses of obesity. It is important to note, that unlike primary TKA, RTKA is often necessary, especially in the face of aseptic or septic loosening of the prothesis, where non-operative treatment is ineffective.

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5. Conclusion

5.1. Rationale for the Study

Obesity is a worldwide pandemic that is affecting all medical and surgical fields, including arthroplasty.[1-7] The higher perceived post-arthroplasty complication rate imparted by obesity has led many surgeons to place an arbitrary threshold above which they do not operate electively.[8,9] The reason behind such decisions, in part, is the impact of complication rate and other quality metrics on the rating of both the surgeons and hospitals, which, in some cases, in turn limit their funding by healthcare payers. Consequentially, patients may lose their access to long-term benefits of arthroplasty due to perceived higher complication rate and costs on the short term based on a BMI threshold that is placed arbitrarily. Although this situation affects both primary and revision total knee arthroplasty (TKA), there has been an increasing number of studies targeting the relationship between obesity and primary TKA from a clinical and economic point of view.[8,9] On the contrary, RTKA is yet to be studied extensively, despite increased reluctance to revise an arthroplasty that has possibly failed due to obesity.

The current literature on RTKA and obesity indicates that obesity is a risk factor for postoperative complications and reoperation, which in turn would increase the costs of treatment.[10-13] Unfortunately, obesity has been treated in those studies as a single entity with a minor proportion looking into morbid obesity (BMI 40-49.9 kg/m^2). Not only does this attitude simplify the dynamic effect of obesity on healthcare, but it also implies that those whose BMI is ≥50 kg/m^2 are excluded from research and arthroplasty a priori due to the perceived negative impact of their weight on the outcome.

Consequently, we decided to approach this study by examining a larger number of patients than previously studied and dissect obesity into four classes based on bariatrics literature, ending up with a total of 6 classes to study.[14] We carried out a retrospective analysis, in which our primary outcomes were functional outcome scores post RTKA, survivorship of RTKA and 90-day costs.

Secondary outcomes included indication for RTKA, type of RTKA, complication rate and readmission rate.

5.2. Summary of Findings

In Chapter 2, we found out that morbid and super obesity cause patients to present for RTKA at a younger age and with poorer health status. Additionally, the indication for RTKA in super obese patients is most commonly septic loosening, resulting in more second-stage operations. Patients of other BMI categories, on the other hand, present most commonly with aseptic loosening, and their most common RTKA is single-stage procedure. Importantly, RTKA improves quality of life and functionality of all patients equally regardless of their BMI.

In Chapter 3, our results showed that super obesity and morbid obesity class 2 (BMI 45 – 49.9) increase the risk of postoperative infection and mortality. Moreover, the survival of RTKA in morbid and super obese patients is less, hence they are more likely to require a second revision. The most common procedure in the second revision is incision and drainage due to acute infection, which in some cases may lead to a second-stage procedure or amputation in a third or even fourth revision.

Finally, in Chapter 4, our findings indicate that only super obese patients are at risk of higher readmission rate postoperatively. While the costs of the initial admission for RTKA are similar across all BMI cohorts, the increased readmission rate of super obese patients results in 25% higher costs in the first 90 days after surgery, while other obesity classes have similar healthcare costs when compared with their nonobese counterparts.

5.3. Challenges

Our challenges arise from the nature of this study, which is a retrospective cohort and the inherent limitations of such a study. Initially, we were confined to the available number of super obese patients in our database, based on which we gathered a sample of convenience. Although patients were selected randomly, the size of our sample remains relatively small to draw conclusions confidently and the possibility of selection bias exists. The retrospective nature of the study introduces information bias as well, since we were dependent on what was recorded over 20 years, which may not have been as accurate. Lastly, we faced a challenge in assessing functionality, as most patients in the cohort did not have preoperative, postoperative or both functional outcome scores, and those who had them had their scores measured at different time intervals, which may have over- or underestimated our findings.

5.4. Future Studies

Our study demonstrated the benefits of RTKA for all obese patients, while highlighting that only those at the higher end of the BMI spectrum are at an increased risk of complications and may result in higher treatment costs. Nevertheless, a well-designed, prospective study with fixed time intervals, in which all functional outcome scores and costs are obtained accurately, is needed to validate our findings and present them confidently. Moreover, the increased costs of RTKA in super obese patients does not necessarily mean that RTKA is disadvantageous economically; instead, a cost-effectiveness study is needed, in which RTKA is compared to medical and conservative management in those patients prior to concluding the economic effect of obesity on RTKA. Nevertheless, we can assume that RTKA is cost-effective in situations like infection and loosening, as non-operative measures are ineffective.

5.5. Clinical Implications

Our study demonstrates that the clinical and functional gain after RTKA is similar across all BMI cohorts, while the increased complications and costs are limited to the high end of the BMI spectrum. Thus, we hope that this work would shift surgeons' perspective to provide patients, who were previously denied RTKA due to their obesity, surgical treatment while understanding the increased costs involved.

5.6. References

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Appendices

Appendix A: List of unit costs in Canadian dollars.

N46	**MUSCULOSKELETAL SYSTEM SURGICAL PROCEDURES**			
KNEE				
		ASST	**SURG**	**ANAE**
	ARTHROPLASTY			
#E564	Revision of arthroplasty Add 35%			
#R509	Patellar arthroplasty	6	241.60	7
#R441	Total replacement / both compartments	8	619.90	8
#R248	Total knee replacement with take down of fusion	8	838.00	8
#R244	Revision total arthroplasty knee	8	1174.3 0	8
#E598	with associated patellar replacement or patelloplasty, to R482, R483, R441, R248 or R244 ---- add		94.60	

Schedule of Benefits - Physician Services under the Health Insurance Act
February 11, 2021 (Effective March 14, 2021)

2021 UNIT COSTS FROM ADMINSTRATIVE DATA	
ITEM	**COSTS**
INPATIENT	
* Hospital Costs (per day)	$746.88/day
* Average consults	$87.61
Knee X-Ray	$97.8
DVT PPX Costs	$0.07/ dose for aspirin 39.70/ unit
OPERATING ROOM	
* OR Time (per min)	$17.92/min
* Anesthesia Equipment	$298.93
Revision Knee Disposables	$ 1500 including 3 cements
Tobramycin Antibiotic Vial	$50
Vancomycin Antbiotic Vial	$ 5
Tobramycin Cement/Box	$ 140
ER admission fee	$304.25

* Obtained from 2015 and inflated using the inflation calculator of Bank of Canada
Administrative data for 2021

How Costs were calculated for every patient?
***Index revision cost*+ER Total cost+ Readmission cost RE**

Index revision cost = consignment costs + OR setup costs + DVT PPX costs + Total OR time cost (OR time * OR time cost) + Total LOS cost (LOS * LOS stay cost) + Surgeon charges + Follow up fees + Anesthesia equipment fees + Assistant charges(basic+ time adjusted)+ Anesthesiology charges(basic+ time adjusted+ BMI adjusted+ ASA adjusted)

ER Total cost = ER cost + X-Ray cost

Readmission cost RE = consignment costs RE+ OR setup costs RE + DVT PPX costs RE+ Total OR cost RE (OR time * OR time cost) + Total LOS cost RE (LOS * LOS stay cost) + Surgeon charges RE+ Follow up fees RE+ Anesthesia equipment fees RE +Assistant charges (basic+ time adjusted) + Anesthesiology charges (basic+ time adjusted+ BMI adjusted+ ASA adjusted)

ASSISTING AT SURGERY AND ANAESTHESIA TIME UNITS TABLE

Time in Minutes [Hours]		Assistant Time Units for Billing	Anaesthesia Time Units for Billing
0-15		1	1
>15-30		2	2
>30-45		3	3
>45-60		4	4
>60-75	[>1h – 1h 15m]	6	6
>75-90	[>1h 15m – 1h 30m]	8	8
>90-105	[>1h 30m – 1h 45m]	10	11
>105-120	[>1h 45m – 2h]	12	14
>120-135	[>2h – 2h 15m]	14	17
>135-150	[>2h 15m – 2h 30m]	16	20
>150-165	[>2h 30m – 2h 45m]	19	23
>165-180	[>2h 45m – 3h]	22	26
>180-195	[>3h – 3h 15m]	25	29
>195-210	[>3h 15m – 3h 30m]	28	32
>210-225	[>3h 30m – 3h 45m]	31	35
>225-240	[>3h 45m – 4h]	34	38
>240-255	[>4h – 4h 15m]	37	41
>255-270	[>4h 15m – 4h 30m]	40	44
>270-285	[>4h 30m – 4h 45m]	43	47
>285-300	[>4h 45m – 5h]	46	50
>300-315	[>5h – 5h 15m]	49	53
>315-330	[>5h 15m – 5h 30m]	52	56
>330-345	[>5h 30m – 5h 45m]	55	59
>345-360	[>5h 45m – 6h]	58	62
>360-375	[>6h – 6h 15m]	61	65
>375-390	[>6h 15m – 6h 30m]	64	68
>390-405	[>6h 30m – 6h 45m]	67	71
>405-420	[>6h 45m – 7h]	70	74
>420-435	[>7h – 7h 15m]	73	77
>435-450	[>7h 15m – 7h 30m]	76	80
>450-465	[>7h 30m – 7h 45m]	79	83
>465-480	[>7h 45m – 8h]	82	86

ANAESTHESIOLOGISTS' SERVICES

EXTRA UNITS

Extra Units: An amount is payable for extra units in addition to basic units when an anaesthesiologist administers an anaesthetic to:

Fee code	Criteria	Number of extra units
E021C	premature *newborn* less than 37 *weeks* gestational age	9 units
E014C	*newborn* to 28 days	5 units
E009C	*infant* from 29 days to 1 year of age	4 units
E019C	*infant* or *child* from 1 year to 8 years of age inclusive	2 units
E007C	*adult* aged from 70 to 79 years, inclusive	1 unit
E018C	*adult* aged 80 years and older	3 units
E010C	patient with *body mass index (BMI)* > 40	2 units
E011C	patient in prone position during surgery	4 units
E024C	patient in sitting position during surgery, greater than 60 degrees upright	4 units
E025C	unanticipated massive transfusion – transfusion of at least one blood volume of red blood cells	10 units
E012C	patient who is known to have malignant hyperthermia or there is a strong suspicion of susceptibility, and the anaesthetic requires full malignant hyperthermia set up and management	5 units
E022C	ASA III - patient with severe systemic disease limiting activity but not incapacitating	2 units
E017C	ASA IV – patient with incapacitating systemic disease that is a constant threat to life	10 units
E016C	ASA V – moribund patient not expected to live 24 hours *with or without* operation	20 units
E020C	ASA E - patient undergoing anaesthesia for emergency surgery which commences within 24 hours of operating room booking, to E022C, E017C or E016C	4 units

Curriculum Vitae

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