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Pre-operative and Post-operative Weight Trends of Total Joint Arthroplasty  
Patients and Outcomes Associated with Weight Change

A Dissertation submitted in partial satisfaction of the requirements for the degree Doctor  
of Philosophy

in

Public Health (Epidemiology)

by

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2013



The Dissertation of Maria Carolina Secorun Inacio is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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Chair

University of California, San Diego

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2013

## DEDICATION

To my friends, family, and co-workers who supported me throughout the process. A special thank you to my mentor and friend Elizabeth W. Paxton for her encouragement and support in the last few years.

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## LIST OF ABBREVIATIONS

ANOVA, Analysis of Variance

BMI, Body Mass Index

CDC, Centers for Disease and Control and Prevention

CI, Confidence Interval

EHR, Electronic Health Record

FDA, Food and Drug Administration

IHS, Integrated Healthcare System

KP, Kaiser Permanente

NHANES, National Health and Nutritional Examination Survey

OR, Odds Ratio

SSI, Surgical Site Infection

THA, Total Hip Arthroplasty

TJA, Total Joint Arthroplasty

TJRR, Total Joint Replacement Registry

TKA, Total Knee Arthroplasty

US, United States

WHO, World Health Organization

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Chapter 2, in full, has been submitted for publication of the materials as it may appear in The Bone and Joint Journal. Inacio, Maria C.S.; Kritz-Silverstein, Donna; Raman, Rema; Macera, Caroline A.; Nichols, Jeanne F.; Shaffer, Richard A.; Fithian, Donald C. Pre- and Post-Operative Weight Patterns of Total Joint Arthroplasty Patients and Characteristics Associated with Weight Change. The dissertation author was the primary investigator and author of this paper.

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Readmission After Total Joint Arthroplasty. The dissertation author was the primary investigator and author of this paper.

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## ABSTRACT OF THE DISSERTATION

Pre-operative and Post-operative Weight Trends of Total Joint Arthroplasty  
Patients and Outcomes Associated with Weight Change

by

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Doctor of Philosophy in Public Health (Epidemiology)

University of California, San Diego, 2013  
San Diego State University, 2013

Professor Donna Kritz-Silverstein, Chair

Little is known about pre- and post-operative weight changes in patients undergoing total joint arthroplasty (TJA). While intra-operative body mass index (BMI) is associated with higher risk of surgical site infections (SSI) and readmission rates post-TJA no studies evaluate the impact of non-surgical pre-operative weight loss and post-operative weight maintenance on risk of these outcomes. This study describes weight changes of patients undergoing TJA, evaluates characteristics associated with weight patterns one year pre- and post-TJA. Additionally, it evaluates whether pre-operative weight loss (5% change) and maintenance post-operatively is associated with SSI and readmission risk post-surgery.

A cohort of primary TJAs (total hip arthroplasty (THA) and total knee arthroplasty (TKA)) performed between 01/01/2008 and 12/31/2010 was identified using a Total Joint Replacement Registry (TJRR). Using electronic medical records weight from one year pre- through one year post-TJA patients were categorized into: gainers (increased weight by 5%), losers (decreased by 5%), remained the same (changed of <5%). Patients were characterized by gender, age, race, health status, and co-morbidities. Endpoints, SSI (deep and superficial) and 90 day readmissions, were ascertained prospectively by the TJRR.

In 30632 TJAs (10572 THAs and 20060 TKAs) most remained the same weight during the year prior (71.5% THAs and 75.7% TKAs) and year after (64.0% THAs and 68.5% TKAs) the procedure. Women, younger patients, Blacks, and those with certain co-morbidities were more susceptible to weight change pre- and post-TJA. Among obese ( $BMI \geq 30 \text{ kg/m}^2$ ) patients (4066 THAs and 10718 TKAs), few (18.0% THAs and 12.4% TKAs) lost weight prior to TJA or became (6% THA, 3% TKAs) non-obese ( $BMI < 30 \text{ kg/m}^2$ ). A significant reduction in risk of SSI and readmission in those who lost 5% of their body weight prior to their TJA procedure was not observed. In obese THA patients who lose weight pre-operatively and keep it off post-operatively (N=444), the likelihood of deep SSI (odds ratio (OR)=3.77, 95% CI 1.59-8.95) is higher than in patients who stayed the same weight. Obese TKA patients who lost weight and kept it off post-operatively (N=937) were at a higher likelihood of readmission (OR=1.63, 95%CI 1.16, 2.28) than those who remained the same weight.

## CHAPTER 1.

### Background and Significance/Research Objectives

### *Obesity*

According to the World Health Organization (WHO), adults with a body mass index (BMI) between 18.5 and 25 kg/m<sup>2</sup> are considered within normal weight range, those between 25-30kg/m<sup>2</sup> are overweight, and those greater than 30 kg/m<sup>2</sup> are obese.<sup>1</sup> The prevalence of obesity in the United States (US) and across the world have increased to such an extent that it is now referred to as epidemic or even pandemic. According to the 2008 National Health and Nutritional Examination Survey (NHANES), carried out by the US Centers for Disease Control and Prevention (CDC) the estimated prevalence of overweight in the US population is 68%, and obese 34%.<sup>2</sup> If these figures are not already of concern, projections based on NHANES data suggest that by 2048 all women in the US will be overweight and by 2084 all women will be obese, with men just a few years behind.<sup>3</sup> While 2084 may seem distant from 2013, the progression is occurring rapidly, with 74% of the population expected to reach overweight status and 40% expected to reach obesity levels by 2015, a mere two years away from the time of this study presentation.<sup>4</sup>

### *Obesity and Osteoarthritis*

Osteoarthritis is a common degenerative condition in older adults. Usually it is caused by normal wear and tear brought on by age. Osteoarthritis causes soft tissues around major joints to become damaged and eventually leads to pain and stiffness. It is estimated that 47 million Americans live with arthritis today, and of those, 27 million have clinical osteoarthritis.<sup>5, 6</sup> By 2030, 67 million are expected to have the disease if the progression rates of obesity and other co-morbidities remain unchanged.<sup>7</sup>

Obesity is one of the main risk factors for osteoarthritis.<sup>8,9</sup> A large body of literature<sup>8,10,11</sup> has quantified this association and shows that obesity impacts not only the prevalence of osteoarthritis but possibly the progression of certain types of arthritis.<sup>8,12,13</sup> While the exact biological mechanism (biomechanical or metabolic) of how obesity is associated with incidence of osteoarthritis is not fully explained by the current literature, the biomechanical component has the strongest evidence for large joint osteoarthritis.<sup>14</sup> Recent studies suggest that if weight trends were reversed to those estimated to exist only 10 years ago, 1.9% (over 100,000 procedures) of the current total knee arthroplasties (TKA) (treatment for the most severe form of knee arthritis) performed in 50-84 year old US citizens could be avoided.<sup>2,15</sup>

#### *Obesity, Osteoarthritis and Total Joint Arthroplasty*

It is estimated that 4.2% of adults over the age of 50 in the US have a TKA.<sup>16</sup> In 2009 alone 1,124,000 total joint arthroplasty (TJA) procedures were performed.<sup>17</sup> As with obesity, the incidence of TJA (specifically total knee and total hip arthroplasty) has dramatically increased in the last two decades in this country.<sup>18,19</sup> Younger patients were disproportionately impacted by these increases. In 1993, patients younger than 65 years olds were only 25-32% of the primary or revision TJA cases in the US and in 2006 they were 40-46% of the cases.<sup>19</sup> The increase incidence of procedures is expected to continue. According to Kurtz et al., by 2030, the incidence of total hip arthroplasties (THA) surgery will increase by 174% and for TKAs 673% compared to 2005 figures.<sup>20</sup> This increase, especially in younger patients, is largely

due to the increase in obesity prevalence in the US population. Early adulthood and middle age high BMIs, as well as persistent overweight, are associated with risk of having a TJA later in life<sup>21</sup> and obesity has also been found to decrease the age at which patients have TJA procedures on average by 10 years in hips and 13 years in knee patients.<sup>22</sup>

Little is known about the pre-operative weight patterns of TJA patients and studies of their post-operative patterns have yielded inconsistent findings. No studies have evaluated the prevalence of weight loss or gain pre-operatively in a nationally representative sample of TJA patients. Two studies, one in THAs and one in TKAs, suggested that patients' pre-operative weight loss is associated with increased risk of post-operative weight gain; but the actual prevalence of patients losing and gaining weight was not reported.<sup>23, 24</sup> A recent literature review, reports post-operatively 11-49% of TJA patients lose at least 5% of their body weight, but these findings are from small, non-representative samples of TJA patients from mostly low quality studies.<sup>25</sup> Since this literature review, two new studies have evaluated THA and TKA patients' weight post-operatively and both report a significant portion of patients gain weight post-operatively, compared to a control group of non TJA patients. TJA patients may be at a higher risk of clinically significant weight gain. Characterization of a nationally representative cohort of TJA patients and their pre-operative patterns is highly desirable and could assist in the targeting of weight loss interventions and patient optimization efforts.

### *Obesity, Total Joint Arthroplasty, and Post-operative Complications*

Patient characteristics, such as obesity and its related co-morbid conditions, are important risk factors for the incidence of TJA, as well as indicators of the outcome of these procedures. The outcomes of TJA that are important to consider when evaluating TJA success are survivorship of the implant and complications involved with the procedure (such as surgical site infection (SSI), thromboembolic events, and service utilization resulting from complications).<sup>26, 27</sup>

In both TKAs<sup>28-32</sup> and THAs,<sup>29, 32, 33</sup> obesity is strongly associated with risk of SSI. Obesity related conditions, such as diabetes, have also been associated with higher SSI incidence after TJA and other wound complications.<sup>30, 33-36</sup> After surgery, rehabilitation can be more challenging for a heavier patient with other co-morbidities, such as osteoarthritis in the other joints, diabetes, or respiratory conditions and can cause higher post-operative complications resulting in higher resource utilization such as readmissions.<sup>26, 37-39</sup>

Because lower intra-operative BMI is associated with fewer SSIs and readmissions, one would expect weight loss prior to TJA to be associated with a decrease in complications but few studies have quantified the impact of weight loss in TJA procedure outcomes. Only three studies, all of which included only patients who underwent surgically induced weight loss, evaluated the post-operative TJA outcomes of patients who lost weight prior to surgery.<sup>40-42</sup> All three studies were small, with the largest having 88 patients undergoing pre-operative surgically induced weight loss, and included mostly patients who at time of surgery were still mostly obese. These studies found that while there was a benefit in certain circumstances to having the

surgical weight loss procedure the incidence of complications was still very high in these cohorts of patients when compared to historical TJA cohorts. These studies did not evaluate the amount of weight loss and its association with the complications evaluated. Furthermore, these studies were descriptive, providing little insight in the complicated relationship between obesity and other co-morbid conditions and the outcomes evaluated.

Because no nationally representative sample of TJA patients has been evaluated in regard to their weight trends pre- and post-TJA, little is known about the prevalence of weight loss or gain during both pre and post-operative periods. The National Weight Control Registry<sup>43</sup> has found that medical triggers can lead to successful weight loss and maintenance,<sup>44</sup> especially in older adults.<sup>45</sup> It is likely that the “teachable moment” opportunity does present itself during TJA pre-operative counseling and this assists with a certain amount of weight loss by patients who are in need. Additionally, the characteristics of patients who are susceptible to weight change pre- and post-operatively are of interest to the community of providers who serve this rapidly growing segment of patients. Finally, the proposed benefits of weight loss pre-operatively and maintenance post-operatively have not been evaluated and could provide insight into the amount of benefit expected from non-surgical weight loss in obese patients.

### *Objectives*

Using data from a large integrated healthcare system in California, which had not previously been used for evaluation of weight patterns and their association with



risk of peri-operative complications in TJA patients, this dissertation had three main objectives:

- (1) To describe the one year pre- and post-operative weight patterns of patients undergoing primary THA and TKA and to evaluate patient characteristics (age, gender, and race) associated with different weight patterns pre and post-TJA.
- (2) To characterize a cohort of obese primary THA and TKA patients according to their demographic characteristics (age, gender, race) and co-morbidities (using the Elixhauser comorbidity algorithm),<sup>46</sup> and to evaluate whether a clinically significant amount of pre-operative weight loss (defined as a 5% decrease in body weight)<sup>47</sup> is associated with a decreased risk of SSI and ninety day readmission post-surgery.
- (3) To characterize a cohort of obese patients who underwent primary THA and TKA patients and lost a non-surgically induced clinically significant amount of weight (defined as a  $\geq 5\%$  decrease in body weight)<sup>47</sup> prior to their procedure and kept it off post-operatively according to their demographic characteristics (age, gender, race) and co-morbidities (using the Elixhauser co-morbidity algorithm),<sup>46</sup> and to estimate whether these patients are at a lower likelihood of SSI and readmissions within ninety days than patients who remained the same weight one year pre and post-TJA.

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## CHAPTER 2.

### Pre- and Post-Operative Weight Patterns of Total Joint Arthroplasty Patients and Characteristics Associated with Weight Change

## ABSTRACT

**Objective:** This study describes the pre- and post-operative weight patterns of patients undergoing total joint arthroplasty (TJA) and evaluates patient characteristics associated with different weight patterns.

**Methods:** A cohort of primary TJAs (total hip arthroplasty (THA) and total knee arthroplasty (TKA)) performed from 01/01/2008-12/31/2010 was identified. Using weight from patient encounters TJA patients were categorized into: gainers (increased weight by 5%), losers (decreased weight by 5%), remained the same (changed <5%) for the pre- and post-operative periods. Patients were characterized according to gender, age, and race.

**Results:** A sample of 30632 TJAs was identified; composed of 34.5% (n=10572) THAs and 65.5% (n=20060) TKAs. The majority of THA and TKA remained the same weight during the year prior to their procedure (71.5% and 75.7% respectively) and during the year after the procedure (64.0% and 68.5%). In THA patients pre- and post-operatively, men were less likely to either lose or gain weight than women. Older patients were less likely than younger patients to gain weight. Among TKA patients, men were less likely to lose weight pre- or post-operatively, or gain weight post-operatively, older patients were less likely to gain weight pre- or post-operatively. A number of racial associations with weight patterns were also observed.

**Conclusions:** Specific patient groups that can benefit from weight management interventions. Targeting these groups will result in increased efficiency of interventions, decrease the financial and personnel burden on implementing interventions, and potentially result in cost savings.



## INTRODUCTION

In 2009 1,124,000 total joint arthroplasty (TJA) procedures were performed in the United States (US)<sup>1</sup>. Both the prevalence of obesity and the incidence of joint arthroplasty (specifically in knees and hips) have dramatically increased over the last two decades in this country<sup>2-4</sup>. These rates are expected to continue to rise; according to Kurtz et al., by 2030, the incidence of total hip arthroplasties (THA) will increase by 174% and total knee arthroplasties (TKA) will increase by 673% compared to 2005 figures<sup>5</sup>. Additionally, the time between procedures in the contralateral joint is expected to decrease because there is a higher risk of bilateral osteoarthritis<sup>6</sup> on obese patients and the age at TJA is also significantly earlier<sup>7</sup>. The increased TJA incidence and decreased time between multiple joint arthroplasty procedures, have been largely, but not exclusively, attributed to the increase in the prevalence of obesity in the US population<sup>8</sup>. While the prevalence of obesity and TJA is known, little is known of the pre- and post-operative weight patterns of patients who have already undergone TJA.

Obese TJA candidates are often advised to lose weight because of the detrimental effects of obesity post surgery<sup>9</sup>. However, whether patients actually lose weight is not known. To our knowledge, only two studies looking at pre-operative weight changes in TJA patients have been published and no description of the patients more susceptible and successful in weight management were described<sup>10, 11</sup>. Riddle et al., in both studies, report pre-operative on weight loss association with post-operative weight gain.

Conversely, several studies have focused on weight changes of patients after TJA, but with inconclusive findings<sup>12</sup>. These inconclusive results, which are also

inconsistent, may have been due to the heterogeneity of study eligibility and analyses performed, small sample sizes or overall quality<sup>12</sup>. Thus, no conclusive evidence exists that weight improves, remains the same, or negatively progresses any time after TJA procedures.

The purpose of this study was to describe the pre- and post-operative weight patterns of patients undergoing TJA in a large integrated healthcare system (IHS). In addition, this study also evaluated patient characteristics associated with different weight patterns one year pre- through one year post-TJA.

## METHODS

### *Study Design and Sample*

A retrospective review of the weight history of patients who underwent TJA at an IHS from January 1, 2008 to December 31, 2010 was undertaken. All primary, unilateral, lower limb TJA (knee and hip) for osteoarthritis, who were at least 18 years old, at the 35 medical centers of the two largest regions covered by the IHS (Northern and Southern California) were included in the study sample (n=36015). Patients with TJA for any reason other than osteoarthritis, those with multiple joint arthroplasties within one year of the procedure were excluded from the sample (n=3601 patients/5222 procedures). Patients who underwent bariatric surgical (n=161) procedure were also excluded.

### *Data Collection*

Data were extracted from an IHS Total Joint Replacement Registry (TJRR) and electronic health records (EHR). Using the TJRR, TJAs were identified. The structure,

capture, validation and data quality of the TJRR have been previously published<sup>13-15</sup>. In brief, the TJRR is voluntary, with 90-95% participation in 2010<sup>15</sup>. The TJRR captures the institution's TJA population and records detailed information on patient characteristics, procedure diagnosis, specific procedures performed, surgical techniques, implant characteristics and outcomes associated with the procedures. The EHR was used to extract the weight measures used and identify patients who had bariatric surgical procedures. The EHR captures weight measures whenever a patient encounter occurs. Weight measures from all encounters during one year pre- through one year post-TJA were extracted. There was no standard protocol for weight assessment. If more than one weight per period was recorded, the median weight was used. Weight data were extracted for the time intervals of (1) 181-365 days pre-operative, (2) 91-180 days pre-operative, (3) 0-90 days pre-operative or intraoperative time, (4) 1-90 days post-operative, (5) 91-180 days post-operative, and (6) 181-365 days post-operative.

#### *Outcomes of Interest*

Patients were categorized into: gainers (increased weight by 5%), losers (decreased weight by 5%), remained the same (change <5%) for both the pre- and post-operative period. A change of 5% or more in pre-operative or post-operative weight was considered a clinically significant weight change and used to categorize the patients studied, as suggested by the Food and Drug Administration (FDA) definition<sup>16</sup>. Weight was recorded for the intervals described and weight changes were calculated using time period 3 (0-90 days) as the referent weight for change.

### *Exposures of Interest*

Patients were characterized according to demographic information (gender, age, and race) and whether a TKA or THA procedure was performed.

### *Statistical Analysis*

Rates for categorical variables and descriptive statistics for continuous variables were calculated. Data from THA and TKA were analyzed separately. Post-operative weight patterns by intra-operative obesity levels (non-obese ( $<30\text{kg/m}^2$ ), obese ( $30\text{--}34\text{kg/m}^2$ ), and morbidly obese ( $\geq 35\text{kg/m}^2$ )) are provided<sup>17</sup>. Chi-square tests and analysis of variance (ANOVA) were used to compare characteristics by weight pattern group. Polychotomous logistic regression was used to model the three weight groups: loser, gainer, and 'remain the same.' Separate models for pre-operative and post-operative patterns and for TKA and THA were created. Those remaining the same constituted the largest group and were used as the reference category. Age, gender, and race (Asian, Black, Native American, White, Hispanic, other, and unknown) associations with weight changes were examined. Missing data were excluded and analyses were conducted to determine whether our estimations were biased by missingness. Collinearity of variables and outliers were also evaluated. Tolerance values  $<0.10$  were used as thresholds for collinearity indication; outliers were manually reviewed. Unadjusted and adjusted odds ratios (OR) for the association of the dependent variables with weight patterns and 95% confidence intervals (CI) are provided. The Wald chi-square test P-value is also provided for each variable. All analyses were two-tailed with  $\alpha=0.05$  used as the statistical significance threshold; all analyses were performed using SAS for Windows 9.2 (Cary, NC, USA).

## RESULTS

30632 TJAs were identified; 34.5% (n=10572) were THAs and 65.5% (n=20060) TKAs. Women were the majority (n= 18612, 60.8%), but a higher proportion of women were in the THA sample (n=12493, 62.3%) compared to TKA sample (n=6119, 57.9%). THA patients were slightly younger than TKA (66.9 vs. 67.7 years old) and had a higher proportion of White patients than TKAs (n=8205, 77.6% vs. n=13353, 66.6%). The mean weight and BMI of the sample at the time of TJA was 192 lbs (SD=43, range 80-446) and 30.7 kg/m<sup>2</sup> (SD=6.0, range=15.0-67.5), respectively. THAs had slightly lower mean weight (185lbs SD=44, range 82-424) and BMI (29.2 kg/m<sup>2</sup>, SD=5.7, range 15.0-58.5) than TKAs (weight 196lbs, SD=43 range 83-484, BMI 31.5 kg/m<sup>2</sup>, SD=6.0 range, 15.4-67.5). Figure 2.1 shows the mean weight of THAs and TKAs. Weights are highest (for both procedures) at six months to one year pre-operative and lowest at the three months post-operative period.

Of the THAs, 9.6% (n=1019) did not have pre-operative weight and 12.6% (n=1336) did not have post-operative weight. Of the TKAs, 7.5% (n=1512) did not have pre-operative weight and 9.3% (n=1866) did not have post-operative weight. The cases with missing data were more likely men and younger than those without missing data. No differences between cases with missing data and those with complete data with respect to intra-operative BMI, year of the operation, or operative side.

Table 2.1 shows the characteristics of the sample by whether they lost, gained, or remained the same during the one year pre- and post-operative TJA. The majority of THA and TKA remained the same weight during the year prior to their procedure (71.5% and 75.7% respectively) and during the year after the procedure (64.0% and 68.5%).

Figure 2.2 shows the patterns of weight change for patients both pre- and post-operatively. The majority of patients remain the same both pre- and post-operative (61.0% of THAs and 63.8% of TKAs).

Figure 2.3 shows the post-operative weight patterns for THAs and TKAs by their intra-operative BMI obesity classification. In THAs, morbidly obese had a higher proportion of weight losers (14.0%) than other groups (8.5% non-obese and 9.5% obese). Post-operatively there were no differences in TKA weight patterns by intra-operative obesity levels.

In THA patients, pre-operatively, men were less likely to either lose or gain a clinically significant amount of weight than women (loser OR=0.74, 95%CI 0.66-0.84; gainer OR= 0.84, 95%CI 0.71-0.99). Asians were less likely to lose weight (OR=0.59, 95%CI 0.40-0.85) than Whites, and older patients were less likely than younger patients to gain weight (2.0% decrease in risk of being gainer per one age increase, 95%CI 2.0%-3.0%). In THA patients post-operatively, men were less likely to lose (OR=0.79, 95%CI 0.69-0.92) or gain (OR=0.86, 95%CI 0.77-0.96) weight. Additionally, older patients were less likely to be gainers (1.0% decrease in odds per one year increase, 95%CI 1.0%-2.0%) and those who were Black were more likely to be gainers (OR=1.22, 95%CI 1.00-1.47) compared to White patients. Table 2.2.

In TKAs, pre-operatively, men and Hispanics had lower odds of losing (OR=0.76, 95%CI 0.69-0.84 and OR=0.74, 95%CI 0.64-0.85, respectively) or gaining weight (OR=0.78, 95%CI 0.70-0.88 and OR=0.77, 95% CI 0.66-0.91, respectively). Asians were less likely than Whites (OR=0.63, 95% CI 0.49-0.80) to lose weight and older patients were less likely to gain weight (OR=3.0% decrease per year of age increase, 95% CI

3.0%-4.0%). Post-operatively, in TKAs, men were less likely than women to lose weight (OR=0.62, 95% CI 0.57-0.68), and Asians and Hispanics were less likely than Whites to lose weight (OR=0.69, 95% CI 0.56-0.84, OR=0.85, 95% CI 0.76-0.96, respectively); while older patients (OR=2.0% decrease per year of age increase, 95%CI 1.0%-3.0%), and Asian and Hispanics compared to White (OR=0.76, 95%CI 0.60-0.97, OR=0.78, 95% CI 0.67-0.91) were less likely to be gainers. Table 2.2.

## DISCUSSION

The majority of patients undergoing TJA procedures in community-based practices were found to remain the same weight pre- and post-TJA procedure (61% THAs and 64% TKAs). However, certain groups of patients were found more likely to gain or lose a clinically significant amount of weight before and/or after the surgery. Specifically, women were more likely than men to change their weight (either gain or lose) pre-operatively in both THAs and TKAs and post-operatively in THAs. Younger patients are more likely to gain weight than older patients both pre- and post-THAs and TKAs. Several racial differences were observed and the proportion of patients who gained and lost weight post-operatively varied depending on the intra-operative weight of the patient.

Few studies have explored the association of sex with post-TJA weight change and no studies examine this issue for pre-operative weight change. Results of the present study are in contrasts with those of Dowsey et al. who evaluated both THAs and TKAs and intra-operative variables associated with a 5% weight loss post-operatively<sup>18, 19</sup> and reported that sex was not associated with weight loss.

Differences in Dowse et al.'s studies may be attributed to the smaller sample size (511 THAs and 573 TKAs), sample heterogeneity (Australian samples, no mention of racial distribution), and differences in weight ascertainment (the studies actively measured all their study participants with a standard protocol). A multitude of biochemical, behavioral, and socioeconomic reasons are noted for the higher prevalence of obesity, dieting and difficulty of weight loss in women<sup>20, 21</sup>, possibly explaining why women in our study were more susceptible to weight change.

Age has also not been studied as a risk factor for pre-operative TJA weight change but has been reported to be associated with post-operative weight changes. Older age has been found to be associated with weight loss one year post-TKA, although the inverse (association weight gain) was not observed<sup>19</sup>. Similarly, Lachiewicz et al. reported age to be significantly associated with post-TKA weight change, reporting younger patients being more likely to be obese than older patients<sup>22</sup>. The prevalence of obesity in TJA patients is also higher than the general population<sup>4, 23</sup>, and the obese patients are younger than non-obese patients. Younger age being associated with an increased likelihood of gaining more weight is likely due to younger patients already being the heavier patients, having a longer history of weight-related issues, and suffering from co-morbid conditions that impact their ability and commitment to weight management.

Racial differences in prevalence of obesity and weight loss, management, and perception are well documented in the literature<sup>4, 24-26</sup>. Non-Hispanic Blacks have the highest prevalence of obesity of all racial/ethnic groups in the US, with a prevalence of obesity reported at 38% for men and 50% for women 60 years old and older (group



representative of our sample). The increased likelihood of Black patients to gain even more weight in this study is not unexpected since these are the patients already at a higher risk of being obese. Previous studies report higher risk of complications<sup>27</sup> and revision<sup>23</sup> procedures in Black patients, which could explain the increase in weight post-operatively of these patients who may be more debilitated, unable to participate in physical activity, or may be taking medication that influences weight gain/activity levels. In addition, Asians and Hispanics were found at certain time periods (Asians at pre-THA and both pre- and post-TKA and Hispanics post-TKA) to be less likely to change their weight than Whites. This lower susceptibility to weight change in these races could be indicative of lower risk of post-operative complications or possible better pre-operative profiles.

The different patterns of post-operative weight change by the intra-operative obesity level for THA patients are also of note. Although small, morbidly obese THA patients had a higher proportion of patients losing weight post-operative. It is likely that regain of mobility and relief from symptoms did indeed lead these patients to a weight reduction post-operative. This was not observed in TKA patients, who had similar proportions of gaining, losing, and remaining the same in all intra-operative obesity levels and are generally heavier than TKA patients. Successful rehabilitation can be more challenging for a heavier patient with other co-morbidities, such as osteoarthritis in other joints and slow recovery has been reported after both procedures in obese patients<sup>28</sup>.

This study has several limitations. First, selection bias could be present due to the sampling frame. Patients not covered by the IHS used in this study are not

included. However, the membership of this system is generally composed of similar age, gender and race members as the regional population where it provides coverage<sup>29</sup>,<sup>30</sup>. Second, the data source used for this study is voluntary and participation in the registry is reportedly 95%. However, contributing sites have non-differential rates of participation in the registry and we do not expect this to impact the study findings. Third, cohort evaluated had an attrition rate of 1.1%. Of these lost to follow up only 11% had missing post-operative weight estimates, similar proportion of missing as the overall cohort. Fourth, there is a potential for inclusion of patients in the sample that have had surgical weight loss interventions outside the system. While unlikely, we cannot be certain procedures did not happen prior to the 2001 EHR records or at another institution. Since the prevalence of surgical weight loss intervention is very small in the US<sup>31</sup>, we do not expect this to bias our sampling. Fifth, the protocol for weight assessment is not standard and measurements are subjected to reporting bias, as well as observer bias. Six, missing data were present (<12.6% depending on procedure and period). We found patients with missing data were more likely to be men and younger, but no other differences were noted. It is possible that the estimations of sex association were overestimated for women (if most of the men without weight measures were the ones changing their weight before and after the procedure), but due to the small amount of missing data and large sample size we believe this underestimation to be minimal. However, age estimations are probably not overestimated since we found younger age to be more likely to gain weight than remain the same for all groups, despite the higher numbers of missing weight.

This study's strengths include the generalizability of the findings, the utilization of a closed IHS EHR, and low likelihood of data handling and response bias. Most importantly, the cases, surgeons and medical centers that make up the sample of this study are believed to be representative of community-based orthopedic practices in the US. The patient samples of each location are of various case mix levels and similar to the larger state population with regards to age, race and gender distribution<sup>29, 30, 32</sup>. Over 300 surgeons and 27 hospitals contributed to the sample evaluated and they are of various training levels, settings (e.g. urban, rural, academic), and volumes. Additionally, this study used a common EHR and TJRR registry to obtain data. The ability to link records, using one common unique identifier in a sample of this size cannot be reproduced by any other larger national samples (Nationwide Inpatient Sample, regional TJR registries). Finally, using the EHRs to obtain the weight measurements also decreased the possibility of response bias that could arise from obtaining this information from the patients directly.

This study found women to be the most susceptible group to change weight either before or after TJA procedure, younger patients to be most likely to gain weight before and after TJA, and Black patients most likely to gain weight after their procedure. Additionally, this study described a different post-operative weight trend in THA patients depending on their intra-operative obesity level, with the morbidly obese having the highest proportion of patients losing weight after the procedure. This information is important to healthcare providers as it characterizes specific groups that can benefit from weight management interventions. Targeting these groups will result in increased efficiency of interventions, decrease the financial and personnel burden on

implementing interventions, and potentially result in cost savings from reducing the number of patients that need to undergo pre-operative counseling for weight loss and other co-morbidity optimization efforts.

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Chapter 2, in full, has been submitted for publication of the materials as it may appear in The Bone and Joint Journal. Inacio, Maria C.S.; Kritz-Silverstein, Donna; Raman, Rema; Macera, Caroline A.; Nichols, Jeanne F.; Shaffer, Richard A.; Fithian, Donald C. Pre- and Post-Operative Weight Patterns of Total Joint Arthroplasty Patients and Characteristics Associated with Weight Change. The dissertation author was the primary investigator and author of this paper.

Table 2.1. Patient Characteristics by Weight Change During the Pre- and Post-operative Period by Total Hip and Knee Arthroplasty, 2008-2010. N=30632 (10572 THAs and 20060 TKAs).

	Pre-Operative Weight Group <sup>1</sup>				Post-Operative Weight Group <sup>1</sup>			
	Gainer	Losers	Remain the Same	Unknown	Gainer	Losers	Remain the Same	Unknown
Total	N (%) 1993 (6.5)	N (%) 3355 (11.0)	N (%) 22753 (74.3)	N (%) 2531 (8.3)	N (%) 3229 (10.5)	N (%) 3696 (12.1)	N (%) 20505 (66.9)	N (%) 3202 (10.5)
THA	598 (5.7)	1394 (13.2)	7561 (71.5)	1019 (9.6)	1586 (15.0)	885 (8.4)	6765 (64.0)	1336 (12.6)
Gender								
Female	360 (60.2)	900 (64.6)	4331 (57.3)	528 (51.8)	956 (60.3)	559 (63.2)	3886 (57.4)	718 (53.7)
Male	238 (39.8)	494 (35.4)	3230 (42.7)	491 (48.2)	630 (39.7)	326 (36.8)	2879 (42.6)	618 (46.3)
Age	64.2 (10.4)	68.0 (11.5)	67.2 (10.8)	64.6 (11.2)	65.7 (11.4)	68.1 (11.3)	67.5 (10.7)	64.2 (11.0)
Race								
White	451 (75.4)	1119 (80.3)	5855 (77.4)	780 (76.6)	1202 (75.8)	708 (80.0)	5248 (77.6)	1047 (78.4)
Black	56 (9.4)	115 (8.3)	590 (7.8)	104 (10.2)	156 (9.8)	72 (8.1)	531 (7.9)	106 (7.9)
Hispanic	43 (7.2)	94 (6.7)	629 (8.3)	66 (6.5)	133 (8.4)	65 (7.3)	552 (8.2)	82 (6.1)
Asian	27 (4.5)	31 (2.2)	266 (3.5)	33 (3.2)	43 (2.7)	25 (2.8)	235 (3.5)	54 (4.0)
Other <sup>2</sup>	9 (1.5)	23 (1.7)	129 (1.7)	16 (1.6)	34 (2.1)	9 (1.0)	108 (1.6)	26 (2.0)
Unknown	12 (2.0)	12 (0.9)	92 (1.2)	20 (2.0)	18 (1.1)	6 (0.7)	91 (1.4)	21 (1.6)
TKA	1395 (7.0)	1961 (9.8)	15192 (75.7)	1512 (7.5)	1643 (8.2)	2811 (14.0)	13740 (68.5)	1866 (9.3)
Gender								
Female	933 (66.9)	1326 (67.6)	9361 (61.6)	873 (57.7)	997 (60.7)	2014 (71.7)	8359 (60.8)	1123 (60.2)
Male	462 (33.1)	635 (32.4)	5831 (38.4)	639 (42.3)	646 (39.3)	797 (28.4)	5381 (39.2)	743 (39.8)
Age	65.0 (9.9)	67.5 (9.7)	68.1 (9.3)	66.2 (10.0)	66.0 (9.7)	68.5 (9.8)	68.0 (9.3)	66.0 (9.9)
Race								
White	950 (68.1)	1375 (70.1)	10025 (66.0)	1003 (66.3)	1127 (68.6)	1894 (67.4)	9041 (65.8)	1291 (69.2)
Black	146 (10.5)	197 (10.1)	1344 (8.9)	175 (11.6)	143 (8.7)	326 (11.6)	1210 (8.8)	183 (9.8)
Hispanic	199 (14.3)	257 (13.1)	2470 (16.3)	170 (11.2)	232 (14.1)	402 (14.3)	2253 (16.4)	209 (11.2)
Asian	66 (4.7)	76 (3.9)	864 (5.7)	94 (6.2)	77 (4.7)	118 (4.2)	799 (5.8)	106 (5.7)
Other <sup>2</sup>	19 (1.4)	42 (2.1)	293 (1.9)	29 (1.9)	38 (2.3)	47 (1.7)	260 (1.9)	38 (2.0)
Unknown	15 (1.1)	14 (0.7)	196 (1.3)	41 (2.7)	26 (1.6)	24 (0.9)	177 (1.3)	39 (2.1)

TKA=Total Knee Arthroplasty. THA= Total Hip Arthroplasty. SD=Standard Deviation.

1. Gainer: weight increase  $\geq 5\%$  compared to weight at operative time. Loser: weight decrease  $\geq 5\%$  compared to weight at operative time. Remain the Same: weight change no greater than  $\pm 5\%$ .
2. Includes multi-race and Native American.

Table 2.2. Associations of Age, Gender and Race with Pre-and Post-operative Weight Change; Results of Polychotomous Logistic Regression. Adjusted Odds Ratios and 95% Confidence Intervals by Total Hip and Knee Arthroplasty.

Reference Group= 'Remain the Same'	Pre-Operative Weight Group <sup>1</sup>		Post-Operative Weight Group <sup>1</sup>	
	Gainer	Loser	Gainer	Loser
THA <sup>2</sup>				
Male vs. Female				
Age (1 year increments)	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
Asian vs. White	0.74 (0.66-0.84)*	0.84 (0.71-0.99)*	0.79 (0.69-0.92)*	0.86 (0.77-0.96)*
Black vs. White	1.00 (1.00-1.01)	0.98 (0.97-0.98)*	1.00 (1.00-1.01)	0.99 (0.98-0.99)*
Hispanic vs. White	0.59 (0.40-0.85)	1.26 (0.83-1.89)	0.77 (0.50-1.17)	0.78 (0.56-1.08)
Other <sup>3</sup> vs. White	1.04 (0.84-1.28)	1.13 (0.84-1.51)	1.02 (0.79-1.32)	1.22 (1.00-1.47)
Unknown vs. White	0.81 (0.65-1.02)	0.79 (0.57-1.10)	0.90 (0.68-1.17)	0.99 (0.81-1.21)
	0.96 (0.61-1.50)	0.85 (0.43-1.69)	0.63 (0.32-1.24)	1.32 (0.89-1.95)
	0.73 (0.40-1.35)	1.51 (0.82-2.78)	0.52 (0.23-1.19)	0.81 (0.49-1.35)
TKA <sup>4</sup>				
Male vs. Female				
Age (1 year increments)	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
Asian vs. White	0.76 (0.69-0.84)*	0.78 (0.70-0.88)*	0.62 (0.57-0.68)*	0.99 (0.89-1.10)
Black vs. White	0.99 (0.99-1.00)	0.97 (0.96-0.97)*	1.01 (1.00-1.01)	0.98 (0.97-0.99)*
Hispanic vs. White	0.63 (0.49-0.80)*	0.78 (0.60-1.01)	0.69 (0.56-0.84)*	0.76 (0.60-0.97)*
Other <sup>3</sup> vs. White	1.01 (0.86-1.19)	1.02 (0.85-1.23)	1.24 (1.09-1.42)*	0.89 (0.74-1.04)
Unknown vs. White	0.74 (0.64-0.85)*	0.77 (0.66-0.91)*	0.85 (0.76-0.96)*	0.78 (0.67-0.91)*
	1.01 (0.73-1.41)	0.62 (0.39-1.00)	0.87 (0.63-1.19)	1.11 (0.78-1.57)
	0.50 (0.29-0.87)*	0.67 (0.40-1.15)	0.69 (0.45-1.05)	1.04 (0.69-1.59)

OR=Odds Ratio; CI=Confidence Interval. TKA=Total Knee Arthroplasty. THA= Total Hip Arthroplasty.

\* Denotes statistical significance (p<0.05).

1. Gainer: weight increase ≥5% compared to weight at operative time. Loser: weight decrease ≥5% compared to weight at operative time. Remain the same (reference): weight change no greater than ±5%.

2. Wald Chi-square test for THA:

a. Adjusted pre-operative: gender (p<0.001), age (p<0.001), race (p=0.051)

b. Adjusted post-operative: gender (p<0.001), age (p<0.001), race (p=0.121).

3. Includes multi-race and Native American.

4. Wald Chi-square test for TKA: all p<0.001 (pre- and post-operative).

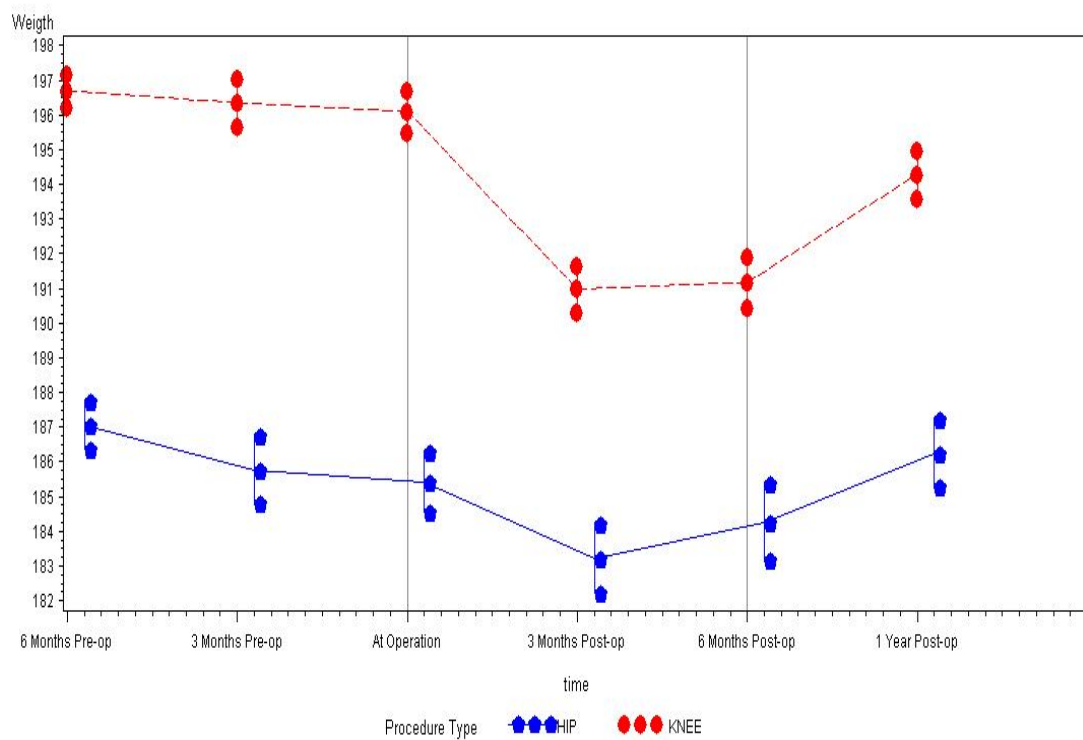
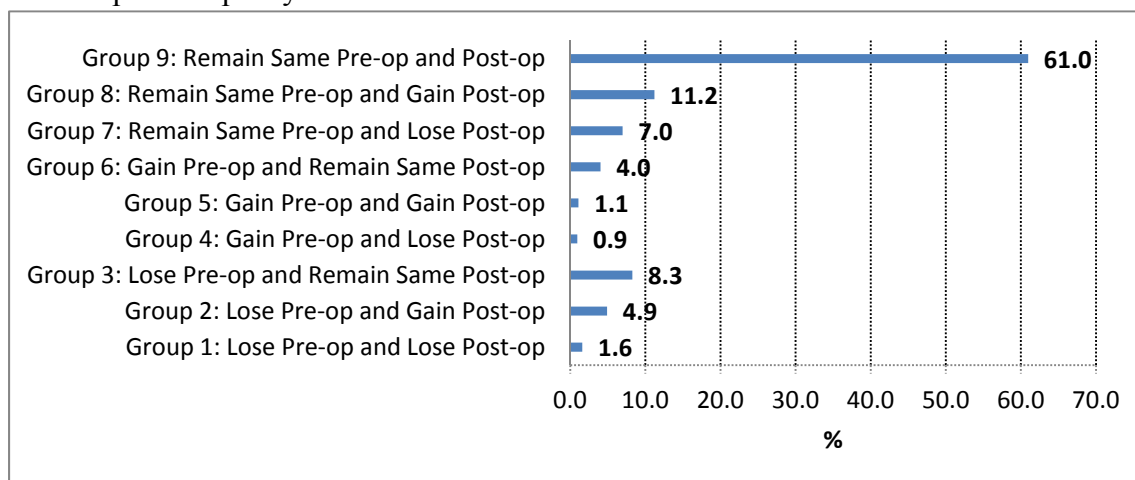


Figure 2.1. Pre- and Post-operative Mean Weight for Each Time Period for Total Hip and Knee Arthroplasty. N=10572 THAs and N=20060 TKAs.  
TKA=Total Knee Arthroplasty. THA= Total Hip Arthroplasty.



### Total Hip Arthroplasty



### Total Knee Arthroplasty

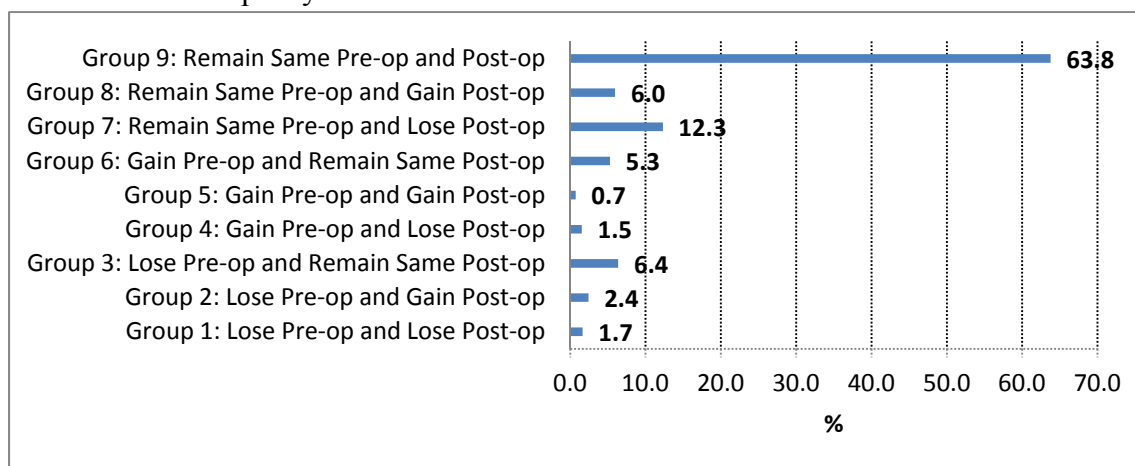


Figure 2.2. Proportion of Patients in Each Weight Group by Pre- and Post-operative Status for Total Hip and Total Knee Arthroplasty.

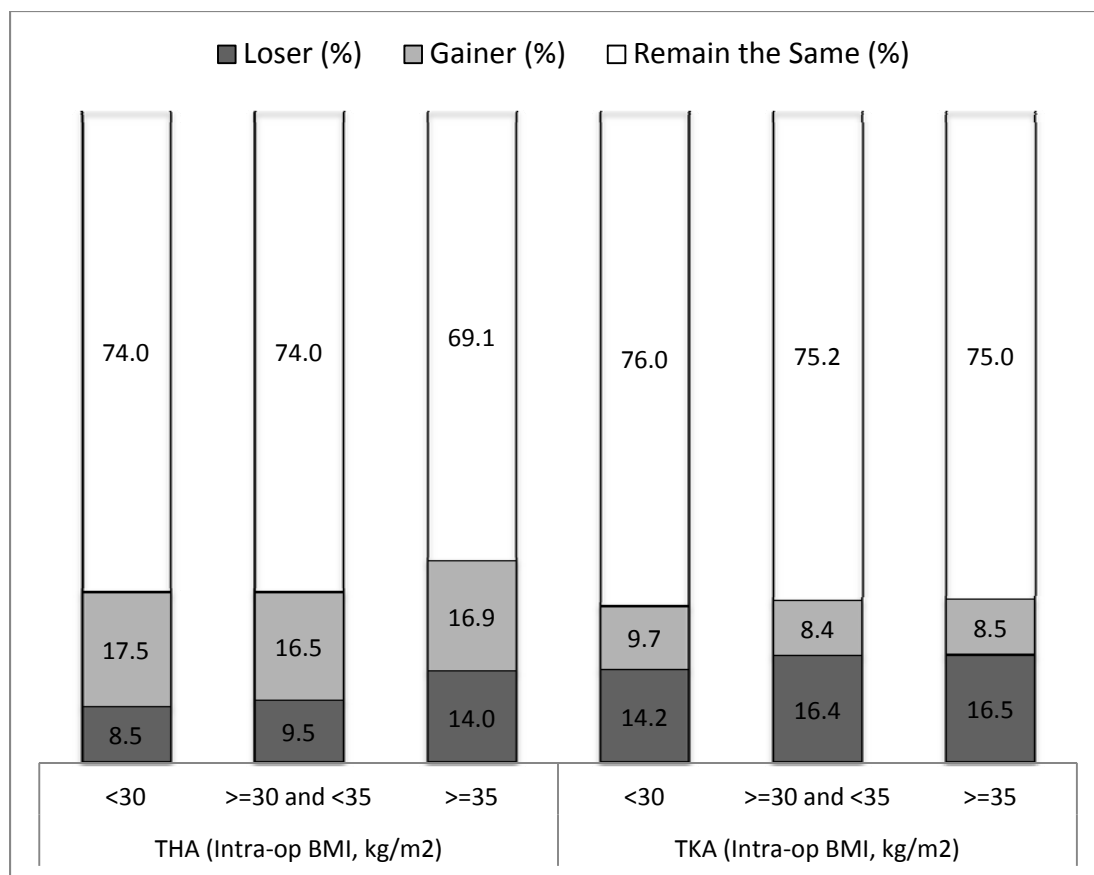


Figure 3. Post-TJA Weight Pattern by Intra-operative Obesity Status.  
 TKA=Total Knee Arthroplasty. THA= Total Hip Arthroplasty. BMI=Body Mass Index.  
 BMI=Body Mass Index.

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## CHAPTER 3.

### The Impact of Pre-operative Weight Loss on Incidence of Surgical Site Infection and Readmission Rates After Total Joint Arthroplasty

## ABSTRACT

**Objective:** To characterize a cohort of obese total hip arthroplasty (THA) and total knee arthroplasty (TKA) patients and evaluate whether a clinically significant amount of pre-operative weight loss (defined as a 5% decrease in body weight) is associated with a decreased risk of SSI and readmissions post-surgery.

**Methods:** Using a total joint replacement registry (TJRR) obese primary TKA and THA patients who had procedures between 1/1/2008-12/31/2010 were identified. The main exposure of the study was the one year pre-operative weight change of the patients. Patients were categorized into: gainers, losers, and those who remained the same. The endpoints SSI (any, deep, superficial) and 90 day readmissions, were ascertained prospectively by the TJRR. Polychotomous regression and logistic regression models were used.

**Results:** Out of the 10718 TKAs identified, in the year before surgery 7.6% (N=817) of patients gained weight, 12.4% (N=1332) lost weight, and 79.9% remained the same. Out of the 4066 THAs identified, in the one year pre-THA, 6.3% (N=258) of patients gained weight, 18.0% (N=732) lost weight, and 75.7% (N=3076) remained the same. TKAs had 124 (1.2%) infections and THAs had 64 (1.6%). The incidence of readmission was 5.2% for TKAs and 6.7% for THAs. In both TKAs and THAs, after adjusting for covariates, the risk of SSI and readmission was not significantly different in the patients who gained or lost weight pre-operatively compared to those who remained the same.

**Conclusion:** Few patients lost weight in the year prior to their TJA procedure and even fewer moved to lower risk profiles ( $\text{BMI} < 30 \text{ kg/m}^2$ ). A significant reduction



in the risk of SSI and 90 day readmission in obese patients who lost 5% of their body weight prior to their TJA procedure was not observed.

## INTRODUCTION

It is estimated that 1,124,000 patients in the United States underwent joint arthroplasty (TJA) in 2009.<sup>1</sup> Obesity, defined as body mass index (BMI)  $\geq 30\text{kg/m}^2$ , is a risk factor for osteoarthritis, the leading cause for lower limb joint arthroplasty, and the population undergoing arthroplasty is disproportionately affected by this condition.<sup>2-4</sup> The prevalence of obesity in a nationally representative cohort of TJA patients is 39%<sup>5</sup> for total hip arthroplasty (THA) patients and 51%<sup>6</sup> for total knee arthroplasty (TKA) patients.

Obesity is also a well-documented risk factor for post-operative morbidity and decrease in implant longevity.<sup>7, 8</sup> Surgical site infections (SSIs), a major complication associated with TJA, affect an estimated 0.6%-1.5% of patients<sup>9-13</sup> and rates are significantly higher in obese patients.<sup>7, 8</sup> Readmission rates post-TJA, estimated at 5%-9% incidence (depending on time period and procedure type),<sup>14, 15</sup> are also higher for obese patients.<sup>16</sup> This higher prevalence of obesity and its documented ill effects increase the need for interventions to address obesity prior to the procedure. In studies that evaluated surgical weight loss prior to TJA high rates of complications were still reported for patients that underwent surgical weight loss prior to TJA.<sup>17-19</sup> However, no studies have evaluated the impact of non-surgical weight loss prior to TJA and the impact of weight reduction on infection or readmissions (or any other outcome) post-TJA.

The purpose of this study was to (1) characterize a cohort of obese primary THA and TKA patients from a large integrated healthcare system according to their demographic characteristics and co-morbidities; and (2) evaluate whether a clinically significant amount of non-surgically induced pre-operative weight loss (defined as a 5% decrease in body weight) is associated with a decreased risk of SSI and readmission during the first 90 days post-surgery.

## METHODS

### *Study Design and Sample*

A retrospective cohort study of patients enrolled in a Total Joint Replacement Registry (TJRR) for a large integrated healthcare system in California was conducted. The integrated healthcare system has 8.6 million members in California and its population is sociodemographically representative of the geographical areas it covers.<sup>20-22</sup>

All obese ( $\text{BMI} \geq 30 \text{ kg/m}^2$ ) primary unilateral TKA and THA patients (no multiple joint surgery) who had the procedure performed for osteoarthritis, without any history of surgical weight loss intervention between 1/1/2008 and 12/31/2010 were included in the sample. Patients had to be obese at the beginning of the study period (one year pre-operative or at the earliest pre-operative weight measurement available on record). After excluding patients missing pre-operative weight change ( $N=315$ ), there remained 14784 individuals who are the focus of this study.

### *Data Collection*

Study data were electronically extracted from two main sources, the TJRR and the integrated healthcare system electronic health records (EHR). Using the TJRR, all TKAs and THAs as well as SSIs and 90 days readmissions associated with these procedures were identified. The structure, data capture, quality control, and validation procedures of the TJRR have been previously published.<sup>23-25</sup> In brief, the TJRR is a voluntary registry, with reportedly 90-95% compliance at participating locations in 2010.<sup>25</sup> It prospectively ascertains outcomes (e.g. SSI, readmissions, thromboembolic events, implant failures) associated with TJA procedures. SSIs are identified and adjudicated quarterly by the TJRR using a validated hybrid electronic algorithm.<sup>10</sup> Readmissions are electronically extracted quarterly and monitored by the TJRR. The EHR was used to extract all weight measures used for the study sample and to identify patients who had bariatric surgical procedures. The EHR is composed of several modules (i.e. inpatient, outpatient, operative), and most instances of patient activity in one of these modules captures weight measurement. Weight obtained in all patient encounters during one year pre-TJA were extracted. There was no standard protocol for weight assessment and patients were not advised or encouraged, as part of the study, to lose weight. If more than one weight per period was recorded, the median weight was used. Weight data were extracted for the time intervals of (1) 181-365 days pre-operative, (2) 91-180 days pre-operative, (3) 0-90 days pre-operative (considered the intraoperative time).

### *Outcomes of Interest*

SSI and 90 day readmissions are the main endpoints of this study. SSIs can be either deep or superficial and these are defined according to the Centers for Disease Control and Prevention/ National Healthcare Safety Network criteria.<sup>26</sup> In brief, a deep

SSI is attributed to the TJA procedure if it occurs up to one year post-operatively and involves deep soft tissue; a superficial infection is attributed to the TJA if occurs within 30 days of the procedure and involves only skin and subcutaneous tissue of the incision site. In addition, to be considered a SSI it must also have (a) purulent drainage; or (b) the incision dehisces or is opened and has positive cultures or if not cultured the patient has fever, pain, tenderness or swelling; or (c) an abscess or other evidence of infection is found during examination; or (d) a surgeon or attending physician diagnoses an infection. Ninety day re-admission is defined as any inpatient readmission for any reason within 90 days of the discharge date of the TJA. The 90 day re-admission endpoint was only available for cases registered between 1/1/2009 and 12/31/2010 onwards; therefore the analysis for this endpoint has a different denominator than for SSIs.

#### *Exposures of Interest*

The main exposure of interest in this study was the pre-operative weight change of the patients. Change in weight was calculated as the percent difference in weight from the earliest time period when weight was available for the patient (181-365 days or 91-180 days pre-operative) to their weight at the time of surgery. Using the Food and Drug Administration (FDA) definition for a clinically significant weight change,<sup>27</sup> patients were categorized into: gainers (increased body weight by  $\geq 5\%$ ), losers (decreased body weight by  $\geq 5\%$ ), and those who remained the same (weight change  $< 5\%$ ).

#### *Covariates*

Patient characteristics (gender, age, race), co-morbidities as defined by the Elixhauser comorbidity algorithm,<sup>28</sup> general health status as defined by the American Society of Anesthesiologist (ASA) score, and intra-operative BMI were the covariates

evaluated. These covariates were used to characterize the study sample and were investigated as confounders of the weight change, SSI and 90 day readmission relationship.

### *Statistical Analysis*

Means, standard deviations, medians and interquartile ranges were calculated for continuous variables and frequencies and rates were used to describe categorical variables. Incidence of SSI and 90 day readmission were calculated as the number of events over the number of cases. Analyses were conducted for TKA and THA procedures separately. Polychotomous regression models were used to characterize the study sample. Multivariable models that included patient characteristics and comorbidities that varied significantly in association with weight change were created based on results of bivariate models. Binary logistic regression models were created to evaluate weight change and likelihood of SSI (deep, superficial, and overall) and readmission. Final logistic models included covariates found to be confounders using the criteria of being associated with one of the pre-operative weight category and the outcome (using  $p < 0.1$ ). Odds ratios (OR), 95% confidence intervals (CI) and Wald Chi-square p-values are reported for all models. Missing data were handled using multiple imputations. Ten versions of the analytic data set were created and Rubin's combining rules were used to calculate the final estimates and CIs from the datasets.<sup>29</sup> The imputation model used included covariates as well as the event indicators.<sup>30</sup> Models using only complete cases were employed to examine consistency and robustness of the estimations. Multicollinearity was evaluated and tolerance values threshold levels

were set at  $<0.1$ . Data were analyzed using SAS (Version 9.2, SAS Institute, Cary, NC, USA) and  $\alpha=0.05$  was used.

## RESULTS

A total of 10718 TKAs and 4066 THAs that fit our study criteria were identified. TKAs were mostly women (64.2%, N=6883), 65 years or older (55.1%, N=5900), white (63.9%, N=6852), with a diabetes prevalence of 32.4% (N=3473). THAs were mostly women (54.9%, N=2232), white (75.2%, N=3056), with a comparable number of patients less than 65 (50.8%, N=2065) and 65 and older (49.2%, N=2001), and with a 26.7% prevalence of diabetes. (Table 3.1) The most common co-morbidities in both TKA and THA patients were hypertension (64.4% TKA, 63.2% THA), chronic pulmonary disease (16.6% TKA, 15.2% THA), hypothyroidism (12.9% TKA, 11.6% THA), deficiency anemia (10.0% TKA, 11.2% THA), and renal failure (8.8% TKA, 8.7% THA). See Table 3.2 for co-morbidities for overall group and by pre-operative weight change.

During the one year pre-TKA 7.6% (N=817) of patients gained a clinically significant amount of weight, 12.4% (N=1332) lost weight, and 79.9% (N=8569) remained the same. Age, gender, race, as well as having the presence of neurological diseases, blood loss anemia, and congestive heart failure were each associated with pre-operative weight change in TKA patients. In the one year pre-THA period, 6.3% (N=258) of patients gained weight, 18.0% (N=732) lost weight, and 75.7% (N=3076) remained the same. Age, gender, as well as depression, anemia, and chronic

pulmonary disease prevalence were found to be associated with pre-operative weight change in TKA patients. (Table 3.3)

The incidence of SSI (any, deep, and superficial) and 90 day readmission is presented in Table 3.4. The TKA sample had 124 (1.2%) infections, of which 86 (0.8%) were deep and 38 (0.4%) were superficial. The THA sample had 64 (1.6%) infections, of which 35 (0.9%) were deep and 29 (0.7%) were superficial. The 90 day incidence of readmission was 5.2% for TKAs and 6.7% for THAs.

After adjusting for covariates, the risk of SSI (any, deep, and superficial) and 90 day readmission was not significantly different in the patients who gained or lost a significant amount of weight pre-operatively as compared to those who did not change weight (weight change <5%) in either the TKA or the THA sample. See Table 3.5 for unadjusted and adjusted estimations.

## DISCUSSION

This study shows that in a cohort of obese TJA patients there were no substantial differences in risk of SSI and 90 day readmission for patients who either lost or gained 5% of their body weight one year before their primary unilateral TJA procedure as compared to those patients who remained the same weight.

This study also showed that certain characteristics are associated with a patient's susceptibility to gaining or losing weight prior to the TJA procedure. Women, younger patients, certain racial groups (white patients compared to Asian and Hispanics) and patients with certain co-morbidities (neurological disorders, blood loss anemia, congestive heart failure, chronic pulmonary disease and depression) were

found to be more susceptible to weight change. While the associations of patient characteristics with weight changes have not been previously reported among TKA and THA patients, these findings are consistent with the varying prevalence of obesity by age, gender, and racial groups in the US.<sup>31</sup> Additionally, we found TKA patients with congestive heart failure and neurological comorbidities were more likely to gain weight pre-operatively whereas those with chronic anemia were more likely to lose weight. In THA patients, depression and chronic pulmonary disease were associated with weight gain and blood loss anemia with weight loss. These associations may reflect the results treatment (eg., possible drug induced gain in the treatment of neurological and depressive disorders),<sup>32</sup> or the disease itself.

Several studies have examined the association of intra-operative BMI with detrimental post-operative TJA outcomes.<sup>7, 8, 16</sup> However, few have focused on pre-operative weight loss and risk of surgical outcome. Three studies evaluated surgically induced weight loss, and consistently report higher rates of peri-operative complications in these patients regardless of their weight loss when compared to the larger TJA population these samples are extracted from.<sup>17-19</sup> Of note, all three studies were descriptive and had limited samples, which limited their ability to estimate risk and control for confounders. Like in our study, the BMI of patients at the time of their TJA was still high (at least over 37kg/m<sup>2</sup> on average in the two studies that reported it)<sup>18, 19</sup> and probably part of the reason their peri-operative complication rate was still elevated. In an attempt to compare alike patients two of the studies also compared patients with pre-operative surgical weight loss interventions to patients who had post-TJA surgical intervention for weight management and had different findings. Severson



et al. found the rates of complications in patients with surgical intervention prior to TKA and those who had weight loss surgery post-TKA were not necessarily different, with a different rate depending on when the patients had their pre-TKA weight loss surgery.<sup>19</sup> Conversely, Kulkarni et al. found rates of wound infection and readmission were lower in those with weight loss surgery pre-TJA.<sup>17</sup> Our study did not find a decrease in risk of SSI and readmission in patients who lost 5% of their body weight compared to those who were obese and stayed the same but this could be due to the likely much smaller weight loss these patients underwent in comparison to the previously published studies which dealt with surgical weight loss. It is also possible that with our larger sample we were able to control for confounding factors that could explain the different rates reported by the other studies (such as other co-morbidities, intra-operative BMI, age, and gender), but this is not necessarily the case for all our estimations, as our univariate and multivariable analysis show.

Several factors could explain the lack of an observed association between 5% pre-operative weight loss and risk of readmission and SSI in this study cohort. First, the amount of weight change evaluated may be too small. While the criteria used were recommended by organizations such as the FDA and Institute of Medicine,<sup>27, 33</sup> it is possible that for the outcomes evaluate in this study larger weight changes suggested by yet other organizations (e.g. American Diabetes Association, 7-10%) or other studies evaluating weight loss (typically 5-10%) would be more sensitive to changes in risk.<sup>34, 35</sup> Second, very few patients in the cohort went from being obese to non-obese during the course of the study. Intra-operative BMI, a risk factor for SSI and readmissions, was not changed. This small number of patients losing weight, suggest

that the current practices promoting pre-surgical weight loss are not effective. Third, the outcomes evaluated may not be sensitive to the supposed benefits of weight loss. It is possible that the incidence of other complications was lower, or rehabilitation was quicker and easier in the patients with lower weight, but these outcomes were not evaluated in the present study. Fourth, it is possible that weight loss one year prior to TJA may be too late for the benefits to be obvious. Patients who are obese suffer from several disabling conditions and the combined biochemical and biomechanical damage of these conditions may require more than just one year of pre-operative weight loss to effectively reduce certain adverse events. The duration of a patient's obesity, which was not studied in this study, has been found to be associated with variation of metabolic health risk in overweight patients,<sup>36</sup> and could therefore be an important factor when evaluating the outcomes of this study. Finally, our study may be underpowered to detect small changes in risk. However, this is unlikely since our study can likely detect clinically significant changes in risk.

We also did not find any associations between 5% weight gain and higher risk of SSI or readmission in our cohort. The lack of association between weight gain and higher risk of SSI is likely because patients were all obese at the starting point of the study and already had a high risk profile for SSI and readmissions.<sup>7, 8, 16</sup>

Limitations of this study include the non-random sample used, lack of standard procedures to obtain weight measurements, and missing data. This sample was subject to non-random sampling bias. However, we believe that the effect of this bias was minimized by the inclusion of all cases registered in the TJRR that fit our inclusion criteria. Because evidence based guidelines for the indications of TJA exist,<sup>37</sup> we did

not include cases without clear indication for TJA nor did we exclude patients who were at need for surgery and elected to have the procedure. This is a retrospective cohort study that used weight data extracted from electronic medical charts; weight measurements were not collected with a single standard protocol leading to the possibility of information bias. However, this bias is most likely non-differential between the assessments for each patient. Overall, 315 patients were excluded from the study sample because they did not have pre-operative weight measurements at any time prior to their TJA; this represents only 2% of the initial sample and would minimally affect our estimations. Finally, there was missing data for some variables, the highest proportion for co-morbidities data (14%), followed by ASA (2.1%), and race (1.4%). However, creating 10 multiple imputation datasets to account for missing data should yield unbiased parameter estimations while correctly accounting for uncertainty as well.

Study strengths include the use of prospectively ascertained outcomes, a representative sample of community-based practices, and the use of a comprehensive database and electronic health records for obtaining the information. The outcomes reported in this study were captured and adjudicated by the TJRR on a quarterly basis using a validated algorithm for SSI identification<sup>10</sup> and standard protocol for readmission ascertainment, minimizing the risk of information bias. The cases, surgeons and medical centers that participate in the TJRR are believed to be representative of community-based practices. The patient samples of each location are of various case mix levels and similar to the larger state population with regards to age, race and gender distribution.<sup>20-22, 38</sup> The variety of surgeon and hospital volumes,

training levels, and setting also increases the generalizability of the findings, which are representative of the larger American orthopedic community. Additionally, an integrated healthcare system was used to obtain the data used in this study. The ability to link all patient records, using one common unique identifier, within the system with such a large sample cannot be reproduced by other smaller centers or by any of the larger national TJA samples (Nationwide Inpatient Sample, regional TJR registries, or the American Total Joint Replacement Registry). This integrated system also decreases the possibility of any data handling bias (merging errors, record linkage bias) in this study.

In conclusion, this observational study did not find a significant reduction in the risk of SSI and 90 day readmission rates in obese patients who lost 5% of their body weight prior to their primary TJA procedure. While a risk reduction was not observed, it should be noted that few patients lost weight prior to their procedure and even fewer moved to lower risk profiles ( $\text{BMI} < 30 \text{ kg/m}^2$ ) at the time of their surgery. Further research is needed to determine what amount of weight loss would impact these specific outcomes and the timing prior to surgery when these changes would be clinically helpful.

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Chapter 3, in full, has been submitted for publication of the materials as it may appear in Journal of Arthroplasty. Inacio, Maria C.S.; Kritz-Silverstein, Donna; Raman, Rema; Macera, Caroline A.; Nichols, Jeanne F.; Shaffer, Richard A.; Fithian, Donald C. The Impact of Pre-operative Weight Loss on Incidence of Surgical Site Infection and Readmission After Total Joint Arthroplasty. The dissertation author was the primary investigator and author of this paper.

Table 3.1. Total Knee and Total Hip Arthroplasty Study Sample Characteristics by Pre-operative Weight Change, 2008-2010.

	TKA			THA		
	Gainer N (%)	Loser N (%)	Remain the Same N (%)	Gainer N (%)	Loser N (%)	Remain the Same N (%)
Total N <sup>1</sup>						
Gender						
Female	817 (7.6)	1332 (12.4)	8569 (79.9)	258 (6.3)	732 (18.0)	3076 (75.7)
Male	562 (68.8)	892 (67.0)	5429 (63.4)	140 (54.3)	448 (61.2)	1644 (53.5)
Age Category, Years						
<65	255 (31.2)	440 (33.0)	3140 (36.6)	118 (45.7)	284 (38.8)	1432 (46.6)
≥65	463 (56.7)	638 (47.9)	3717 (43.4)	163 (63.2)	364 (49.7)	1538 (50.0)
Race						
Asian	354 (43.3)	694 (52.1)	4852 (56.6)	95 (36.8)	368 (50.3)	1538 (50.0)
Black	26 (3.2)	34 (2.6)	307 (3.6)	3 (1.2)	11 (1.5)	47 (1.5)
Hispanic	97 (11.9)	147 (11.0)	933 (10.9)	30 (11.6)	69 (9.4)	317 (10.3)
Other/Multi	130 (15.9)	204 (15.3)	1615 (18.9)	22 (8.5)	62 (8.5)	324 (10.5)
White	14 (1.7)	31 (2.3)	179 (2.1)	3 (1.2)	16 (2.2)	57 (1.9)
Unknown	543 (66.5)	906 (68.0)	5403 (63.1)	195 (75.6)	567 (77.5)	2294 (74.6)
Diabetes	7 (0.9)	10 (0.8)	132 (1.5)	5 (1.9)	7 (1.0)	37 (1.2)
ASA Score						
1&2	258 (31.6)	423 (31.8)	2792 (32.6)	74 (28.7)	200 (27.3)	811 (26.4)
Category						
≥3	369 (45.2)	674 (50.6)	4430 (51.7)	129 (50.0)	389 (53.1)	1595 (51.9)
Unknown	432 (52.9)	629 (47.2)	3962 (46.2)	124 (48.1)	331 (45.2)	1415 (46.0)
Intra-operative BMI category, kg/m <sup>2</sup>						
<30	16 (2.0)	29 (2.2)	177 (2.1)	5 (1.9)	12 (1.6)	66 (2.2)
≥30 and <35	3 (0.4)	338 (25.4)	420 (4.9)	3 (1.2)	243 (33.2)	209 (6.8)
≥35	314 (38.4)	565 (42.4)	4447 (51.9)	115 (44.6)	312 (42.6)	1750 (56.9)
	500 (61.2)	429 (32.2)	3702 (43.2)	140 (54.3)	177 (24.2)	1117 (36.3)

TKA=Total Knee Arthroplasty. THA=Total Hip Arthroplasty. ASA=American Society of Anesthesiologists. BMI=Body Mass Index.

1. Total N row has row percentage for values. All other percentages in this table are for column values.

Table 3.2. Total Knee and Total Hip Arthroplasty Study Sample Co-morbidities by Pre-operative Weight Change, 2008-2010.

	Total Knee Arthroplasty				Total Hip Arthroplasty			
	All	Gain	Loser	Remain the Same	All	Gain	Loser	Remain the Same
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
Total N	10718 (100)	817 (7.6)	1332 (12.4)	8569 (79.9)	4066 (100)	258 (6.3)	732 (18.0)	3076 (75.7)
Hypertension	6905 (64.4)	500 (61.2)	870 (65.3)	5535 (64.6)	2571 (63.2)	148 (57.4)	478 (65.3)	1945 (63.2)
Chronic pulmonary disease	1782 (16.6)	150 (18.4)	227 (17.0)	1405 (16.4)	617 (15.2)	51 (19.8)	116 (15.9)	450 (14.6)
Hypothyroidism	1382 (12.9)	98 (12.0)	188 (14.1)	1096 (12.8)	473 (11.6)	32 (12.4)	89 (12.2)	352 (11.4)
Deficiency anemia	1074 (10.0)	93 (11.4)	140 (10.5)	841 (9.8)	457 (11.2)	25 (9.7)	94 (12.8)	338 (11.0)
Renal failure	942 (8.8)	69 (8.5)	114 (8.6)	759 (8.9)	352 (8.7)	17 (6.6)	82 (11.2)	253 (8.2)
Depression	744 (6.9)	79 (9.7)	106 (8.0)	559 (6.5)	268 (6.6)	25 (9.7)	59 (8.1)	184 (6.0)
Psychoses	634 (5.9)	55 (6.7)	92 (6.9)	487 (5.7)	205 (5.0)	17 (6.6)	40 (5.5)	148 (4.8)
Fluid and electrolyte disorders	551 (5.1)	31 (3.8)	54 (4.1)	466 (5.4)	212 (5.2)	5 (1.9)	43 (5.9)	164 (5.3)
Peripheral vascular disease	392 (3.7)	28 (3.4)	48 (3.6)	316 (3.7)	159 (3.9)	8 (3.1)	30 (4.1)	121 (3.9)
Congestive heart failure	350 (3.3)	35 (4.3)	42 (3.2)	273 (3.2)	139 (3.4)	4 (1.6)	37 (5.1)	98 (3.2)
Valvular disease	287 (2.7)	18 (2.2)	32 (2.4)	237 (2.8)	99 (2.4)	3 (1.2)	17 (2.3)	79 (2.6)
Other neurological disorders	270 (2.5)	31 (3.8)	35 (2.6)	204 (2.4)	84 (2.1)	7 (2.7)	15 (2.1)	62 (2.0)
Liver disease	252 (2.4)	20 (2.5)	22 (1.7)	210 (2.5)	89 (2.2)	8 (3.1)	16 (2.2)	65 (2.1)
Rheumatoid arthritis/collagen vas	255 (2.4)	29 (3.6)	32 (2.4)	194 (2.3)	86 (2.1)	6 (2.3)	11 (1.5)	69 (2.2)
Chronic blood loss anemia	229 (2.1)	16 (2.0)	49 (3.7)	164 (1.9)	78 (1.9)	7 (2.7)	22 (3.0)	49 (1.6)
Coagulopathy	160 (1.5)	12 (1.5)	18 (1.4)	130 (1.5)	57 (1.4)	6 (2.3)	13 (1.8)	38 (1.2)
Alcohol abuse	123 (1.2)	13 (1.6)	15 (1.1)	95 (1.1)	69 (1.7)	8 (3.1)	11 (1.5)	50 (1.6)

Table 3.2. Total Knee and Total Hip Arthroplasty Study Sample Co-morbidities by Pre-operative Weight Change, 2008-2010. Continued.

	Total Knee Arthroplasty				Total Hip Arthroplasty			
	All	Gain	Lose	Remain the Same	All	Gain	Lose	Remain the Same
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
Solid tumor w/out metastasis	91 (0.9)	5 (0.6)	13 (1.0)	73 (0.9)	39 (1.0)	0 (0.0)	5 (0.7)	34 (1.1)
Pulmonary circulation disease	80 (0.8)	6 (0.7)	11 (0.8)	63 (0.7)	42 (1.0)	1 (0.4)	6 (0.8)	35 (1.1)
Drug abuse	62 (0.6)	9 (1.1)	13 (1.0)	40 (0.5)	46 (1.1)	3 (1.2)	12 (1.6)	31 (1.0)
Weight loss	46 (0.4)	0 (0.0)	4 (0.3)	42 (0.5)	22 (0.5)	0 (0.0)	3 (0.4)	19 (0.6)
Paralysis	42 (0.4)	4 (0.5)	6 (0.5)	32 (0.4)	20 (0.5)	0 (0.0)	3 (0.4)	17 (0.6)
Lymphoma	21 (0.2)	2 (0.2)	2 (0.2)	17 (0.2)	13 (0.3)	2 (0.8)	3 (0.4)	8 (0.3)
Metastatic cancer	13 (0.1)	2 (0.2)	0 (0.0)	11 (0.1)	6 (0.2)	0 (0.0)	1 (0.1)	5 (0.2)
Peptic ulcer disease with bleeding	1 (<0.1)	0 (0.0)	0 (0.0)	1 (<0.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Acquired immune deficiency syndrome	2 (<0.1)	0 (0.0)	0 (0.0)	2 (<0.1)	2 (0.1)	0 (0.0)	1 (0.1)	1 (<0.1)
Unknown	1500 (14.0)	114 (14.0)	173 (13.0)	1213 (14.2)	450 (11.1)	29 (11.2)	61 (8.3)	360 (11.7)



Table 3.3. Patient Characteristics and Co-morbidities Associated with Likelihood of Pre-operative Weight Change. Adjusted Odds Ratios, 95% Confidence Intervals and Wald Chi-square P value.

<i>Reference group= Remain the Same</i>	<i>Gainer</i>		<i>Loser</i>	
	<b>OR (95% CI)</b>	<b>P Value</b>	<b>OR (95% CI)</b>	<b>P Value</b>
<b>TKA</b>				
Age (per 1 year increment)	0.96 (0.95-0.97)	<0.001	0.99 (0.98-1.00)	0.002
Gender (Male vs. Female)	0.78 (0.66-0.91)	0.002	0.85 (0.75-0.96)	0.009
Asian vs. White	0.81 (0.53-1.22)	0.311	0.65 (0.45-0.93)	0.018
Black vs. White	0.91 (0.72-1.15)	0.446	0.90 (0.75-1.09)	0.291
Hispanic vs. White	0.74 (0.61-0.91)	0.004	0.73 (0.62-0.86)	<0.001
Other race vs. White	0.71 (0.41-1.24)	0.234	1.48 (0.68-1.48)	0.989
Diabetes	1.02 (0.87-1.20)	0.794	1.01 (0.89-1.14)	0.936
Blood Loss Anemia	1.04 (0.62-1.75)	0.872	1.84 (1.32-2.56)	<0.001
Congestive Heart Failure	1.70 (1.17-2.47)	0.005	1.04 (0.74-1.46)	0.829
Depression	1.28 (0.99-1.65)	0.056	1.12 (0.90-1.40)	0.315
Deficiency anemia	1.21 (0.96-1.53)	0.103	1.12 (0.93-1.35)	0.237
Neurological Disorders	1.49 (1.00-2.21)	0.048	1.03 (0.71-1.50)	0.867
<b>THA</b>				
Age (per 1 year increment)	0.97 (0.96-0.99)	<0.001	1.00 (0.99-1.01)	0.811
Gender (Male vs. Female)	0.95 (0.72-1.23)	0.676	0.73 (0.62-0.86)	<0.001
Asian vs. White	0.64 (0.20-2.11)	0.465	0.99 (0.51-1.93)	0.972
Black vs. White	1.07 (0.71-1.61)	0.743	0.87 (0.66-1.15)	0.319
Hispanic vs. White	0.71 (0.44-1.12)	0.141	0.78 (0.58-1.04)	0.090
Other race vs. White	0.57 (0.18-1.84)	0.348	1.15 (0.65-2.02)	0.639
Diabetes	1.31 (0.86-1.77)	0.085	1.02 (0.84-1.24)	0.837
Blood Loss Anemia	1.62 (0.71-3.66)	0.250	1.73 (1.02-2.94)	0.042
Congestive Heart Failure	0.52 (0.20-1.37)	0.184	1.44 (0.97-2.15)	0.074
Depression	1.62 (1.03-2.55)	0.038	1.22 (0.90-1.65)	0.197
Fluid and Electrolyte Disorders	0.43 (0.18-1.01)	0.052	0.98 (0.69-1.39)	0.901
Chronic Pulmonary Disease	1.44 (1.04-2.00)	0.029	0.97 (0.77-1.21)	0.770
Renal Failure	0.98 (0.57-1.66)	0.926	1.32 (0.99-1.76)	0.060
Hypertension	0.80 (0.59-1.08)	0.141	0.94 (0.77-1.14)	0.517

TKA=Total Knee Arthroplasty. THA=Total Hip Arthroplasty. OR=Odds ratio.  
CI=Confidence Intervals.

Table 3.4. Crude Incidence of Post-operative Outcomes by Pre-operative Weight Change.

	Total Sample		Pre-Operative Weight Group					
			Gainer		Loser		Remain the Same	
	N	(%)	N	(%)	N	(%)	N	(%)
TKA	10718	100.0	817	7.6	1332	12.4	8569	79.9
Surgical Site Infection (any)	124	1.2	16	2.0	15	1.1	93	1.1
Surgical Site Infection Deep	86	0.8	11	1.4	11	0.8	64	0.8
Surgical Site Infection Superficial	38	0.4	5	0.6	4	0.3	29	0.3
Readmission within 90 days <sup>1</sup>	392	5.2	38	6.7	51	5.8	303	5.0
THA	4066	100.0	258	6.3	732	18.0	3076	75.7
Surgical Site Infection (any)	64	1.6	5	1.9	14	1.9	45	1.5
Surgical Site Infection Deep	35	0.9	2	0.8	9	1.2	24	0.8
Surgical Site Infection Superficial	29	0.7	3	1.2	5	0.7	21	0.7
Readmission within 90 days <sup>1</sup>	194	6.7	18	9.5	35	7.0	141	6.4

TKA=Total Knee Arthroplasty. THA=Total Hip Arthroplasty.

1. Readmission denominator is from 2009 onward. (Total TKA N=7515, Total THA N=2894)

Table 3.5. Risk of Surgical Site Infection (Any, Deep, and Superficial) and 90 Day Readmission by Pre-operative Weight Change. Odds Ratios, 95% Confidence Intervals and Wald Chi-square P Value.

		Unadjusted OR (95%CI)	P Value	Adjusted OR (95%CI)	P Value
TKA					
Surgical Site	Loser	1.04 (0.60-1.80)	0.894	1.13 (0.65-1.96)	0.668
Infection (any) <sup>1</sup>	Gainer	1.82 (1.07-3.11)	0.028	1.50 (0.87-2.58)	0.144
Surgical Site	Loser	1.11 (0.90-1.36)	0.328	1.27 (0.66-2.42)	0.473
Infection Deep <sup>2</sup>	Gainer	1.81 (1.48-2.22)	<0.001	1.59 (0.83-3.06)	0.162
Surgical Site	Loser	0.89 (0.31-2.53)	0.822	0.83 (0.29-2.37)	0.728
Infection	Gainer	1.81 (0.70-4.70)	0.220	1.46 (0.56-3.82)	0.440
Superficial <sup>3</sup>					
Readmission	Loser	1.09 (0.81-1.47)	0.570	1.20 (0.88-1.63)	0.240
within 90 days <sup>4</sup>	Gainer	1.28 (0.91-1.80)	0.155	1.29 (0.90-1.84)	0.167
THA					
Surgical Site	Loser	1.31 (0.72-2.41)	0.377	1.48 (0.80-2.75)	0.212
Infection (any) <sup>5</sup>	Gainer	1.33 (0.52-3.39)	0.547	1.11 (0.43-2.85)	0.826
Surgical Site	Loser	1.58 (0.73-3.42)	0.243	1.83 (0.83-4.02)	0.135
Infection Deep <sup>6</sup>	Gainer	0.99 (0.99-4.23)	0.999	0.88 (0.20-3.81)	0.868
Surgical Site	Loser	1.00 (0.38-2.66)	0.999	1.16 (0.43-3.13)	0.765
Infection	Gainer	1.71 (0.51-5.78)	0.387	1.40 (0.41-4.77)	0.591
Superficial <sup>7</sup>					
Readmission	Loser	1.09 (0.75-1.58)	0.656	1.05 (0.70-1.57)	0.811
within 90 days <sup>8</sup>	Gainer	1.61 (0.98-2.63)	0.058	1.35 (0.80-2.27)	0.259

Reference group=remain the same (weight change <5%). TKA=Total Knee Arthroplasty. THA=Total Hip Arthroplasty. OR=Odds ratio. CI=Confidence Intervals.

1. Model adjusted for intra-operative body mass index (BMI), gender, age, chronic blood loss anemia.
2. Model adjusted for intra-operative BMI, gender, chronic blood loss anemia.
3. Model adjusted for age and gender.
4. Model adjusted for intra-operative BMI, age, and congestive heart failure
5. Model adjusted for intra-operative BMI, gender, chronic blood loss anemia.
6. Model adjusted for intra-operative BMI, age and chronic blood loss anemia.
7. Model adjusted for intra-operative BMI and age.
8. Model adjusted for intra-operative BMI, age, chronic blood loss anemia and chronic pulmonary disease.

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## CHAPTER 4.

The Risk of Surgical Site Infection and Readmission in Obese Total Joint Arthroplasty

Patients Who Lose Weight Prior to Surgery and Keep it Off Post-operatively



## ABSTRACT

**Objective:** To characterize a group of obese (body mass index (BMI)  $\geq 30 \text{ kg/m}^2$ ) patients undergoing primary TJA who lost weight non-surgically prior to their procedure and kept it off post-operatively and to assess whether these patient were at a lower risk of surgical site infection (SSI) or readmission than patients who remained the same weight in both pre and post-TJA periods.

**Methods:** Obese patients at one year prior to primary total hip arthroplasty (THA) or total knee arthroplasty (TKA) were identified using a Total Joint Replacement Registry (TJRR). Weight measurements one year pre and post-TJA were obtained from electronic health records. Pre-operative weight loss ( $\geq 5\%$  weight change) sustained or progressive post-operatively was the exposure of interest. Patients who remained the same weight throughout the year before and after TJA were the reference. Endpoints of this study, SSI and ninety day readmission, were obtained from the TJRR. Gender, age, race, co-morbidities, health status, and intra-operative BMI were used to characterize the study sample and investigated as confounders of the weight group, SSI and ninety day readmission relation.

**Results:** 444 THA and 937 TKA patients lost weight pre-operatively and sustained after surgery. In THA patients, gender, congestive heart failure, and coagulopathy were associated with postoperative weight loss. In TKA patients, gender, race, chronic blood loss, and liver disease were associated with weight loss. In THA patients, significant higher odds of deep SSI (OR=3.77, 95% CI 1.59-8.95) was observed in patients who lost weight and kept it off post-operatively than the reference group. In TKA patients, a 1.63 (95%CI 1.16, 2.28) higher odds of ninety day

readmissions was observed in patients who lost weight and kept it off compared to the reference group.

Conclusions: Patient characteristics and co-morbidities are associated with ability to lose weight one year pre-TJA and keep it off post-operatively. In obese THA patients who lose weight pre-operatively and keep it off post-operatively the likelihood of deep SSI is higher than in patients who stayed the same weight throughout the study period. Obese TKA patients who lost weight were at a higher likelihood of readmission. These findings raise questions in regards to the safety of, and proper weight management interventions prior to, TJA procedures.

## INTRODUCTION

Patient characteristics, such as obesity and its related co-morbid conditions are important risk factors for osteoarthritis which in its most severe stages, can lead to total joint arthroplasty (TJA). Obesity is also an indicator of the outcome of TJA.<sup>1, 2</sup> Survivorship of the implant and post-operative complications (such as surgical site infection (SSI), thromboembolic events, and service utilization after procedure) are the most important outcomes by which the success of TJA procedures can be evaluated and can be more common in obese patients.<sup>3-5</sup> Obesity, due to biomechanical or metabolic factors, may result in a challenging surgical procedure.<sup>6</sup> The presence of more fat around the joint can lead to increased operative time, leading in turn, to increased risk of infection. In both knee<sup>7-11</sup> and hip procedures,<sup>8, 11, 12</sup> obesity has been strongly associated with risk of surgical site infection, increased risk of readmission after the procedure, and a generally negative impact on the outcomes of these procedures.<sup>3-5, 13</sup>

Current recommendations in the orthopedic literature<sup>3-5, 13</sup> and presumably practice, are to advise patients to lose weight prior to joint arthroplasty. Major medical triggers, such as planning for TJA, have been reported to be associated with successful weight loss and maintenance. This “teachable moment” has been reported by the National Weight Control Registry to be the weight loss trigger for 23% of registry enrollees.<sup>14</sup> Although a few small studies evaluated how surgically-induced weight loss in joint arthroplasty affects the outcomes of the procedure, no studies evaluate whether non-surgically induced weight loss<sup>15-17</sup> is associated with risk of post-operative complications. In addition, little is known about whether post-operative

maintenance of pre-operative weight loss is associated with lower risk of post-operative complications.

The purpose of this study was to (1) characterize a group of obese patients who underwent primary TJA and lost weight non-surgically prior to their procedure and kept it off post-operatively, and (2) determine whether patients who lost weight pre-TJA and kept it off post-TJA were at a lower risk of SSI or readmission than obese patients who remained the same weight in both the pre and post-TJA periods.

## METHODS

### *Study Design, Data Collection and Sample*

A retrospective analysis of patients who underwent TJA from January 1<sup>st</sup>, 2008 to December 31<sup>st</sup>, 2010 was conducted. Two data sources were used:

(1) A Total Joint Replacement Registry (TJRR) was used to identify the sample of patients who underwent primary total hip arthroplasty (THA) or total knee arthroplasty (TKA) and their post-operative SSI and ninety-day readmissions. The TJRR data collection mechanism, structure, and coverage have been previously described.<sup>18-20</sup> In brief, this TJRR covers an integrated healthcare system membership of over 9 million in the United States. Data are collected using both surgeon reported data (intra-operative information) and direct extraction from patients' electronic health records, administrative and/or claims data, as well as other databases within the institution (e.g., a Diabetes Registry). The TJRR ascertains re-operations, revisions, SSIs, thromboembolic events, and readmissions associated with TJA procedures prospectively. The 2010 voluntary participation in the registry was 90% for THAs and 95% for TKAs.

(2) The institution's electronic health records (EHR) were used to extract the sample's weight measurements. The EHR is composed of several modules (i.e. inpatient, outpatient, operative); during most patient encounters with the healthcare system weight measurements are captured. Patients were not advised or encouraged, as part of the study, to lose weight and no standard protocol for weight assessment was in effect during patient encounters. Weight data were extracted for the time intervals of (1) 181-365 days pre-operative, (2) 91-180 days pre-operative, (3) 0-90 days pre-operative (considered the intraoperative time), (4) 1-90 days post-operative, (5) 91-180 days post-operative, and (6) 181-365 days post-operative. If more than one weight per period was recorded, the median weight for that period was used.

Patients who were obese ( $\text{BMI} \geq 30 \text{ kg/m}^2$ ) one year prior to their primary unilateral THA or TKA for osteoarthritis were identified ( $N=15099$ ). Only TJA procedures performed in the two largest geographical regions (Southern and Northern California) covered by the TJRR were included in the sample due to the availability of patient co-morbidity information. Patients who had undergone surgical weight loss were not included in the sample. Patients who had missing one year pre- and post-operative ( $N=1436$ ) weight measurements were excluded. Finally, weight change was defined as  $\geq 5\%$  body weight change, according to the Food and Drug Administration (FDA) suggestion of a clinically significant amount of weight change.<sup>21</sup> Only patients who had lost weight non-surgically prior to their procedure and kept it off post-operatively and those who remained the same weight through the study period were included in the sample. Patients who fit any other weight pattern- either a) gaining weight pre-operatively or post-operatively, b) losing weight pre-operatively but then regaining, or c)

remaining the same pre-operatively and then gaining or losing weight post-operatively - were not included in the analysis (N=3988). The remaining sample had 9675 patients.

Institutional Review Board approval was obtained before study commencement.

### *Exposure of Interest*

Pre-operative weight loss sustained or continued post-operatively was the exposure of interest. Patients who remained the same weight throughout the year prior and after TJA were used as the reference group for the study.

### *Outcomes of Interest*

SSI and ninety day readmissions were the endpoints of this study. Deep and superficial SSIs were defined according to the Centers for Disease Control and Prevention/ National Healthcare Safety Network criteria.<sup>22</sup> In brief, a deep SSI is attributed to the TJA procedure if it occurs up to one year post-operatively and involves deep soft tissue; a superficial infection is attributed to the TJA if occurs within thirty days of the procedure and involves only skin and subcutaneous tissue of the incision site. In addition, to be considered a SSI (a) it must also have purulent drainage; or (b) the incision dehisces or is opened and has positive cultures or if not cultured the patient has fever, pain, tenderness or swelling; or (c) an abscess or other evidence of infection is found during examination; or (d) a surgeon or attending physician diagnoses an infection. Ninety day readmission is defined as any inpatient readmission for any reason within ninety days of the discharge date of the TJA. The ninety day readmission endpoint was only available for cases registered between January 1<sup>st</sup>, 2009 and December 31<sup>st</sup>, 2010 (N=6859); therefore the analysis for this endpoint has a different denominator than for SSIs.

### *Covariates*

Patient characteristics (gender, age, race), co-morbidities as defined by the Elixhauser comorbidity algorithm,<sup>23</sup> general health status as defined by the American Society of Anesthesiologists (ASA) score, and intra-operative BMI were the covariates evaluated. These covariates were used to characterize the study sample and investigated as confounders of the weight group, SSI and ninety day readmission relation.

### *Statistical Analysis*

Means and standard deviations were used to describe continuous variables and frequencies and rates were used to describe categorical variables. Cumulative incidence of SSI and ninety day readmission were calculated as the number of events over the number of cases. Analyses were conducted for TKA and THA procedures separately. Binary logistic regression models were used to characterize patients who lost weight pre-operatively and kept it off or continued to lose weight post-operatively, compared to those who remained the same weight. Multivariable models comparing the likelihood of a patient being in one group versus the other were created by including all patient characteristics associated with the outcome ( $p < 0.1$ ) in bivariate models. Binary logistic regression models were created to evaluate whether losing weight pre-operatively and maintaining post-operatively was associated with likelihood of SSI (deep and superficial) and readmission compared to those who remained the same weight throughout the study period. Final binary logistic models included variables associated with being a patient who lost weight pre-operatively and maintained post-operatively and the outcome of interest (using  $p < 0.1$ ). Odds ratios (OR), 95% confidence intervals (CI) and Wald Chi-square p-values are reported for all models.

Missing data were excluded from analysis. Groups with complete data and those with missing data were compared. Multicollinearity was evaluated and tolerance values threshold levels were set at  $<0.1$ . Data were analyzed using SAS (Version 9.2, SAS Institute, Cary, NC, USA) and  $\alpha=0.05$  was used as the criterion of statistical significance.

## RESULTS

During the study period 444 obese THA patients lost weight one year pre-operatively and either kept off or continued to lose after surgery while 2110 obese THA patients remained the same weight one year pre- and post-operatively. THA patients who lost weight pre-operatively started the study period (6 months to 1 year pre-operatively) at average BMI  $35.8\text{kg/m}^2$  (SD=4.8) and ended the study period (6 months to 1 year post-operatively) at an average of  $31.8\text{kg/m}^2$  (SD=4.5). Average weight loss of THA patients was 9.2% (SD=4.5) pre-operatively and 1.5% (SD=5.4) post-operatively. Obese THA patients who did not change their weight throughout the study period started the study at an average BMI of  $34.6\text{kg/m}^2$  (SD=4.2) and ended at  $34.5\text{kg/m}^2$  (SD=4.3). Table 4.1 shows distribution characteristics of THA and TKA groups and Table 4.2 has patients' co-morbidities profiles. Figure 4.1 shows average weights per time period for the THA groups.

Amongst TKA patients, 937 obese patients lost weight pre-operatively and kept off or lost more post-operatively while 6184 stayed the same weight during the entire study period. See Table 4.1 for sample description. TKA patients who lost weight pre-operatively and kept off or lost more weight post-operatively started the study at an



average BMI of 36.9 kg/m<sup>2</sup> (SD=5.4) and ended at 33.0 kg/m<sup>2</sup> (SD=4.8). The average weight loss of these patients was 8.2% (SD=3.7) pre-operatively and 2.0% (SD=5.1) post-operatively. TKA patients who remained the same weight throughout the study period started at an average BMI of 35.3kg/m<sup>2</sup> (SD=4.5) and ended at 35.2kg/m<sup>2</sup> (SD=4.6). Figure 4.2 shows the average weights per time period for the different weight groups in TKA patients.

The multivariable models in Table 4.3 show the patient characteristics associated with likelihood of being in the group who lost weight compared to those who remained the same the entire study period. In THA patients, men were less likely than women to lose weight and keep it off during the study period (OR=0.59, 95% CI 0.47-0.74). Patients with congestive heart failure (OR=1.79, 95% CI 1.10-2.92) or coagulopathy (OR=2.70, 95% CI 1.30-5.56) were more likely to lose weight pre-operatively and keep it off after the procedure than those without these co-morbidities. In TKA patients, men were also less likely to lose weight pre-operatively and keeping it off post-operatively (OR=0.75, 95% CI 0.64-0.88) than women. Racial differences were found, such that Asian patients (OR=0.60, 95% CI 0.38-0.93) and Hispanics (OR=0.66, 95% CI 0.54-0.81) being less likely to lose weight and keep it off than Whites. In addition, in TKA patients, chronic blood loss anemia was associated with higher likelihood (OR=2.20, 95% CI 1.52-3.19) of pre-operative weight loss and maintenance while patients with liver disease were less likely to be in the group who lost weight and maintained (OR=0.48, 95% CI 0.26-0.88).

THA patients who lost weight and kept it off post-operatively had an incidence rate of 2.7% (n=12) for SSIs (deep and superficial combined) and 8.1% (n=22) for

readmissions within ninety days while patients who remained the same weight throughout the study had an incidence rate of 1.4% (n= 29) for SSIs and 6.6% (n=88) for readmissions. In TKA patients, 1.2% (n=11) had a SSI (deep and superficial combined) and 8.1% (n=45) were readmitted within ninety days of the procedure in patients who lost weight and kept it off compared to 0.9% (n=53) SSIs and 5.2% (n=197) readmissions among those who remained the same weight for the entire study period. See Table 4.4.

In THA patients, after adjusting for confounders a statistically significant higher odds of deep SSI was found in patients who lost weight and kept it off post-operatively than those who remained the same weight throughout the study period (OR=3.77, 95% CI 1.59-8.95). No differences in likelihood of superficial SSI or readmission were observed. In TKA patients, after adjustments, a 1.63 (95%CI 1.16, 2.28) higher odds of ninety days readmissions was found in patients who lost weight and kept it off compared to those who remained the same the entire study period. No differences in likelihood of SSIs were observed. See Table 4.5.

## DISCUSSION

Patient characteristics such as gender, age, and race are associated with the ability to lose weight one year prior to their joint arthroplasty and keep it off post-operatively. Certain co-morbidities, such as congestive heart failure and coagulopathy in THA patients and chronic blood loss anemia and liver disease in TKA patients, are also associated with weight loss. Most importantly, in this study obese THA patients who lost weight pre-operatively and kept it off post-operatively had a higher likelihood of deep

SSI than patients who stayed the same weight throughout the study period. Additionally, obese TKA patients who lost weight had a higher likelihood of ninety day readmission.

Two previous studies, using the same data source as this study, reported that certain patient characteristics were associated with weight pattern prior to and after the THA procedure.<sup>24, 25</sup> While the present study evaluated the characteristics of patients' ability to lose weight and keep off weight, and the other evaluated only pre-operative weight change, consistent patient characteristics were associated with the cohort evaluated in this study. Except for these studies, the associations of patient characteristics with weight changes have not been previously reported among TKA and THA patients. However, the patterns found in the current study are consistent with the varying prevalence of obesity by age, gender and racial groups in the US<sup>26</sup> and likely ability of these groups to change their weight.<sup>27</sup>

The association of co-morbidities with pre-operative weight loss sustained post-operatively should be interpreted in relation to both its pre and post-operative impact. In a previous study, we did not find coagulopathy or congestive heart failure to be associated with pre-operative weight change in THAs as in the current study, leading us to believe that these are characteristics associated with the post-operative weight change of the cohort.<sup>25</sup> Similarly, we did not find liver disease to be associated with a lower likelihood of weight loss in our previous study (again without post-operative maintenance) while in the current study it was significantly associated with TKA patients' ability to lose weight. Chronic blood loss anemia had been previously reported to be associated with susceptibility to weight loss prior to TKA, confirming this weight loss is likely symptomatic of the cause of this co-morbidity. The

difference in patterns of associations of these co-morbidities (coagulopathy and congestive heart failure in THAs and liver disease in TKA) suggests that these co-morbidities are associated with the post-operative weight maintenance or further weight loss post-operatively, either due to associated complications or other mechanisms by which they impact the patients' metabolism post-operatively. Further study to evaluate the association of these co-morbidities with weight change in these patients is necessary.

Four studies have evaluated post-operative outcomes associated with pre-operative weight loss alone- without mention of post-operative maintenance.<sup>15-17, 25</sup> One, from the same data source used in this study, evaluated obese patients (1332 TKA and 732 THA) who underwent non-operative weight loss prior to surgery and did not find any association of a 5% pre-operative weight loss with risk of SSI or readmissions in obese TKA and THA patients.<sup>25</sup> Three studies evaluated patients who underwent surgical weight loss interventions and their post-operative TJA outcomes.<sup>15-17</sup> Those studies consistently report higher rates of peri-operative complications in these patients regardless of weight loss when compared to the larger TJA population from which they were drawn. Of note, all studies had limited sample size, with the largest having only 88 patients with pre-operative surgical intervention, and all were descriptive; no adjustments for other factors that could be associated with the outcomes were evaluated. These studies also do not mention the amount of weight loss patients experience during the procedure, which may be much higher than with non-surgical weight loss study and could account for the differences reported. The non-surgical weight loss study considered any patient with a weight loss of 5% or

more a “successful” weight loser, which is likely a minimal change compared to those patients with surgical weight loss.

The current study found that patients who lose weight pre-operatively and continue to lose weight post-operatively have a higher likelihood of deep SSI in the case of THAs and readmission in the case of TKAs. These unexpected results could be due to several reasons. First, because these patients continue to be obese, their risk of both these complications continues to be high.<sup>3-5, 13</sup> While we tried to compare them to other obese patients for control and adjust for possible co-morbid conditions that could influence complication risk, the possibility of residual confounding from unevaluated characteristics cannot be ruled out. Second, it is possible that post-operative weight loss occurred as a result of the complications and not the reverse. We evaluated the amounts of weight loss in patients by their complications in an attempt to clarify this possibility and found that in THA patients, those who had infections had lost 8.0% of weight pre-operative and 2.4% post-operative, compared to 9.2% and 1.5% in the ones without infections. In TKA patients, the pre-operative weight loss of those who were and were not readmitted was nearly identical (8% both) but their post-operative weight loss was 1.8% in those not readmitted and 4.5% in the readmitted patients. While these are higher rates of post-operative weight loss of the patients with complications, the amount is not sufficient to explain the temporal relationship of these events. Third, patients with weight loss in this study may be similar those in the surgical weight loss studies where patients are still undergoing weight loss post-TKA (assuming they have not reached their goal weight at their reported weight, which in the two studies available was still over 35kg/m<sup>2</sup> for most patients). While the body is

undergoing major changes associated with weight loss, some unintended consequences are possible, such as malnutrition, which is associated with poor post-TJA outcomes.<sup>28</sup> In addition, the added trauma of a surgical procedure, could have triggered a catabolic state in these patients, thereby increasing patients' risk of complications.<sup>29, 30</sup>

This study's limitations include its non-random sample, the lack of standardization in the weight data collection, and our inability to discern whether post-operative weight loss was due to complications or the inverse. From the available sample of 15099 obese patients 1436 (9.5%) were missing pre- and post-operative weight and were not included in the study. In the knees, patients with missing data were not different from the ones with data in regards to gender, intra-operative BMI, and infections. TKA patients with missing data were, however, younger (66 vs. 68 years), more Hispanic (18% vs. 12%), had less co-morbidities (6.6% vs. 8.8%), were generally healthier at the time of surgery (ASA 1&2 58% vs. 50%), and had less readmission (0.9% vs. 6.4%) than those with data. In hip patients, those with missing data were not different from the ones with data in regards to race, intra-operative BMI, co-morbidities, and superficial infection. But THA with missing data were younger (62 vs. 65 years), more likely male (51% vs. 44%), had lower ASA scores (1&2 59% vs. 53%), had less readmissions (2.1% vs. 8.2%) and less deep infections (0% vs. 1.0%) than those with complete data. This pattern of missing data suggests that healthier patients may have been excluded from our sample because they did not have weight measures. This could potentially bias our estimates; however, it does not explain why the potential benefit of weight loss was not observed in the risk of SSI and readmissions in our sample and why post-operative risks were increased in certain

cases. Our sample was a convenience sample from a cohort registered in a TJRR. While there are clear indications for TJA<sup>31</sup> and the TJRR has a high capture rate<sup>20</sup> this sample could be biased by instances where TJA procedures are being delayed due to patients' obesity, non-compliance, or other reasons. The weight data reported in this study were captured during patient encounters with the integrated healthcare system the TJRR covers. Because a large number of locations and providers contributed data, no protocol for exposure ascertainment was available and this could bias our findings. However, there is no reason to believe this bias would be differential amongst locations, providers, and types of patients. Finally, this study is limited in ability to discern the temporal relation between the patients' postoperative weight loss and the complications reported. However, we do not believe that the pre-operative weight loss in these patients caused post-operative complications as previous work by this group has shown<sup>25</sup> but we are unable to comment whether the post-operative complications were due to or a cause of the post-operative weight loss.

Study strengths include the use of prospectively ascertained outcomes, a representative sample of community-based practices, and the use of a comprehensive database and electronic health records for obtaining the information. The outcomes reported in this study were captured and adjudicated by the TJRR on a quarterly basis using a validated algorithm for SSI identification<sup>35</sup> and standard protocol for readmission ascertainment, minimizing the risk of information bias. The cases, surgeons and medical centers that participate in the TJRR are believed to be representative of community-based practices. The patient samples of each location are of various case mix levels and similar to the larger state population with respect to age,

race and gender distribution.<sup>32-34, 36</sup> The variety of surgeon and hospital volumes, training levels, and setting also increases the generalizability of the findings, which are representative of the larger American orthopedic community. Additionally, an integrated healthcare system was utilized to obtain the data used in this study. The ability to link all patient records, using one common unique identifier, within a system with such a large sample cannot be reproduced by other smaller centers or by any of the larger national TJA samples (Nationwide Inpatient Sample, regional TJR registries, or the American Total Joint Replacement Registry). This integrated system also decreases the possibility of any data handling bias (merging errors, record linkage bias) in this study.

In conclusion, while this study provides important information regarding non-surgical weight loss in obese patients and its implication in the likelihood of SSI and readmission it raises more questions in regards to the safety of, and proper weight management interventions prior to, TJA procedures.



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Chapter 4, in full, is currently being prepared for submission for publication of the material. Inacio MCS, Kritz-Silverstein D, Raman R, Macera CA, Nichols JF, Shaffer RA, Fithian DC. The Risk of Surgical Site Infection and Readmission in Obese Total Joint Arthroplasty Patients Who Lose Weight Prior to Surgery and Keep it Off Post-operatively. The dissertation author was the primary investigator and author of this paper.

Table 4.1. Sample Characteristics by Procedure Type and Weight Group, 2008-2010.

		THA		TKA	
		Pre-op Losers who kept off/lost post-op	Stay the same pre- and post-op	Pre-op Losers who kept off/lost post-op	Stay the same pre- and post-op
		N(%)	N(%)	N(%)	N(%)
Total N		444 (17.4)	2110 (82.6)	937 (13.2)	6184 (86.8)
Gender	Female	289 (65.1)	1109 (52.6)	639 (68.2)	3843 (62.1)
	Male	155 (34.9)	1001 (47.4)	298 (31.8)	2341 (37.9)
Age Category, years	<65	192 (43.2)	994 (47.1)	427 (45.6)	2639 (42.7)
	≥65	252 (56.8)	1116 (52.9)	510 (54.4)	3545 (57.3)
Race	Asian	7 (1.6)	35 (1.7)	25 (2.7)	228 (3.7)
	Black	39 (8.8)	220 (10.4)	107 (11.4)	647 (10.5)
	Hispanic	37 (8.3)	228 (10.8)	145 (15.5)	1243 (20.1)
	Other/Multi <sup>1</sup>	9 (2.0)	42 (2.0)	19 (2.0)	129 (2.1)
	Unknown	4 (0.9)	26 (1.2)	5 (0.5)	99 (1.6)
	White	348 (78.4)	1559 (73.9)	636 (67.9)	3838 (62.1)
Diabetes		131 (29.5)	559 (26.5)	287 (30.6)	2032 (32.9)
ASA Score Category	Unknown	7 (1.6)	41 (1.9)	17 (1.8)	138 (2.2)
	1&2	224 (50.5)	1097 (52.0)	466 (49.7)	3181 (51.4)
	≥3	213 (48.0)	972 (46.1)	454 (48.5)	2865 (46.3)
Intra-operative BMI, Kg/m <sup>2</sup>	<30	151 (34.0)	142 (6.7)	222 (23.7)	281 (4.5)
	≥30 and <35	191 (43.0)	1219 (57.8)	407 (43.4)	3225 (52.2)
	≥35	102 (23.0)	749 (35.5)	308 (32.9)	2678 (43.3)
Number of co- morbidities	Unknown	42 (9.5)	257 (12.2)	117 (12.5)	907 (14.7)
	0	32 (7.2)	154 (7.3)	64 (6.8)	343 (5.6)
	1	66 (14.9)	398 (18.9)	138 (14.7)	933 (15.1)
	2	104 (23.4)	502 (23.8)	199 (21.2)	1437 (23.2)
	3	102 (23.0)	404 (19.2)	207 (22.1)	1221 (19.7)
	4	46 (10.4)	219 (10.4)	120 (12.8)	750 (12.1)
	≥5	52 (11.7)	176 (8.3)	92 (9.8)	593 (9.6)

THA=Total Hip Arthroplasty. TKA=Total Knee Arthroplasty. BMI=Body Mass Index. ASA=American Society of Anesthesiologists.

1. Other/Multi=includes Native American, mixed races, and other.

Table 4.2. Total Knee and Total Hip Arthroplasty Study Sample Co-morbidities by Weight Groups, 2008-2010.

	THA			TKA		
	Pre-op Losers who kept off/lost post-op	Stay the same pre- and post-op	N (%)	Pre-op Losers who kept off/lost post-op	Stay the same pre- and post-op	N (%)
Total N	444 (17.4)	2110 (82.6)		937 (13.2)	6184 (86.8)	
Hypertension	298 (67.1)	1346 (63.8)		615 (65.6)	3993 (64.6)	
Chronic pulmonary disease	68 (15.3)	309 (14.6)		167 (17.8)	962 (15.6)	
Deficiency anemia	58 (13.1)	220 (10.4)		102 (10.9)	600 (9.7)	
Renal failure	53 (11.9)	190 (9.0)		83 (8.9)	541 (8.8)	
Hypothyroidism	50 (11.3)	236 (11.2)		136 (14.5)	768 (12.5)	
Depression	35 (7.9)	126 (6.0)		71 (7.6)	391 (6.3)	
Fluid and electrolyte disorders	32 (7.2)	109 (5.2)		46 (4.9)	340 (5.5)	
Psychoses	26 (5.9)	98 (4.6)		65 (6.9)	339 (5.5)	
Congestive heart failure	25 (5.6)	65 (3.1)		32 (3.4)	192 (3.1)	
Peripheral vascular disease	21 (4.7)	90 (4.3)		33 (3.5)	236 (3.8)	
Valvular disease	13 (2.9)	54 (2.6)		26 (2.8)	178 (2.9)	
Liver disease	12 (2.7)	39 (1.9)		11 (1.2)	156 (2.5)	
Coagulopathy	12 (2.7)	22 (1.0)		14 (1.5)	97 (1.6)	
Other neurological disorders	11 (2.5)	42 (2.0)		25 (2.7)	145 (2.3)	
Chronic blood loss anemia	11 (2.5)	31 (1.5)		39 (4.2)	120 (1.9)	
Rheumatoid arthritis/collagen vas	9 (2.0)	52 (2.5)		22 (2.4)	137 (2.2)	
Drug abuse	7 (1.6)	16 (0.8)		7 (0.8)	30 (0.5)	

TKA=Total Knee Arthroplasty. THA=Total Hip Arthroplasty. AIDS= Acquired immune deficiency syndrome.

Table 4.2. Total Knee and Total Hip Arthroplasty Study Sample Co-morbidities by Weight Groups, 2008-2010. Continued.

	THA		TKA	
	Pre-op Losers who kept off/lost post-op	Stay the same pre- and post-op	Pre-op Losers who kept off/lost post-op	Stay the same pre- and post-op
	N (%)	N (%)	N (%)	N (%)
Total N	444 (17.4)	2110 (82.6)	937 (13.2)	6184 (86.8)
Alcohol abuse	6 (1.4)	29 (1.4)	12 (1.3)	69 (1.1)
Solid tumor w/out metastasis	4 (0.9)	21 (1.0)	8 (0.9)	55 (0.9)
Pulmonary circulation disease	3 (0.7)	18 (0.9)	9 (1.0)	43 (0.7)
Weight loss	3 (0.7)	13 (0.6)	3 (0.3)	30 (0.5)
Lymphoma	2 (0.5)	5 (0.2)	1 (0.1)	13 (0.2)
Paralysis	1 (0.2)	9 (0.4)	3 (0.3)	21 (0.3)
AIDS	1 (0.2)	1 (0.1)	0 (0.0)	2 (0.0)
Peptic ulcer disease x bleeding	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.0)
Metastatic cancer	0 (0.0)	5 (0.2)	0 (0.0)	8 (0.1)
Unknown	42 (9.5)	257 (12.2)	117 (12.5)	907 (14.7)

TKA=Total Knee Arthroplasty. THA=Total Hip Arthroplasty. AIDS= Acquired immune deficiency syndrome.

Table 4.3. Patient Characteristics and Co-morbidities Associated with Likelihood of Pre-operative Weight Loss and Post-operative Maintenance Compared to Patients with No Weight Change Pre- and Post-operative. Adjusted Odds Ratios, 95% Confidence Intervals and Wald Chi-square P Value.

	OR	95% CI	P Value
<b>THA</b>			
Gender (Male vs. Female)	0.59	0.47-0.74	<0.001
Age (per 1 year increment)	1.01	0.99-1.02	0.400
Congestive Heart Failure	1.79	1.10-2.92	0.020
Coagulopathy	2.70	1.30-5.56	0.008
<b>TKA</b>			
Gender (Male vs. Female)	0.75	0.64-0.88	0.001
Race: Asian vs White	0.60	0.38-0.93	0.024
Race: Black vs White	0.85	0.67-1.08	0.186
Race: Hispanic vs White	0.66	0.54-0.81	<0.001
Race: Other/Multi <sup>1</sup> vs White	0.87	0.52-1.47	0.610
Chronic blood loss anemia	2.20	1.52-3.19	<0.001
Liver disease	0.48	0.26-0.88	0.018

Reference group= patients who remain the same pre and post arthroplasty (weight change <5%).

OR=Odds Ratio. CI=Confidence Interval. THA=Total Hip Arthroplasty. TKA=Total Knee Arthroplasty.

1. Other/Multi=includes Native American, mixed races, and other.

Table 4.4. Crude Incidence of Post-operative Outcomes by Weight Change Group.

	THA		TKA	
	Pre-op Losers who kept off/lost post-op	Stay the same pre- and post-op	Pre-op Losers who kept off/lost post-op	Stay the same pre- and post-op
	N (%)	N (%)	N (%)	N (%)
Total N	444 (17.4)	2110 (82.6)	937 (13.2)	6184 (86.8)
Deep Surgical Site Infection	9 (2.0)	14 (0.7)	8 (0.9)	37 (0.6)
Superficial Surgical Site Infection	3 (0.7)	15 (0.7)	3 (0.3)	16 (0.3)
Readmission within 90 days <sup>1</sup>	22 (8.1)	88 (6.6)	45 (8.1)	197 (5.2)

THA=Total Hip Arthroplasty. TKA=Total Knee Arthroplasty.

1. For THA: N=1809 ( $\geq 2009$ ), 206 (11%) missing readmission data. For TKA: N=5050, 706 (14%) missing readmission data.

Table 4.5. Unadjusted and Adjusted Risk of Surgical Site Infection (Deep and Superficial) and 90 Day Readmission for Patients with Pre-operative Weight Loss and Post-operative Maintenance Compared to Patients with No Weight Change Pre- and Post-operative. Odds Ratios, 95% Confidence Intervals and Wald Chi-square P value.

	Unadjusted			Adjusted		
	OR	95% CI	P Value	OR	95% CI	P Value
THA						
Surgical Site Infection Deep <sup>1</sup>	3.10	1.33-7.20	0.009	3.77	1.59-8.95	0.003
Surgical Site Infection Superficial <sup>2</sup>	0.95	0.27-3.30	0.936	0.95	0.27-3.30	0.936
Readmission within 90 days <sup>3</sup>	1.26	0.77-2.04	0.360	1.18	0.72-1.93	0.502
TKA						
Surgical Site Infection Deep <sup>4</sup>	1.43	0.66-3.08	0.360	1.67	0.77-3.61	0.195
Surgical Site Infection Superficial <sup>1</sup>	1.24	0.36-4.26	0.734	1.41	0.41-4.85	0.589
Readmission within 90 days <sup>5</sup>	1.60	1.14-2.24	0.006	1.63	1.16-2.28	0.005

Reference group= patients who remain the same pre- and post-TJA (weight change <5%).  
 TKA=Total Knee Arthroplasty. THA=Total Hip Arthroplasty. OR=Odds ratio.  
 CI=Confidence Intervals.

1. Model adjusted for intra-operative BMI.
2. No confounders- model same as univariate.
3. Model adjusted for liver disease.
4. Model adjusted for intra-operative BMI and gender.
5. Model adjusted for age and congestive heart failure.

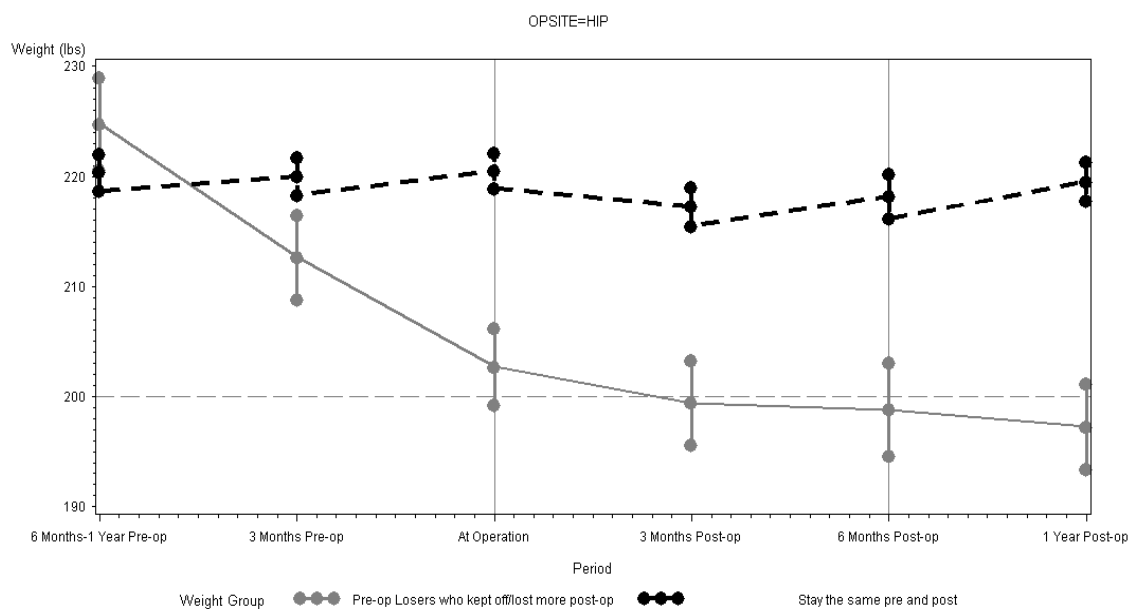


Figure 4.1. Mean Weight by Weight Group and Time Period in Relation to Procedure for Total Hip Arthroplasty Patients.



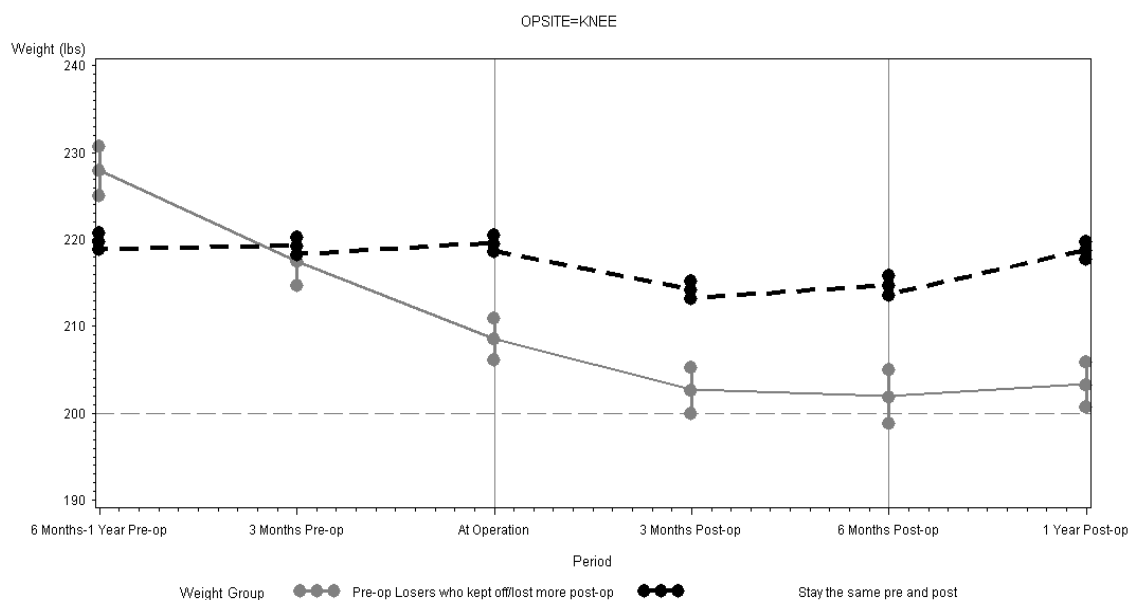


Figure 4.2. Mean Weight by Weight Group and Time Period in Relation to Procedure for Total Knee Arthroplasty Patients.

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## CHAPTER 5.

### Overall Conclusions and Discussion

## RESEARCH CONTRIBUTIONS

Little is known about the weight patterns and how weight change affects the outcomes for the over 1.1 million patients<sup>1</sup> undergoing total joint arthroplasty (TJA) in the US each year. The presented research has examined the weight patterns of TJA patients both pre and post surgery, characterized patients by their weight change during these periods, and evaluated the associations of certain patterns of weight change with surgical site infection (SSI) and readmission in a large representative sample of patients undergoing TJA in California between 2008 and 2010. This research was conducted using data from the largest Total Joint Replacement Registry (TJRR) in the United States, the Kaiser Permanente TJRR,<sup>2,3</sup> and leveraging the electronic health records of the institution the TJRR covers to obtain the weight measures of the patients identified for the study. Results of this research are of importance to both healthcare providers involved in treatment of TJA patients and obese osteoarthritic patients considering TJA. The ability to characterize a representative sample of TJA sample will assist providers to better tailor pre- and post-operative weight and complications management efforts.

## SUMMARY OF FINDINGS

### *Pre- and Post-Operative Weight Patterns of TJA Patients and Characteristics Associated with Weight Change (Chapter 2)*

During the study period, 30632 primary unilateral TJAs were identified; 34.5% were THAs and 65.5% TKAs. The majority of THA and TKA patients remained the same weight during the year prior to their procedure (71.5% and 75.7%, respectively) and during the year after the procedure (64.0% and 68.5%, respectively). However, certain

groups of patients were found to be more likely to gain or lose a clinically significant amount of weight, defined as a 5% change in weight,<sup>4</sup> before and/or after the surgery.

Pre-operatively, in THA patients, men were less likely to either lose or gain a clinically significant amount of weight than women. Asians were less likely to lose weight than Whites, and older patients were less likely than younger patients to gain weight. Post-operatively, in THA patients, men were less likely to lose or gain weight. Additionally, older patients were less likely to be gainers and those who were Black were more likely to be gainers compared to White patients.

In TKAs, pre-operatively, men and Hispanics had lower odds of or gaining weight. Asians were less likely than Whites to lose weight and older patients were less likely to gain weight. Post-operatively, men were less likely than women to lose weight, and Asians and Hispanics were less likely than Whites to lose weight; while older patients, and Asians and Hispanics compared to White patients were less likely to be weight gainers.

In summary, women were more likely than men to change their weight (either gain or lose) pre-operatively in both THAs and TKAs, and post-operatively in THAs. Younger patients are more likely to gain weight than older patients both pre- and post-THAs and TKAs. Several racial differences were observed and the proportion of patients who gained and lost weight post-operatively varied depending on the intra-operative weight of the patient. While the associations of patient characteristics with weight changes have not been previously reported among TKA and THA patients in the literature, these findings are consistent with the varying prevalence of obesity<sup>5</sup> and



perceived obesity risks and adherence to weight loss interventions<sup>6-8</sup> by age, gender, and racial groups in the US.

*The Impact of Pre-operative Weight Loss on Incidence of Surgical Site Infection and Readmission Rates After TJA (Chapter 3)*

The study sample (10718 TKAs and 4066 THAs) included primary unilateral TKA and THA patients who were obese ( $BMI \geq 30 \text{ kg/m}^2$ ) at the beginning of the study period (one year pre-operative). During the one year pre-TKA 7.6% of patients gained a clinically significant amount of weight, 12.4% lost weight, and 79.9% remained the same. Age, gender, race, as well as the co-morbidities neurological diseases, chronic blood loss anemia, and congestive heart failure were each associated with pre-operative weight change in TKA patients. On year pre-THA, 6.3% of patients gained weight, 18.0% lost weight, and 75.7% remained the same weight. Age, gender, as well as depression, anemia, and chronic pulmonary disease prevalence were associated with pre-operative weight change in TKA patients. Again associations of patient characteristics with weight changes that have not been previously reported among TKA and THA patients, were found in this study and are consistent with the varying prevalence of obesity<sup>5</sup> and perceived obesity risks and adherence to weight loss interventions<sup>6-8</sup> by age, gender, and racial groups in the US. Additionally, co-morbidities were identified that were associated with pre-operative weight patterns, which likely reflect the results of treatment for these conditions (e.g., possible drug induced gain in the treatment of neurological and depressive disorders),<sup>9</sup> or the disease itself.

After adjustments for confounders, the risk of SSI (any, deep, and superficial) and ninety day readmission was not significantly different in the patients who gained or lost a significant amount of weight pre-operatively as compared to those who did not change weight (weight change <5%) in both TKA and THA groups. Few studies have focused on pre-operative weight loss and risk of surgical complications. Three studies evaluated surgically induced weight loss, and consistently report higher rates of peri-operative complications in these patients regardless of their weight loss when compared to the larger TJA population these samples are extracted from.<sup>10-12</sup> This is similar to our findings that the weight loss in these obese patients does not decrease the risk of SSI and readmission in these patients who continue to be at a higher overall risk of these complications compared to their non-obese TJA patients.

*The Risk of Surgical Site Infection and Readmission in Obese TJA Patients Who Lose Weight Prior to Surgery and Keep it Off Post-operatively (Chapter 4)*

This study focused on patients who were obese ( $\text{BMI} \geq 30 \text{ kg/m}^2$ ) one year prior to their primary unilateral THA or TKA for osteoarthritis, lost weight prior to their TJA procedure and either maintained or continued to lose more weight post-operatively. 444 obese THA patients and 937 obese TKA patients who lost weight and maintained or lost more post-operatively were identified. These patients were compared to obese patients who remained the same weight throughout the study period (2110 THAs and 6184 TKAs).

Patient characteristics such as gender, age, and race were associated with a patient's ability to lose weight one year prior to their joint arthroplasty and keep it off post-operatively. This was reported by the two previous studies. Certain co-morbidities, such as congestive heart failure and coagulopathy in THA patients and chronic blood loss anemia and liver disease in TKA patients, were also associated with their pre-operative weight loss and post-operative maintenance. These associations should be interpreted in relation to both its pre and post-operative contexts. Further study to evaluate the association of these co-morbidities with weight change in these patients is necessary. The temporal relationship of weight loss, development/interaction of the co-morbidities evaluated, and the outcomes evaluated needs to be clarified in further studies.

Most importantly, this study found that in obese THA patients who lose weight pre-operatively and kept it off post-operatively, the likelihood of deep SSI is higher (OR=3.77, 95% CI 1.59-8.95) than in patients who stayed the same weight throughout the study period. Similarly, obese TKA patients who lost weight were at a higher likelihood of readmission (OR=1.63, 95%CI 1.16, 2.28). Three previous studies evaluated patients who underwent surgical weight loss interventions and their post-operative TJA outcomes.<sup>10-12</sup> These studies evaluated only surgical intervention for weight loss and reported higher rates of peri-operative complications in these patients regardless of their weight loss when compared to the larger TJA population they are drawn from. However, no studies have evaluated the sustainment or increase of weight loss post-operative. Further studies are required to confirm the observations presented in this study.

## LIMITATIONS AND STRENGTHS

The presented research has several limitations. First, selection bias could be present due to the sampling frame. Patients not covered by the integrated healthcare system used in this study are not included. However, this system is composed of members of similar demographic and socioeconomic characteristics as the regional population where it provides coverage.<sup>13-15</sup> Second, the TJRR data source used for this study is voluntary and participation in the registry is reportedly 90% for THAs and 95% for TKAs.<sup>3</sup> However, contributing sites have non-differential rates of participation in the registry and we do not expect this to impact the study findings. Third, the protocol for weight assessment is not standard and measurements are subjected to reporting bias, as well as observer bias. Fourth, missing data (either due to attrition of the cohort or missing weight measures) was a concern in this secondary data analysis. This was addressed in two ways throughout the study. In each instance of missing data, patients with missing data were evaluated and determined how their missing data could affect the presented information. Additionally, multiple imputations techniques were also used when appropriate.

This study's strengths include the generalizability of the findings, the utilization of a closed integrated healthcare system electronic health record, the low likelihood of data handling and response bias, and the prospective ascertainment of the outcomes evaluated in chapter 3 and 4. Most importantly, the cases, surgeons and medical centers that make up the sample of this study are believed to be representative of community-based orthopedic practices in the US. Over 300 surgeons and 27 hospitals contributed to the sample evaluated and they are of various training levels, settings

(e.g. urban, rural, academic), and volumes. Additionally, this research used a common electronic health record and TJRR registry to obtain data. The ability to link records, using one common unique identifier in a sample of this size cannot be reproduced by any other larger national samples (Nationwide Inpatient Sample, regional TJR registries). Using the electronic health records to obtain the weight measurements also decreased the possibility of response bias that could arise from obtaining this information from the patients directly. The outcomes reported in this study were captured and adjudicated by the TJRR on a quarterly basis using a validated algorithm for SSI identification<sup>16</sup> and standard protocol for readmission ascertainment, minimizing the risk of information bias.

#### FUTURE DIRECTION

Due to the expected increase in the prevalence of TJA in the United States,<sup>17</sup> the decreasing age at which patients are undergoing these procedures,<sup>18</sup> and high prevalence of obesity in these patients,<sup>19, 20</sup> determining groups that are susceptible and receptive to weight loss interventions as well as the best weight loss interventions and target outcomes for these groups are highly desirable. Understanding who will most likely benefit for weight loss interventions can decrease the burden on the providers treating these patients and help target interventions that are personalized, this was partially done in the presented work but further investigation into this is necessary. The role co-morbidities play in the weight loss and pre and post-TJA needs to be clarified. Additionally, the findings from this research highlight that non-surgical weight loss alone is not the solution for decrease of certain TJA post-operative

complications and other obesity related issues such as amount of weight change, time of weight loss, time of development and duration of obesity must be further evaluated. The 5% weight loss (one year pre and post-TJA) does not seem to decrease the risk of SSI and readmissions in this group of patients. If patients lose enough weight to move to a lower risk profile ( $BMI < 30 \text{ kg/m}^2$ ) for the complications reported it is possible their risks of these complications would decrease; highlighting that higher amount of weight loss should be investigated. Due to the metabolic and physical changes that weight loss could cause, a longer period of time between weight loss and TJA should be evaluated. Finally, the duration of an individual's obesity and time at which developed (childhood, teenager, adulthood, middle age), as it has been shown in other conditions,<sup>21-23</sup> can play a role in the occurrence of these complications and should be evaluated.

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