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Clinically important body weight gain following total hip arthroplasty: a cohort study with 5-year follow-up

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SUMMARY

Objective: Literature examining the effects of total hip arthroplasty (THA) on subsequent body weight gain is inconclusive. Determining the extent to which clinically relevant weight gain occurs following THA has important public health implications.

Design: We used multi-variable logistic regression to compare data from one of the largest US-based THA registries to a population-based control sample from the same geographic region. We also identified factors that increased risk of clinically important weight gain specifically among persons undergoing THA. The outcome measure of interest was weight gain of ≥5% of body weight up to 5 years following surgery.

Results: The multi-variable adjusted [age, sex, body mass index (BMI), education, comorbidity and pre-surgical weight change] odds ratio for important weight gain was 1.7 [95% confidence interval (CI), 1.06, 2.6] for a person with THA as compared to the control sample. Additional arthroplasty procedures during the 5-year follow-up further increased odds for important weight gain (OR = 2.0, 95% CI, 1.4, 2.7) relative to the control sample. A patient with THA had increased risk of important post-surgical weight gain of 12% (OR = 1.12, 95% CI, 1.08, 1.16) for every kilogram of pre-operative weight loss.

Conclusions: While findings should be interpreted with caution because of missing follow-up weight data, patients with THA appear to be at increased risk of clinically important weight gain following surgery as compared to peers. Patients less than 60 years and who have lost a substantial amount of weight prior to surgery appear to be at particularly high risk of important post-surgical weight gain.

Introduction

Total hip arthroplasty (THA) is a common major surgery conducted in many countries. For example, in 2010, an estimated 300,000 hip arthroplasty procedures were conducted in the US[1] and approximately 70,000 were conducted in England and Wales[2]. Prevalence of obesity in persons who are potential candidates for hip arthroplasty is especially high[3,4], and is associated with increased risks of short and long term complications and higher costs[5–7]. Weight gain following THA has substantial public health implications particularly for obese persons in their 50s and 60s[8] who are more likely than older persons to gain weight and to develop or exacerbate obesity related disorders[9–11].

Evidence examining the potential impact of THA on subsequent weight gain is inconclusive. In the largest study we found, Paans and colleagues determined whether the body weight of 618 patients changed from baseline to 1-year following THA[12]. In addition, a sample of 100 patients were assessed 4.5 years following surgery. During the first year following surgery, overweight and obese patients [body mass index (BMI) ≥25 kg/m^2] lost 3.2 kgs, on average, while patients with BMI <25 kg/m^2 gained approximately 1 kg. Weight loss among overweight and obese patients was slightly greater 4.5 years after surgery. One limitation of the study by Paans and colleagues was that height and weight data were self-reported which likely led to an underestimation of body weight[13]. Four other studies examined weight changes 1-year following THA and findings were mixed with one study finding a significant gain in weight[14] and three finding no statistically significant weight changes[15–17]. Three other studies with a longer

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follow-up period found average increases in BMI or body weight particularly in obese patients (BMI $\geq$ 30) 2[18,19] or 3 years[20] following surgery. With the exception of the work by Dowsey and colleagues[16], no other studies identified independent risk factors for subsequent clinically important weight gain among THA patients. Clinicians could potentially intervene with weight loss interventions if they knew which patients were at risk for clinically important weight gain subsequent to THA surgery.

The inconsistent evidence on the influence of THA on post-surgical body weight is likely due to a variety of factors. Follow-up times varied from 3 months to 4.5 years and sample sizes varied from 64 to 618 patients recruited from multiple countries suggesting the potential for social and cultural influences. No studies recruited a population-based sample of similarly aged persons without THA to account for weight gain attributable to normal aging[21–23]. Most of the literature also has reported group-level results rather than specifically focusing on the identification of subgroups of patients at risk for clinically important weight gains. If a sub-group of THA patients are at risk for clinically important weight gains, clinicians could direct treatment to this sub-group to reduce risk of weight gain and subsequent complications, including prosthetic loosening and failure[24,25], cardiovascular and other systemic disorders[7,9,11]. One purpose of our study was to determine if persons undergoing THA are at risk for clinically important weight gain (defined as a 5% or greater increase in weight relative to baseline)[21,26–29] over a 5-year period as compared to an age and gender matched population-based sample. Our second purpose was to study a large sample comprised exclusively of persons with THA to identify variables that increased risk of clinically important weight gain.

Methods

The two study samples

Data for patients with THA were derived from the Mayo Clinic electronic and administrative **hip** joint registry database. Only primary THA surgeries during the period of January 1, 1995–December 31, 2005 were considered for study inclusion. Revision THAs were not considered for this study. We chose this time frame to: (1) collect data on a large sample of patients receiving THA and, (2) allow for use of the same definitions of potential confounders and methods of height and weight data collection during clinic visits and, (3) allow for a 5 year follow-up data for all THA persons in the study. We further classified THA patients into those who did and those who did not undergo additional arthroplasty surgeries of either knee or of the contralateral hip during the 5-year post-operative period.

We excluded persons who had bariatric surgery ($n = 15$), and all forms of cancer other than basal cell carcinoma because of risk of cancer related weight loss ($n = 260$) $\leq$2 years prior to or up to 5 years following the index THA. In addition, 35 persons undergoing THA did not provide informed consent. There were 693 THAs, in 597 patients meeting criteria for inclusion in the study over the time period. A total of 47 of these patients had no post-operative weight data in the Mayo clinic system (see Fig. 1).

The second data source was the Rochester Epidemiology Project (REP) a population-based medical records linkage system based in Olmsted County, Minnesota, home of Mayo Clinic. The REP has been continuously funded by NIH since 1966[30]. Previous work has indicated that the REP is a valid representation of Olmsted County residents as compared to US Census Bureau estimates[30]. The REP has been used extensively to study the epidemiology of a variety of health problems including rheumatic diseases[31] and obesity[32].

To estimate weight changes over time in the general population, we used the REP to select from all persons residing in Olmsted County and frequency matched for age, sex and time, within 30 days, to the dates of the index THA surgeries based on clinic visit dates. Frequency matching randomly selects persons from the population based on selected variables and can be more statistically efficient than more traditional matching approaches[33]. Based on an *a priori* power analysis, we selected a random sample of 277 persons using frequency matching and stratifying on age (groupings of 18–55, 56–65, 66–75, >75), sex, and year of THA (1995–2005), from the approximately 124,000 people (2000 US census)

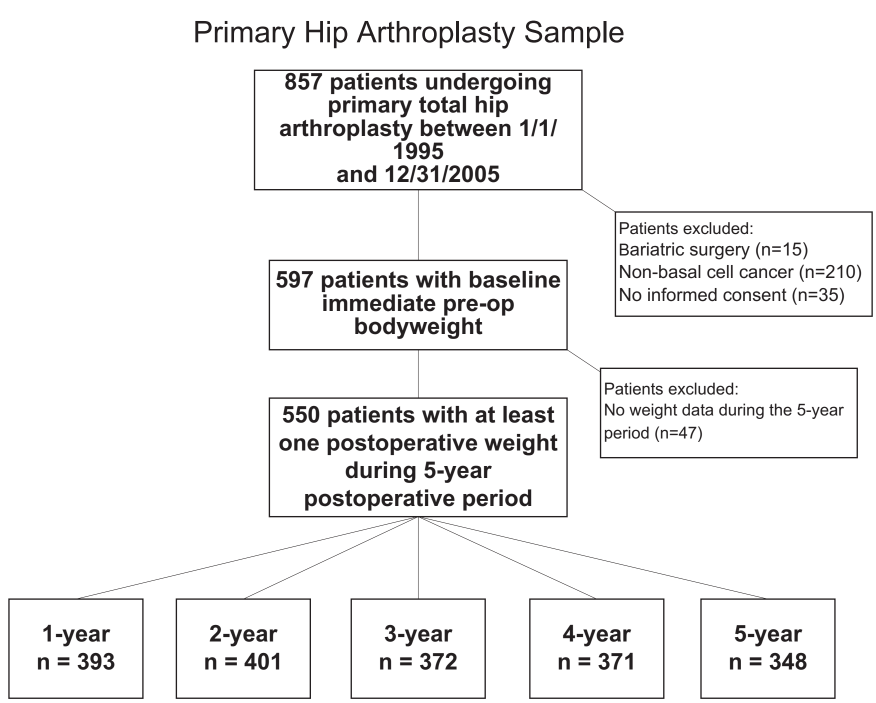

Fig. 1. The figure illustrates the flow of hip arthroplasty patients through the study and the number of patients with body weight data at each time point.

in Olmsted County. We excluded persons who underwent bariatric surgery or were diagnosed with any form of cancer other than basal cell carcinoma during the study period. For the REP data, body weight collection rates ranged from 99.3% for the baseline surgery index date to 64% for the 5-year post-operative index date. The Mayo Clinic Institutional Review Board approved the study and all subjects provided informed consent.

We recruited three trained chart abstractors who extracted data from charts of all persons in both the THA cohort and the random sample of REP community residents for a total of 874 chart reviews. Abstractors reviewed charts for height, weight, education status and Deyo-Charlson comorbidity scores[34,35]. Cancer diagnoses were found through electronic medical record searches. International Classification of Diseases ninth edition diagnosis codes, or cancer diagnostic labels in cases where abstractors found additional cancer diagnoses were used to identify cancer diagnoses during the study period (1995–2005).

The a priori power analysis was conducted to estimate the number of persons required to detect a difference among THA and REP groups. Assuming a common standard deviation (SD) for weight change over 5 years of 4.5 kgs[36,37] and using a two-sided, two-sample *t* test to compare 5 year weight change, we needed 720 patients with THA and 270 community residents to provide greater than 80% power to detect a body weight difference in group means of 1 kg or more.

Assessment of body weight and BMI

During each medical visit, whether for THA follow-up or for any type of medical visit, all persons in the Mayo Clinic health system undergo routine height and weight measurements on digital scales that are calibrated yearly by hospital and clinic staff. Trained chart abstractors extracted yearly height and weight data on the index date (day of surgery) and each year for 5 years prior to and 5 years after the THA surgery date (in total, this covered years 1990–2010, depending on the index surgery date). Abstractors were instructed to extract yearly height and weight data that were as close to the yearly anniversary dates of the index surgery date. Height and weight data for the REP subjects were extracted by chart abstractors for the 5 years prior to and 5 years following the matched cases' THA index dates. Overall, yearly body weight collection rates from the chart reviews of the THA patients for the 5 years following surgery ranged from 99.5% at baseline to 58.3% at 5 years.

Outcome variable of interest

We categorized THA and REP subjects as weight gainers if they gained ≥5% of body weight from the index date to final follow-up. Persons who did not gain ≥5% or more of their body weight were classified as weight maintainers. A 5% or greater gain in body weight has been found to lead to clinically meaningful effects on cardiovascular and diabetes related disorders as well as pain and function[28,29,38], and has been recommended as a threshold for clinically meaningful weight loss in multiple guidelines[26,27].

Potential baseline predictor variables

We examined the following variables in the THA and REP cohorts: (1) case control status categorized as either REP or THA. In addition, persons with THA were further grouped into those with and those without follow-up arthroplasty surgery of the contralateral hip or either knee during 5 years of follow-up; (2) age, categorized in approximate quartiles as follows, <60 years, 60–69 years, 70–75 years and >75 years; (3) sex; (4) comorbidity, assessed using the Deyo-Charlson index, a validated comorbidity scale that includes 17 comorbidities with higher scores indicating greater comorbidity; [34,35](5) baseline BMI (kg/m^2) categorized into <25, 25.0–29.9, 30–34.9, and ≥35 with <25 (mild thinness to normal weight) being the referent group; [39](6) education, categorized into three groups [<high school (HS) diploma, HS diploma or some college, at least 4 years of college]; and (7) two additional variables created to account for extent of weight gain or loss in the 5 years prior to surgery. For maximum 5-year pre-THA weight loss, we subtracted the largest weight in the 5 years prior to surgery from the index weight (e.g., day of surgery for the THA group and matched date for the REP group). If the subject demonstrated no weight loss in the 5 years prior to the index date, this variable was coded as zero. We used a similar approach to indicate the amount of weight gain that occurred from up to 5 years prior to the index surgery date up to the date of surgery. We reasoned that if the subject had either lost or gained weight in the years leading up to the index date, the extent of weight gain following the index date may be impacted by this pre-surgical weight variation[40].

Statistical analyses

Descriptive statistics are reported in Table I for the characteristics of the THA patients and the REP community residents. A *t*-test or Chi-square test, as appropriate, was used to compare baseline characteristics of patients with the population-based controls (see Table I) and the combined THA and REP samples of those without missing data at years 2 and 4 (see Table II).

We used two logistic regression models to analyze variables associated with clinically important weight gain, accounting for

Table I
Characteristics of the THA and Rochester REP samples*

N(%)	REP (*n* = 277)	THA (*n* = 597)	Chi-square *P*-value†
Male gender	119 (43)	252 (42)	0.83
Education			0.33
<H.S.	27 (11)	54 (9)	
H.S. or some college	149 (61)	332 (57)	
≥4 years college	69 (28)	192 (33)	
Missing	32	19	
Deyo-Charlson index			0.18
=0	129 (47)	271 (45)	
=1	70 (25)	125 (21)	
>1	78 (28)	201 (34)	
Age			0.89
≤50	43 (16)	89 (15)	
50–59	46 (17)	104 (17)	
60–69	77 (28)	172 (29)	
70–80	78 (28)	174 (29)	
>80	33 (12)	58 (10)	
Baseline BMI			0.053
<25	86 (31)	146 (25)	
25–29.9	96 (35)	210 (35)	
30–34.9	63 (23)	150 (25)	
35–40	23 (8)	49 (8)	
>40	7 (3)	39 (7)	
Missing	2	3	
1-year data present	207 (75)	393 (66)	0.008
2-year data present	201 (73)	401 (67)	0.11
3-year data present	197 (71)	372 (62)	**0.01**
4-year data present	187 (68)	371 (62)	0.12
5-year data present	178 (64)	348 (58)	0.09

BMI (calculated as the weight in kilograms divided by height in meters squared). Estimates in bold are statistically significant.

* Data are given as mean (SD) for continuous variables and percentage for categorical variables unless otherwise indicated.

† *P*-value for *t*-test was used for continuous variables and X^2 for categorical variables.

Table II
Relationship between non-missing 2- and 4-year weight data and baseline characteristics for the combined samples*

N(%)	Two-year data		Four-year data	
	Present	P-value†	Present	P-value†
Gender		**0.006**		0.07
Female	365 (73)		334 (66)	
Male	237 (64)		224 (60)	
Education		0.18		0.50
<H.S.	56 (69)		51 (63)	
H.S. or some college	348 (72)		324 (67)	
≥4 years college	172 (66)		166 (64)	
Charlson index		0.18		0.53
=0	263 (66)		253 (63)	
=1	139 (71)		131 (67)	
>1	200 (72)		174 (62)	
Age		**<0.001**		**0.005**
≤50	71 (54)		71 (54)	
50–59	101 (67)		98 (65)	
60–69	176 (71)		167 (67)	
70–80	187 (74)		174 (69)	
>80	67 (74)		48 (53)	
Baseline BMI		0.47		0.67
<25	157 (68)		146 (63)	
25–29.9	204 (67)		194 (63)	
30–34.9	152 (71)		135 (63)	
35–40	55 (76)		52 (72)	
>40	33 (72)		30 (65)	

BMI (calculated as the weight in kilograms divided by height in meters squared). Estimates in bold are statistically significant.
* Data are given as mean (SD) for continuous variables and percentage for categorical variables unless otherwise indicated.
† P-value for t-test was used for continuous variables and X^2 for categorical variables.

within subject correlation (Proc Genmod in SAS with repeated statement). The first model compared the THA sample to the REP sample. The second model examined only the THA sample. The primary purpose of this second model was to identify pre-surgical risk factors for clinically important weight gain in the 5 years following surgery.

The second logistic regression model of only the THA group also included as predictor variables, diagnosis [osteoarthritis (OA) vs rheumatoid arthritis (RA)] and American Society of Anesthesiologists (ASA) score, a validated measure of immediate post-operative morbidity and perioperative mortality and scored as classes `I–II vs III–IV[41,42]. The American Society of Anesthesiology[41,42] score was retrieved using a registry maintained by the department of Anesthesiology. Statistical analyses were performed with SAS statistical software, version 9.2 (SAS Institute, Cary, North Carolina, USA). Two-way interactions were assessed in both models.

Because of the imbalance in baseline BMI distributions between the THA and REP groups, we conducted a sensitivity analysis using the Marginal Structural Models method as described by Robbins and colleagues[43]. For the THA patients, case weights were used to balance the distribution of baseline BMI between the THA and REP patients to allow for statistical comparisons of THA and REP groups when baseline BMI distributions were equivalent.

Results

The THA sample ($n = 597$ persons with 96 undergoing additional knee or contralateral hip arthroplasty procedures during the 5-year follow-up) and the population-based control sample descriptions and comparisons appear in Table I. Baseline attributes were not significantly different between groups. With the exception of a preferential loss to follow-up of males at year 2 and persons younger than 50 years or older than 80 years at years 2 and 5, samples with and without missing data at years 2 and 4 were similar for the baseline attributes (see Table II).

A total of 92% of our THA sample and 100% of the REP sample had at least one follow-up weight measure in the analyses. Over the 5-year post-operative period, the control group ($n = 275$) gained a mean of 0.02 kg (SD = 4.7). The patients with subsequent additional knee or hip arthroplasty(ies) ($n = 96$) during the 5-year follow-up gained a mean of 3.35 kg (SD = 5.6) while cases with no additional lower extremity arthroplasty during 5 years of follow-up ($n = 501$) gained a mean of 2.12 kgs (SD = 6.2). The percentage of persons in the THA and REP groups who gained a clinically important amount of body weight varied each year during the 5-year post-operative period (see Table III). For example, at the 1-year post-operative time point, 13.0% (27/207) of the REP sample gained ≥5% of their baseline body weight while 30.8% (121/393) of the THA sample gained ≥5% of baseline body weight.

In univariate analyses, patients undergoing a single THA had an odds of gaining ≥5% body weight up to 5 years following surgery that was more than double that of the control group [OR = 2.1, 95% confidence interval (CI), 1.6, 2.8]. Patients undergoing at least one additional arthroplasty during the follow-up period had a significantly higher odds [odds ratio (OR = 2.3, 95% CI, 1.5, 3.3)] of clinically important weight gain relative to the REP sample. In the multi-variable model, the odds for a ≥5% body weight gain in the THA group with no follow-up arthroplasty was 1.7 (95% CI, 1.1, 2.6), after adjusting for potential confounders (see Table IV). Patients with multiple arthroplasty had double the odds OR = 2.0 (95% CI, 1.4, 2.7) of clinically important weight gain relative to the REP sample. Our sensitivity analysis (see Table VI) which weighted cases to balance the distributions of BMI categories among the REP and THA groups found very similar estimates to those reported in Table IV.

For the multi-variable logistic regression model examining only patients in the THA sample, those who were most likely to gain ≥5% body weight lost more weight in the 5 years prior to surgery. The odds for a clinically important post-surgical weight gain increased by 12% [OR = 1.12, (95% CI, 1.08, 1.16)] for every kilogram of body weight lost during the 5 year pre-operative period. Persons with a baseline BMI of between 30 and 34.9 kg/m^2 had a 40% reduced risk of clinically important weight gain (OR = 0.6, 95% CI, 0.4, 0.96) relative to the referent group (BMI < 25 kg/m^2). In addition, persons aged 70–75 years had a 60% reduced risk of clinically important weight gain (OR = 0.4, 95% CI, 0.2, 0.7) relative to the referent group of persons aged >75 years (see Table IV). Follow-up arthroplasty procedures did not increase risk of post-surgical weight gain in the THA sample. No two-way interactions were found for any of the models.

Discussion

We found that persons undergoing THA were at increased risk of clinically important weight gain relative to a population-based sample of persons from the same geographic region who did not

Table III
Percentage of subjects in the total hip and REP samples who gained a clinically important amount of body weight

Post-operative year	THA sample		REP sample	
	Number assessed	% with clinically important weight gain	Number assessed	% with clinically important weight gain
Year 1	393	121 (30.8%)	207	27 (13.0%)
Year 2	401	140 (34.9%)	201	36 (17.9%)
Year 3	372	126 (33.9%)	197	44 (22.3%)
Year 4	371	142 (38.3%)	187	51 (27.3%)
Year 5	348	132 (37.9%)	178	50 (28.1%)

Table IV
Logistic regression model of clinically important weight gain (≥5% body weight) in persons with THA and persons from the REP

Variable	Unadjusted analysis			Adjusted analysis		
	OR (95% CI)	*P*-value	Overall *P*-value‡	OR (95% CI)	*P*-value	Overall *P*-value
Subject status			<0.001			<0.001
THA (follow-up arthroplasty)	**2.3** (**1.5, 3.3**)	**<0.001**		**2.0** (**1.4, 2.7**)	**<0.001**	
THA (no follow-up arthroplasty)	**2.1** (**1.6, 2.8**)	**<0.001**		**1.7** (**1.06, 2.6**)	**0.03**	
REP group	1.0 (ref)			1.0 (ref)		
BMI			0.02			0.003
≥25.0–29.9	0.8 (0.6, 1.02)	0.06		**0.7** (**0.5, 0.99**)	**0.05**	
≥30.0–34.9	**0.6** (**0.4, 0.8**)	**0.002**		**0.5** (**0.3, 0.7**)	**<0.001**	
≥35	0.9 (0.6, 1.3)	0.4		0.7 (0.4, 1.03)	0.07	
<25	1.0 (ref)			1.0 (ref)		
Age			<0.001			<0.001
<60	**1.5** (**1.1, 2.1**)	**0.01**		**2.0** (**1.3, 3.0**)	**0.001**	
60–69	1.0 (0.7, 1.3)	0.76		1.1 (0.7, 1.6)	0.68	
70–75	**0.5** (**0.4, 0.8**)	**0.004**		**0.6** (**0.4, 0.96**)	**0.03**	
>75	1.0 (ref)			1.0 (ref)		
Gender						
Male	1.0 (0.8, 1.3)	0.88		0.9 (0.7, 1.2)	0.46	
Female	1.0 (ref)			1.0 (ref)		
Education			0.15			0.65
<HS diploma	0.8 (0.5, 1.2)	0.24		0.9 (0.5, 1.6)	0.76	
HS or some college	0.8 (0.6, 1.01)	0.06		0.9 (0.7, 1.2)	0.35	
College degree or >	1.0 (ref)			1.0 (ref)		
Deyo-Charlson index			0.07			0.03
0	1.1 (0.9, 1.5)	0.40		1.2 (0.9, 1.7)	0.20	
1	0.8 (0.6, 1.1)	0.16		0.8 (0.5, 1.1)	0.20	
>1	1.0 (ref)			1.0 (ref)		
Pre-surgical 5-year max wt loss, per 1 kg*	**1.12** (**1.1, 0.15**)	**<0.001**		**1.13** (**1.1, 1.2**)	**<0.001**	
Pre-surgical 5-year max wt gain, per 1 kg†	1.0 (0.96, 1.03)	0.74		1.0 (0.97, 1.04)	0.79	

BMI (calculated as the weight in kilograms divided by height in meters squared). Estimates in bold are statistically significant.
* Maximum weight loss (in kgs), relative to baseline, during the 5 years prior to the baseline knee arthroplasty.
† Maximum weight gain (in kgs), relative to baseline, during the 5 years prior to the baseline knee arthroplasty.
‡ The overall *P*-value describes the extent of statistical significance among the levels for each variable with more than two levels.

Table V
Logistic regression model of clinically important weight gain (≥5% body weight) among persons with THA

Variable	Unadjusted analysis			Adjusted analysis		
	OR (95% CI)	*P*-value	Overall *P*-value‡	OR (95% CI)	*P*-value	Overall *P*-value
Subject status						
THA (follow-up arthroplasty)	1.1 (0.8, 1.5)	0.66		0.9 (0.6, 1.3)	0.58	
THA (no follow-up arthroplasty)	1.0 (ref)			1.0 (ref)		
BMI			0.12			0.25
≥25.0–29.9	0.8 (0.6, 1.2)	0.29		0.8 (0.5, 1.2)	0.23	
≥30.0–34.9	**0.7** (**0.5, 0.9**)	**0.02**		**0.6** (**0.4, 0.98**)	**0.04**	
≥35	0.9 (0.6, 1.5)	0.80		0.7 (0.4, 1.3)	0.28	
<25	1.0 (ref)			1.0 (ref)		
Age			<0.001			<0.001
<60	**1.5** (**1.01, 2.2**)	**0.05**		1.6 (0.96, 2.6)	0.07	
60–69	1.1 (0.8, 1.6)	0.61		1.1 (0.7, 1.7)	0.73	
70–75	**0.5** (**0.3, 0.8**)	**0.005**		**0.4** (**0.2, 0.7**)	**<0.001**	
>75	1.0 (ref)			1.0 (ref)		
Gender						
Male	1.0 (0.7, 1.3)	0.91		0.8 (0.6, 1.1)	0.19	
Female	1.0 (ref)			1.0 (ref)		
Diagnosis						
OA	1.1 (0.7, 1.8)	0.64		1.3 (0.8, 2.3)	0.27	
Other	1.0 (ref)			1.0 (ref)		
Education			0.09			0.42
<HS diploma	0.6 (0.3, 1.1)	0.10		0.8 (0.4, 1.5)	0.46	
HS or some college	0.8 (0.6, 1.01)	0.06		0.8 (0.6, 1.1)	0.20	
College degree or >	1.0 (ref)			1.0 (ref)		
ASA score						
III or IV	0.9 (0.6, 1.2)	0.34		0.8 (0.6, 1.2)	0.33	
I or II	1.0 (ref)			1.0 (ref)		
Charlson index			0.14			0.21
0	1.4 (0.97, 1.9)	0.07		1.3 (0.9, 1.9)	0.22	
1	1.0 (0.7, 1.5)	0.96		0.9 (0.6, 1.3)	0.48	
>1	1.0 (ref)			1.0 (ref)		
Pre-surgical 5-year max wt loss, per 1 kg*	**1.11** (**1.07, 1.14**)	**<0.001**		**1.12** (**1.08, 1.16**)	**<0.001**	
Pre-surgical 5-year max wt gain, per 1 kg†	1.0 (0.96, 1.04)	0.99		1.0 (0.96, 1.05)	0.90	

Estimates in bold are statistically significant.
* Maximum weight loss (in kgs), relative to baseline, during the 5 years prior to the baseline knee arthroplasty.
† Maximum weight gain (in kgs), relative to baseline, during the 5 years prior to the baseline knee arthroplasty.
‡ The overall *P*-value describes the extent of statistical significance among the levels for each variable with more than two levels.

Table VI
Sensitivity analysis correcting for imbalances in baseline BMI distributions among THA and REP cohorts

Variable	Unadjusted analysis			Adjusted analysis		
	OR (95% CI)	*P*-value	Overall *P*-value‡	OR (95% CI)	*P*-value	Overall *P*-value
Subject status			<0.001			<0.001
THA (follow-up arthroplasty)	**2.6** (**1.8, 4.0**)	**<0.001**		**1.8** (**1.2, 2.8**)	**0.009**	
THA (no follow-up arthroplasty)	**2.2** (**1.6, 2.9**)	**<0.001**		**2.0** (**1.5, 2.8**)	**<0.001**	
REP group	1.0 (ref)			1.0 (ref)		
BMI			**0.02**			**0.003**
≥25.0–29.9	**0.8** (**0.6, 1.04**)	**0.08**		**0.7** (**0.5, 0.99**)	**0.04**	
≥30.0–34.9	**0.6** (**0.4, 0.9**)	**0.005**		**0.5** (**0.3, 0.7**)	**<0.001**	
≥35	**1.2** (**0.8, 1.8**)	**0.48**		**0.8** (**0.5, 1.3**)	**0.34**	
<25	1.0 (ref)			1.0 (ref)		
Age			**<0.001**			**<0.001**
<60	**1.7** (**1.2, 2.4**)	**0.004**		**1.9** (**1.2, 2.9**)	**0.003**	
60–69	**1.0** (**0.7, 1.5**)	**0.98**		**1.1** (**0.7, 1.6**)	**0.74**	
70–75	**0.5** (**0.3, 0.8**)	**0.007**		**0.6** (**0.3, 0.95**)	**0.03**	
>75	1.0 (ref)			1.0 (ref)		
Gender						**0.65**
Male	**1.0** (**0.7, 1.3**)	**0.88**		**0.9** (**0.6, 1.2**)	**0.33**	
Female	1.0 (ref)			1.0 (ref)		
Education			**0.15**			**0.03**
<HS diploma	**0.7** (**0.4, 1.2**)	**0.17**		**0.9** (**0.5, 1.5**)	**0.59**	
HS or some college	**0.8** (**0.6, 1.04**)	**0.09**		**0.8** (**0.6, 1.1**)	**0.19**	
College degree or >	1.0 (ref)			1.0 (ref)		
Deyo-Charlson index			**0.07**			
0	**1.3** (**0.9, 1.8**)	**0.13**		**1.4** (**0.99, 2.1**)	**0.06**	
1	**0.8** (**0.6, 1.2**)	**0.35**		**0.9** (**0.6, 1.3**)	**0.55**	
>1	1.0 (ref)			1.0 (ref)		
Pre-surgical 5-year max wt loss, per 1 kg*	**1.13** (**1.10, 1.16**)	**<0.001**		**1.14** (**1.11, 1.18**)	**<0.001**	
Pre-surgical 5-year max wt gain, per 1 kg†	**1.02** (**0.98, 1.05**)	**0.37**		**1.01** (**0.98, 1.05**	**0.44**	

BMI (calculated as the weight in kilograms divided by height in meters squared). Estimates in bold are statistically significant.
* Maximum weight loss (in kgs), relative to baseline, during the 5 years prior to the baseline knee arthroplasty.
† Maximum weight gain (in kgs), relative to baseline, during the 5 years prior to the baseline knee arthroplasty.
‡ The overall *P*-value describes the extent of statistical significance among the levels for each variable with more than two levels.

undergo THA. The multi-variable odds of gaining ≥5% of baseline body weight over the 5-year post-operative period for persons with THA was 70% higher than the population-based REP sample. Odds of clinically important weight gain doubled, on average, relative to that of the REP sample for persons who underwent at least one additional arthroplasty procedure during the 5-year post-operative period. Persons with a higher BMI and persons aged 70–75 years were less likely to gain weight as compared to other BMI and age categories. Older persons are known to be less likely to gain weight than younger adults[9–11] and this was consistent with our findings. Persons with the lowest BMI (<25 kg/m^2) were most at risk for clinically important weight gain and this may be attributable to the fact that they needed to gain the least amount of weight to reach the 5% threshold.

In the multi-variable analysis, patients with THA (Table V) were at risk for clinically important weight gain at the rate of 12% for every kg of weight lost during the 5 years prior to surgery. Some THA patients were protected from risk of important weight gain and these were patients in the BMI range of 30–34.9 kg/m^2 compared to those with a BMI of <25 kg/m^2, and those aged 70–75 years, relative to patients aged >75 years. Overweight or obese patients with THA who had higher or lower BMIs than the 30–34.9 range were not protected from subsequent weight gain relative to THA patients with body weight in the normal range of <25 kg/m^2. Even with a reduced risk for post-surgical weight gain for patients in the ≥30 to <35 kg/m^2 BMI category, we still support weight loss counseling given these patients' risks for obesity related disorders and excessive joint loading. Persons with THA aged <60 years were 60% more likely (OR = 1.6, 95% CI = 0.96, 2.6) to experience important weight gain relative to patients aged >75 years.

These findings, in total, suggest that patients undergoing primary THA are at risk for weight gain, relative to population-based peers, even after adjusting for age, gender and baseline BMI. These data suggest that all THA patients who are overweight or obese should be counseled about weight loss and the higher than normal risk of important post-surgical weight gain. Our data suggest risk for weight gain doesn't vary substantially from the first to the fifth year post surgery (see Table III). Patients should be made aware that weight gain risk begins within the first year and persist for at least 5 years following surgery. Compared to their peers, persons with multiple arthroplasties are at even higher risk of clinically important weight gain.

Work by Paans and colleagues[12] suggests that persons with BMIs higher than 25 kg/m^2 tend to lose weight after surgery and persons in the highest BMI category (>30 kg/m^2) lose the most weight, 6.2 kgs, on average, at 4.5 years follow-up. Our findings are not consistent with this evidence. We speculate that these differences may be attributable either to differences in reporting (i.e., Paans and colleagues did not report the proportion of patients gaining ≥5% of body weight and relied on self-reported weight and height) or to social and cultural differences across the two countries. In the US, adult obesity rates (BMI ≥30) are 36%[44] while in the Netherlands, approximately 12% of Dutch adults are obese[45]. In addition, in the Netherlands walking and bicycling are preferred modes of transportation for adults in contrast to the US[12]. These data suggest that activity levels are generally higher in Dutch populations and this increased mobility may be contributing to the differential effects of THA on post-surgical weight gain for overweight and obese patients in the US and in the Netherlands.

Dowsey and colleagues studied 474 THA Australian patients and found that 25% had gained ≥5% of baseline body weight in 1-year[16]. We had similar findings in our study with 30.8% of THA patients gaining ≥5% of their baseline weight 1-year after surgery. Others also found weight gain more than 1 year post-operatively. Middleton and colleagues reported a significant BMI mean increase of approximately one BMI point, 2 years following hip arthroplasty in a sample of 180 overweight or obese patients from England[19]. Aderinto and colleagues reported a mean gain of 2.3 kgs in 140 Scottish patients 3 years following THA with obese patients (BMI $\geq$ 30) showing the greatest weight gains[20].

Of particular importance is the role of pre-operative weight loss as a risk factor for post-operative weight gain. Patients with THA who lose weight are likely to gain back at least some of this weight after surgery. Future research should examine interventions designed to maintain weight loss in this sub-group at risk for post-operative weight gain. Weight gain following surgery is particularly important for women who are at increased risk of future hip arthroplasty due to weight gain[46].

The only other study that identified pre-operative risk factors for important post-operative weight gain was the work of Dowsey and colleagues[16]. The only pre-operative predictor of a $\geq$5% body weight gain was a lower SF-12 mental health score. Forman-Hoffman examined whether baseline depressive symptoms increased risk for weight gain of $\geq$5% body weight over an 8-year period in a sample of 9,130 women and men aged 53–63 years[47]. Baseline depressive symptoms were found to predict subsequent important weight gain in women but not in men. More research needs to examine the potential role of mental health generally and specific mental health disorders such as depression in patients undergoing THA.

Our study found that pre-operative weight loss prior to THA surgery and age less than 60 years are independent risk factors for post-surgical weight gain. Intentional weight loss is known to frequently lead to subsequent weight gain[48,49]. Overweight and obese patients preparing for THA are frequently advised by their surgeons to lose weight but, in our experience, patients receive little formal instruction on weight loss maintenance. Evidence suggests pre-operative weight loss will reduce risk of complications and potentially revision surgery[50] and while pre-surgical weight loss may aid in enhancing early recovery, our data suggests at least a portion of the weight is gained back after surgery. Weight fluctuation increases risk of a variety of disorders[51,52] which argues for future research designed to identify effective weight control strategies to minimize fluctuations.

Our study has some notable limitations. Loss to follow-up was substantial with over 40% of THA patients and over 30% of control subjects with missing weight data at 5 years. We found only subtle differences among those with complete and those with missing follow-up weight data (see Table II), but these differences along with unmeasured confounding may have influenced our findings. We do not know whether the weight changes in our subjects were intentional or unintentional and we do not know what would have happened to our THA patients' weight had they not had surgery. Reasons for weight change may influence outcome following THA surgery[52]. There appears to be differential effects of THA depending on the country or region of the world being studied. Our results may not generalize to some countries.

Given our limitations and particularly our missing follow-up body weight data, our study suggests an association between THA surgery and subsequent clinically important weight gain relative to that seen in a population-based control sample. Compared to an age and gender matched population and after adjusting for potential confounders including baseline BMI differences, patients undergoing THA, and particularly patients undergoing multiple arthroplasty surgeries are at risk of clinically important weight gain up to 5 years following THA surgery. The most powerful independent risk factor for post-operative weight gain specifically among patients with THA appears to be pre-operative weight loss and age less than 60 years. For every kilogram of 5-year pre-operative weight loss, risk for clinically important weight gain increases by 12%. Patients who have lost more substantial amounts of weight in the years leading up to surgery are particularly vulnerable to post-surgical weight gain.

Author contributions

All authors played an important role in the study design and reporting including: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted. Daniel L. Riddle takes responsibililty for the work as a whole and Mr. William S. Harmsen takes responsibility for the statistical analysis.

Role of the funding source

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Competing interest statement

Dr. Singh has received grants from Allergan, Takeda, Savient and is a consultant with Allergan, Takeda, Savient, URL, Regeneron, Ardea and Novartis. Dr. Lewallen has received royalties/speaker fees from Zimmer, has been a paid consultant to Zimmer and has received institutional research funds from DePuy, Stryker and Zimmer.

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Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.joca.2012.09.010

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