Public Health Nutrition: 12(8), 1122–1132 doi:10.1017/S1368980009005072

Impact of body mass on hospital resource use in total hip arthroplasty

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Submitted 16 July 2008: Accepted 7 January 2009: First published online 12 March 2009

Abstract

Objective: To determine the impact of BMI on post-operative outcomes and resource utilization following elective total hip arthroplasty (THA).
Design: A retrospective cohort analysis on all primary elective THA patients between 1996 and 2004. Primary outcomes investigated using regression analyses included length of stay (LOS) and costs (US dollars).
Setting: Mayo Clinic Rochester, a tertiary care centre.
Subjects: Patients were stratified by pre-operative BMI as normal (18·5–24·9 kg/m^2), overweight (25·0–29·9 kg/m^2), obese (30·0–34·9 kg/m^2) and morbidly obese (≥35·0 kg/m^2). Of 5642 patients, 1362 (24·1 %) patients had a normal BMI, 2146 (38·0 %) were overweight, 1342 (23·8 %) were obese and 792 (14·0 %) were morbidly obese.
Results: Adjusted LOS was similar among normal (4·99 d), overweight (5·00 d), obese (5·02 d) and morbidly obese (5·17 d) patients ($P = 0·20$). Adjusted overall episode costs were no different ($P = 0·23$) between the groups of normal ($17 211), overweight ($17 462), obese ($17 195) and morbidly obese ($17 655) patients. Overall operative and anaesthesia costs were higher in the morbidly obese group ($5688) than in normal ($5553), overweight ($5549) and obese ($5593) patients ($P = 0·03$). Operating room costs were higher in morbidly obese patients ($3418) than in normal ($3276), overweight ($3291) and obese ($3340) patients ($P < 0·001$). Post-operative costs were no different ($P = 0·30$). Blood bank costs differed ($P = 0·002$) and were lower in the morbidly obese group ($180) compared with the other patient groups ($P < 0·05$). Other differences in costs were not significant. Morbidly obese patients were more likely to be transferred to a nursing home (24·1 %) than normal (18·4 %), overweight (17·9 %) or obese (16·0 %) patients ($P = 0·001$ each). There were no differences in the composite endpoint of 30 d mortality, re-admissions, re-operations or intensive care unit utilization.
Conclusions: BMI in patients undergoing primary elective THA did not impact LOS or overall institutional acute care costs, despite higher operative costs in morbidly obese patients. Obesity does not increase resource utilization for elective THA.

Keywords
Arthroplasty
Obesity
Costs
Resource utilization

The National Health and Nutrition Examination Surveys revealed that the prevalence of obesity in the US population has increased from 14·5 % in 1976–80[1] to 32·2 % in 2003–4[2]. This trend is likely to continue, as will the economic burden of obesity-related disorders[3]. Patients with moderate to severe obesity have higher health-care utilization and costs[4,5] compared with other standardized body mass groups. The direct and indirect costs of obesity-related disorders in the USA are estimated to be between $US 52 and $US 95 billion annually[4,6].

The increase in the obesity epidemic parallels that of hip osteoarthritis. Twenty million adults in the USA are estimated to have osteoarthritis[7]. The total societal cost of caring for patients with arthritis has burgeoned from $US 20 billion in 1997 to $US 128 billion in 2003[8,9]. Although age is the most important risk factor[10], obesity

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is also associated with the development of symptomatic osteoarthritis of the hip[11,12].

Total hip arthroplasty (THA) for osteoarthritis improves mobility, relieves osteoarthritic pain and is cost-effective in ageing adults[13]. From a societal perspective, THA is one of the costliest inpatient procedures considering the sheer volume performed[14]. In 2004 alone, there were 235 000 elective THA performed in the USA[15]. Few studies have examined the impact of body mass on resource utilization in the orthopaedic population[16,17]. With the increasing prevalence of both obesity and osteoarthritis, our aim was to determine if hospital costs and length of stay (LOS) are impacted by BMI.

Experimental methods

Study design and setting

A retrospective, observational cohort study was conducted on all elective unilateral THA patients admitted between 1 January 1996 and 31 December 2004. Thirteen different orthopaedic surgical teams, including an attending orthopaedic surgeon and rotating residents, performed all THA procedures at all one hospital. All surgeries were performed from Monday to Friday. Participating patients had authorized the use of their medical records for research purposes. The study was approved by the Institutional Review Board.

Data sources

All elective primary THA performed at our institution were identified (*n* 6009) using a previously described joint registry[18]. We specifically did not include in our query any of the following groups of patients including: those requiring urgent, revision or bilateral arthroplasties; patients transferred or initially treated at outside institutions; or a primary surgical indication of trauma or septic arthritis.

We abstracted clinical and demographic data, including age, gender, height and weight at the time of surgery, surgical indication, use of cement, dates of admission, surgery, death, discharge and last follow-up date from the joint registry. Type of anaesthesia (general, regional, combined), American Society of Anaesthesiologists (ASA) physical status, and the time and date of admissions and discharges from the intensive care unit (ICU) were abstracted from departmental databases. Other patient characteristics were obtained using the Decision Support System (DSS) database (Eclipsys, Boca Raton, FL, USA). Admission times, LOS, dismissal time and date, discharge disposition, physical location, and individual and composite centre costs were also obtained. Patient expiration was confirmed using our electronic medical record, and verified using state and federal death registries. Major co-morbidities documented in this database were identified to compute a composite Charlson co-morbidity index[19], as well as individual indicators.

Variables and definitions

BMI was calculated by dividing weight, in kilograms, by the square of height, measured in metres. All measurements were performed at the time of admission by trained nursing personnel. Our cohort was classified as follows: normal BMI (18·5–24·9 kg/m^2), overweight (25·0–29·9 kg/m^2), obese (30·0–34·9 kg/m^2) and morbidly obese ($\geq$35·0 kg/m^2). We defined LOS as the number of days from the time of admission to the time of discharge. Economic analyses were conducted from the provider perspective at the patient service level and focused on direct costs of care associated with hospital and physician services during inpatient stay. Administrative data sources identified medical resource utilization and were valued using standard methods. Hospital-billed services were valued using departmental cost-to-charge ratios, while physician services were weighted by Medicare reimbursement rates. Accounting practices remained unchanged during the study duration. All costs presented have been adjusted to reflect 2005 constant US dollars[20]. Blood bank charges were defined as the costs of storage, processing and transfusion delivery. A re-admission was defined as any re-admission to our institution related to the primary surgery performed within 30 d of dismissal. An in-hospital death was defined as a death during the indexed initial surgical episode, while 30 d mortality was defined as a death within thirty days of the indexed surgery. Patient re-operations were defined as patients requiring further surgical intervention, following the initial surgery. A priori, a composite endpoint including re-admissions, re-operations and 30 d mortality was developed to account for the anticipated low numbers of these outcomes in this elective surgical population and is referred to as 30 d outcomes[21].

Study cohort

We excluded 367 patients from the analysis for the following reasons: incomplete cost data (*n* 227); multiple joint replacements during the indexed hospitalization (*n* 3); no research authorization (*n* 58). Underweight patients (BMI $\leq$ 18·5 kg/m^2) were excluded due to sample size and analysis considerations (*n* 79). Our final cohort consisted of 5642 patients. With the observed sample size and overall variability, our study had 80 % power to detect a difference between each group as small as 0·19 d and \$620 in costs between the comparison and obese groups.

Statistical analysis

Primary outcomes included determination of LOS and resource utilization. Analysis of resource utilization focused on three approaches as outlined in Table 1. These approaches were selected specifically to examine resource utilization according to BMI on three separate elements of hospital flow. Statistical comparisons on baseline variables focused on a four-way comparison between normal, overweight, obese and morbidly obese

Table 1 Characteristics of three analyses examining resource utilization within the indexed surgical episode in patients undergoing total hip arthroplasty

	Analysis 1	Analysis 2	Analysis 3
	Overall hospital utilization	Impact of nursing + allied health staff unit on utilization	Pre-operative and intra-operative costs
Representative of	Entire surgical episode of care from admission to discharge	From time of transfer from PACU to discharge	From time of admission to pre-surgical area to discharge from PACU
Total costs	X	X	
Hospital	X	X	
Room and board	X	X	
Intensive care unit	X	X	
Pharmacy	X	X	
Laboratory	X	X	
Radiology	X	X	
PT/OT/RT	X	X	
Transfusion-related	X	X	
Physician costs	X	X	
E&M	X	X	
Physician radiology	X	X	
Other	X	X	
Operative costs	X		X
Anaesthesia costs	X		X

PACU, post-anaesthesia care unit; PT, physical therapy; OT, occupational therapy; RT, respiratory therapy; E&M, evaluation and management.

groups (Table 2). A χ^2 test was used for baseline characteristics, including gender, co-morbid conditions, anaesthesia type, admitting diagnosis, use of cemented arthroplasties, 30 d re-admission rates and discharge locations. Unadjusted LOS, unadjusted costs, age, ICU days, re-operations and ASA functional class were tested using an ANOVA. Univariate costs are demonstrated in Table 3. Bonferroni adjustments were performed where appropriate.

The effect of BMI on the primary outcomes of LOS, overall, hospital and physician costs was examined using the entire cohort after adjusting for the baseline and surgical covariates through use of generalized linear regression models, and testing for appropriate interactions (Table 4). In order to provide costs adjusted for covariates, separate regression models were analysed for each categorization of cost. Covariates included in this model were age, sex, ASA class, surgical indication, use of a cemented arthroplasty, admission the day before surgery, anaesthesia type and ICU stay. Because year of surgery and Charlson co-morbidities could affect our primary outcomes, these variables were also included. For adjustment, age was classified into five different categories: <55, 55–64, 65–69, 70–74 and >75 years. The 65–69 years age group was identified as the median age, and labelled the reference group. Each co-morbid condition was treated as an indicator variable. BMI was also treated as a nominal variable with four levels. Indicator variables were also assigned for the calendar year in which the patient was operated with 2004 as the reference category. We also adjusted for nursing unit as it has previously been demonstrated that it may impact costs[22].

Secondary outcomes included unexpected admission to the ICU from regular nursing floor, 30 d outcomes and discharge disposition. Assessments of the effects of BMI on transfer to the ICU, and on the combined endpoint of 30 d mortality, re-admissions or re-operations, were performed using logistic regression models adjusting for the specified covariates described above. A P value $<0{\cdot}05$ was considered statistically significant. Analyses were performed using the SAS statistical software package version 9·1 (SAS Institute, Cary, NC, USA).

Results

Patient baseline characteristics are outlined in Table 2. Age differed between BMI groups ($P<0{\cdot}001$) as did gender ($P<0{\cdot}001$). A higher BMI was associated with a higher ASA class ($P<0{\cdot}001$) and a higher overall Charlson co-morbidity index ($P<0{\cdot}001$).

Univariate costs are demonstrated in Table 3. Adjusted LOS was similar among normal (4·99 (SD 0·11) d), overweight (5·00 (SD 0·09) d), obese (5·02 (SD 0·11) d) and morbidly obese (5·17 (SD 0·14) d) patients ($P=0{\cdot}20$; Table 4). We analysed LOS after excluding nursing home patients but it was no different ($P=0{\cdot}56$; data not shown). Overall, hospital and physician costs in Analysis 1 were similar among all groups ($P=0{\cdot}20$, $P=0{\cdot}25$ and $P=0{\cdot}19$, respectively). Blood bank costs were significantly lower in morbidly obese patients ($180) than in obese ($206), overweight ($255) or normal BMI ($274) patients (ANOVA, $P=0{\cdot}002$; multiple comparison analysis, all $P<0{\cdot}05$). Post-operative overall, hospital and physician costs (Analysis 2) were no different between groups ($P=0{\cdot}30$, $P=0{\cdot}32$ and $P=0{\cdot}24$, respectively). Analysis 3 represents operative and anaesthesia costs, which were higher in the morbidly obese group than in

https://doi.org/10.1017/S1368980009005072 Published online by Cambridge University Press

Table 2 Characteristics of 5642 patients undergoing elective hip arthroplasty by BMI category*

	BMI category								
	Normal (18·5–24·9 kg/m²) (n 1362)		Overweight (25·0–29·9 kg/m²) (n 2146)		Obese (30·0–34·9 kg/m²) (n 1342)		Morbid obesity (≥35·0 kg/m²) (n 792)		
Patient characteristic	Mean or n	SD or %	Mean or n	SD or %	Mean or n	SD or %	Mean or n	SD or %	P value†
Mean age (years)	62·4	17·2	64·3	14·1	62·7	13·0	61·2	12·7	<0·001
Gender									
Males	441	32·4	1220	56·9	739	55·1	363	45·8	<0·001
Mean weight (kg)	63·9	10·5	80·3	10·8	93·7	13·1	111·8	18·9	<0·001
Mean BMI (kg/m²)	22·7	1·67	27·5	1·4	32·1	1·4	40·5	11·3	<0·001
Local residents	144	10·6	203	9·5	138	10·3	101	12·8	0·08
Insurance type									
Private	574	21·1	891	41·5	653	48·7	301	50·6	<0·001
Government	769	56·5	1239	57·7	682	50·8	388	49·0	<0·001
Other	19	1·4	16	0·8	7	0·5	3	0·4	0·03
Indication for surgery									
Avascular necrosis	163	12·0	198	9·2	101	7·5	54	6·8	<0·001
Cancer	34	2·5	33	1·5	20	1·5	10	1·3	0·08
Congenital	27	2·0	26	1·2	16	1·2	5	0·6	0·05
Degenerative joint disease	1035	76·0	1806	84·2	1164	86·7	694	87·6	<0·001
Rheumatologic disorder	61	4·5	52	2·4	24	1·8	16	2·0	<0·001
Other	42	3·1	31	1·4	17	1·3	13	1·6	0·001
Year of surgery									
1996	140	10·3	198	9·2	126	9·4	55	6·9	
1997	143	10·5	234	10·9	123	9·2	71	9·0	
1998	156	11·5	218	10·2	124	9·2	65	8·2	
1999	180	13·2	222	10·3	118	8·8	85	10·7	<0·001
2000	143	10·5	231	10·8	127	9·5	75	9·5	
2001	139	10·2	232	10·8	154	11·5	99	12·5	
2002	146	10·7	215	10·0	184	13·7	125	15·8	
2003	140	10·3	271	12·6	195	14·5	112	14·1	
2004	175	12·9	325	15·1	191	14·2	105	13·3	
Anaesthesia type									
General	649	47·7	1021	47·6	689	51·3	504	63·6	<0·001
Regional	609	44·7	984	45·9	555	41·4	252	30·6	<0·001
Combined	104	7·6	141	6·6	98	7·3	46	5·8	0·34
Mean anaesthesia time (min)	214·8	55·4	213·3	56·2	218·7	54·6	232·1	59·1	<0·001
Mean operative time (min)	169·8	52·2	169·4	56·3	173·3	51·2	184·1	54·9	<0·001
Cemented arthroplasties	487	35·8	753	35·1	444	33·1	251	31·7	0·16
Discharge to orthopaedic unit	1263	92·7	2000	93·2	1269	94·6	739	93·3	0·25
ASA class									
1	144	10·6	151	7·0	76	5·7	18	2·3	
2	794	58·3	1316	61·3	811	60·5	375	47·4	<0·001
3	416	30·6	666	31·0	446	33·3	393	49·7	
4	7	0·51	13	0·6	7	0·5	5	0·63	
Charlson conditions									
Myocardial infarction	8	0·6	13	0·6	6	0·5	6	0·8	0·83
Congestive heart failure	19	1·4	29	1·4	17	1·3	11	1·4	0·99
Peripheral vascular disease	11	0·8	17	0·8	11	0·8	6	0·8	0·99
Cerebrovascular disease	6	0·4	5	0·2	3	0·2	1	0·1	–

Table 2 *Continued*

Patient characteristic	BMI category: Normal (18·5–24·9 kg/m²) (*n* 1362) Mean or *n*	SD or %	Overweight (25·0–29·9 kg/m²) (*n* 2146) Mean or *n*	SD or %	Obese (30·0–34·9 kg/m²) (*n* 1342) Mean or *n*	SD or %	Morbid obesity (≥35·0 kg/m²) (*n* 792) Mean or *n*	SD or %	*P* value†
Dementia	1	0·1	3	0·1	0	0	0	0	–
Chronic obstructive pulmonary disease	85	6·2	104	4·9	76	5·7	52	6·6	0·19
Ulcers	2	0·2	4	0·2	5	0·4	3	0·4	–
Diabetes	44	3·2	115	5·4	137	10·2	138	17·4	<0·001
Hemiplegia	0	0	2	0·1	0	0	0	0	–
Renal disease	16	1·2	11	0·5	8	0·6	3	0·4	0·07
Metastatic tumour	23	1·7	22	1·0	14	1·0	7	0·9	0·23
AIDS	2	0·2	1	0·1	3	0·2	0	0	–
Rheumatologic disease	8	0·6	6	0·3	3	0·2	4	0·5	0·34
Cancer	37	2·7	54	2·5	25	1·9	13	1·6	0·24
Mean score	0·19	0·5	0·18	0·5	0·23	0·49	0·31	0·54	<0·001

ASA, American Society of Anaesthesiologists.

*All data are represented as means and counts, with their standard deviation or proportions in adjacent column.

†Patient characteristics contain empty or too few data to perform statistical analyses.

all others (all $P<0{\cdot}05$). All other adjusted costs were non-significant and are represented in Table 4.

There were no statistical differences in our composite 30 d endpoint among the normal, overweight, obese or morbidly obese groups (6·7 % *v.* 6·2 % *v.* 6·6 % *v.* 7·6 %; $P=0{\cdot}62$). In addition, morbidly obese patients were more likely to be discharged to an assisted living facility or a nursing home (24·1 %) compared with normal BMI (18·4 %; $P=0{\cdot}001$), overweight (17·9 %; $P<0{\cdot}001$) or obese patients (16·0 %; $P<0{\cdot}001$). There were no differences in the number of patients transferred to the ICU ($P=0{\cdot}47$) or the number of ICU days ($P=0{\cdot}88$).

Discussion

The relationship between BMI and health-care utilization is of vital importance due to the continual increase in the prevalence of obesity in the USA. Our key findings in this large inclusive cohort of over 5600 patients demonstrate that neither obese nor morbidly obese patients undergoing primary elective THA have differing LOS or overall hospital resource costs than normal BMI or overweight patients. Such findings are important in dispelling myths regarding the possible added resource use of obese patients in the peri-operative setting. However, our study is restricted to the hospital stay and lacks longer-term clinical outcome data and costs associated with the post-hospital course.

Length of stay is often a major determinant in overall inpatient medical costs. There was a lack of statistical or clinical significance between groups. A previous study demonstrated that LOS is related to BMI with a 'J'- or 'U'-shaped relationship in a US population cohort(23); however, that particular study focused on all hospitalizations, including urgent surgeries which often portend to higher costs and may indeed be related to sicker patients, contrary to what is observed in an elective arthroplasty population. Thompson *et al.* estimated that future health-care costs will be higher for obese patients(24) along with a need for arthroplasty, thereby making costs likely contributing factors. However, our results suggest that in-hospital costs for obese patients are no different, suggesting that much of the possible burden, in attempts of reducing LOS, have been shifted to rehabilitation centres or home-health services, entities not captured by our data set.

Our study results confirm the results of Jibodh *et al.*, who did not observe any differences in resource utilization among the four BMI categories they examined in elective THA patients(16). The costs outlined in their paper ranged from \$13 355 in the group with BMI < 25 kg/m² to \$14 055 in the morbidly obese group, all of which are markedly lower than what we have demonstrated in the current study. Whether their annualized costs were standardized as ours were, is unknown. Furthermore, that paper also did not observe any differences in LOS.

https://doi.org/10.1017/S1368980009005072 Published online by Cambridge University Press

Table 3 Univariate unadjusted length of stay and cost centre estimates of 5642 elective total hip arthroplasty patients by BMI category*

	BMI category									
	Normal (18·5–24·9 kg/m²) (*n* 1362)		Overweight (25·0–29·9 kg/m²) (*n* 2146)		Obese (30·0–34·9 kg/m²) (*n* 1342)		Morbid obesity (≥35·0 kg/m²) (*n* 792)		*P* value (ANOVA)	Statistical comparisons†
	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
Length of stay (days)	5·09	2·31	4·97	2·35	4·92	2·06	5·23	1·96	0·005	b,e,f
Cost centre charge ($US)										
Analysis #1										
Total costs	17 480	6530	17 262	8292	16 966	5644	18 129	5900	0·002	b,c,e,f
Hospital costs	14 901	5896	14 759	7828	14 493	5185	15 511	5384	0·005	c,e,f
Room and board costs	4479	2279	4510	3626	4467	2262	4745	2085	0·13	–
ICU costs	42	382	70	786	25	304	51	466	0·13	–
Pharmacy costs	853	1570	849	3339	810	1284	898	1043	0·86	–
Laboratory costs	463	497	442	546	418	397	485	436	0·009	b,e,f
Radiology costs	170	366	186	440	171	406	183	301	0·62	–
PT/OT/RT costs	752	507	756	553	763	546	786	532	0·50	–
Blood bank costs	296	572	240	828	191	357	209	366	<0·001	a,b,c,d
Physician costs	2113	859	2087	903	2018	607	2111	700	0·009	b,d,f
Surgeon costs	1839	547	1808	435	1786	401	1790	457	0·02	b,c
Physician radiology costs	93	221	108	325	88	158	103	191	0·08	–
E&M costs	88	250	89	347	77	202	102	214	0·24	–
Other costs	29	227	30	183	23	79	40	185	0·24	–
Analysis #2										
Total costs (excluding op/anaesthesia)	11 886	6180	11 719	8041	11 404	5407	12 415	5696	0·008	b,c,e,f
Hospital costs (excluding op/anaesthesia)	11 606	5724	11 475	7685	11 171	5050	12 073	5267	0·02	b,e,f
Physician costs (excluding op/anaesthesia)	273	658	279	780	233	511	317	606	0·04	d,f
Analysis #3										
Anaesthesia + operating room costs	5589	1219	5541	1116	5562	1068	5701	1168	0·008	b,e,f
Anaesthesia	456	92	451	94	456	91	473	96	<0·001	c,e,f
Operating room	3295	851	3284	808	3321	799	3438	802	<0·001	c,e,f

ICU, intensive care unit; PT, physical therapy; OT, occupational therapy; RT, respiratory therapy; E&M, evaluation and management.
*All cost data are represented as unadjusted costs and are rounded to the nearest dollar. *P* value <0·05 is considered statistically significant.
†Multiple comparison analyses performed for individual comparisons between groups when ANOVA significant: a, normal BMI *v.* overweight; b, normal *v.* obese; c, normal *v.* morbidly obese; d, overweight *v.* obese; e, overweight *v.* morbidly obese; f, obese *v.* morbidly obese.

Table 4 Multivariate analysis of length of stay and cost centre estimates of 5642 elective total hip arthroplasty patients by BMI category*

	BMI category									
	Normal (18·5–24·9 kg/m²) (*n* 1362)		Overweight (25·0–29·9 kg/m²) (*n* 2146)		Obese (30·0–34·9 kg/m²) (*n* 1342)		Morbid obesity (≥35·0 kg/m²) (*n* 792)		*P* value (ANOVA)	Statistical comparisons†
	Mean	SE	Mean	SE	Mean	SE	Mean	SE		
Length of stay (days)	4·99	0·11	5·00	0·09	5·02	0·11	5·17	0·14	0·20	–
Cost centre charge ($US)										
Analysis #1										
Total costs	17 211	330·5	17 462	258·5	17 195	326	17 665	436	0·23	–
Hospital costs	14 663	307	14 945	240·5	14 702	302·5	15 069	404·5	0·25	–
Room and board costs	4389	145·5	4542	114	4564	144	4654	191·5	0·15	–
ICU costs	49	29·5	71	23	27	29	33	39	0·10	–
Pharmacy costs	886	125	885	98	795	123·5	768	165	0·50	–
Laboratory costs	451	23	455	17·5	434	22	445	30	0·54	–
Radiology costs	170	20·5	185	16	172	20	181	27	0·62	–
PT/OT/RT costs	735	27·5	761	22	779	27·5	775	36·5	0·16	–
Blood bank costs	274	33	255	26	206	32·5	180	43·5	0·002	f
Physician costs	2091	38·5	2094	30	2044	37·71	2088	50·5	0·19	–
Surgeon costs	1826	24·5	1808	19	1795	24·5	1796	32·5	0·31	–
Physician radiology costs	94	13	108	10·5	89	13	100	17·5	0·13	–
E&M costs	90	13	94	10	81	13	78	17·5	0·30	–
Other costs	26	8·5	31	6·5	28	8·5	38	11·5	0·41	–
Analysis #2										
Total costs (excluding op/anaesthesia)	11 655	320·5	11 911	251	11 602	316·5	11 962	422·5	0·30	–
Hospital costs (excluding op/anaesthesia)	11 387	302	11 653	236·5	11 363	298	11 651	398	0·32	–
Physician costs (excluding op/anaesthesia)	263	31·5	285	24·5	248	31·5	288	42	0·24	–
Analysis #3										
Anaesthesia + operating room costs	5553	60·5	5549	47·5	5593	60	5688	79·5	0·03	e,f
Anaesthesia	451	43·5	451	34	459	43	475	57·5	<0·001	c,e,f
Operating room	3276	4·5	3291	3·5	3340	4·5	3418	6	<0·001	c,e,f

ICU, intensive care unit; PT, physical therapy; OT, occupational therapy; RT, respiratory therapy; E&M, evaluation and management.
*All cost data are represented as costs adjusted for age, sex, ASA (American Society of Anaesthesiologists) class, surgical indication, use of a cemented arthroplasty, admission the day before surgery, anaesthesia type, ICU stay, year of surgery, Charlson co-morbidities and nursing unit, and are rounded to the nearest dollar. *P* value <0·05 is considered statistically significant.
†Multiple comparison analyses performed for individual comparisons between groups when ANOVA significant: a, normal BMI *v.* overweight; b, normal *v.* obese; c, normal *v.* morbidly obese; d, overweight *v.* obese; e, overweight *v.* morbidly obese; f, obese *v.* morbidly obese. $P < 0·05$ after Bonferroni adjustment.

The only other known study examining this relationship was conducted by Epstein *et al.*[17] in 1987; however, their data can be considered out-of-date not only due to practice changes, differing surgical techniques and changes in interdisciplinary care, but also because their study was in an era where LOS was markedly longer than what is expected nowadays.

The observation of lower blood bank costs in the morbidly obese group is inconsistent with previous data which did not demonstrate any cost differences[16] or an association between obesity and increased intra-operative blood loss[25,26]. As administrative data sets were used in our study, we were unable to determine the reasons for laboratory tests or the particular indications for transfusion. One possibility may be that morbidly obese patients have higher blood volumes, and can therefore lose more blood before their Hb may reach a level where transfusion is indicated. In addition, anaesthesia and operating room costs (Analysis 3, Table 4) were statistically higher in morbidly obese patients than other BMI categories, suggesting that there were other miscellaneous factors involved that were not captured by our databases. These higher costs, though, are consistent with the higher operative and anaesthesia times observed in our cohort.

Although we hypothesized that obese or morbidly obese patients would have a higher number of unexpected ICU admissions and ICU days, no differences were observed. The relationship between obesity and resource utilization has been examined in detail in the ICU setting and following cardiac surgery[27,28]. Studies have been equivocal, with some demonstrating a 'U'-shaped relationship between costs and BMI, but others failing to find such a relationship[29]. Although we did not specifically measure ICU complications, our results may be due to the fact that patients admitted for elective surgical intervention have pre-operative assessments whose primary purpose is to optimize their surgical candidacy and identify peri-operative strategies to reduce surgical and post-operative complications.

We used a composite 30 d endpoint for death, re-admissions and re-operations, as we had insufficient power to examine these outcomes individually. Obese patients have a higher peri-operative mortality risk due to their coexisting co-morbidities[30]. Because our centre also acts as a referral centre, we likely would be unable to capture all relevant clinical data (reason for re-admission and reason for re-operation at the patient's local facility) if a standard 90 d post-operative payment period was used; hence our data may underestimate the impact of BMI on longer-term outcomes. Yet, the present data are consistent with studies that have not shown any identifiable increases in mortality or post-operative complications among obese or morbidly obese patients undergoing cholecystectomy, hysterectomy or even cardiac surgery[30,31]. Although there was an increasing non-statistical trend in this outcome as BMI increased, it is unknown as to whether this would differ at a higher BMI. We agree, though, that obesity is likely not associated with higher peri-operative risk or an increased risk in treatment[32].

Obesity is known to be a risk factor for long-term nursing home placement[33]. There are some studies which have demonstrated that orthopaedic surgery predicts nursing home placement[34], but to the best of our knowledge, no data exist which primarily examine impact of obesity in post-operative elective hip arthroplasty on nursing home placement, particularly with regard to short-term placement. Our results demonstrate that morbidly obese patients were more likely to be discharged to a care facility compared with the other BMI categories following elective arthroplasty.

Peri-operative complications and care of the surgical obese patient are of concern, both to medical staff and hospital administrators. The risks associated with surgery in this population may lead to increased costs, particularly in the morbidly obese group, as has been demonstrated in our study. This analysis focuses on an economically important issue from an institutional perspective, as to whether obese or morbidly obese patients, populations at higher risk for requiring arthroplasties, have higher resource use following elective primary THA. Although the costs differences per patient may not seem overtly large, when one considers that over 200 000 hip arthroplasties are performed annually, one cannot ignore the overall economic and societal impact, particularly in a health-care system such as that in the USA where the burden of costs rests upon public funding in this population group[35,36].

The study results can be applied to high-volume tertiary care centres with orthopaedic expertise. Such centres have lower lengths of stay and costs than corresponding lower-volume centres[37]. Previous population-based epidemiological studies demonstrated that our institution's patient population, which is of white Northern European descent in >90 % of cases, often is generalizable to a significant portion of the US white population[38]. However, we caution that our results may not necessarily be extrapolated to other races or ethnic backgrounds and that further studies are warranted to better elucidate our hypothesis in these patients[39]. By using standardized measurements, we eliminated measurement bias. Many studies estimate BMI using self-reported height and weight, which generally underestimate BMI[40]. Our costs were also standardized and adjusted for inflation. Finally, we limited our registry search to focus on unilateral elective primary THA patients to minimize any potential confounding, as urgent repairs, revisions, septic arthritis and bilateral procedures are associated with higher costs, lengths of stay and complication rates[41]. Our results can therefore provide excellent external validity only to such patients.

Our study has the inherent limitations of a retrospective study. We relied on the validity of the data in various administrative databases, whose use has been challenged by others[42,43]. Minor procedures and diagnoses may be ignored in chart abstraction or incorrectly entered; however, the likelihood that these differences exist should be similar between groups. Administrative databases do not permit abstraction of the time and date when all hospital staff deemed that the patient was ready for discharge. Hence we relied on the actual time of discharge, which can be heavily dependent on availability at skilled nursing facilities. However, after excluding patients discharged to such facilities, our results were no different. Furthermore, a 90 d period in ascertaining costs and outcomes would be more appropriate, but could not be performed using our data set.

Our results may underestimate the differences in LOS and costs observed in obese or morbidly obese patients. Although we adjusted for baseline characteristics and medical co-morbidities, including diabetes and cardiac disease which are known to portend to higher costs[44,45], patients with notable co-morbid conditions may not have been surgical candidates, thereby introducing an element of selection bias. It is possible that some of the underlying differences across weight groups were removed through regression covariates. Well-known variables, including ASA, Charlson co-morbidity, surgical year and indication, cemented arthroplasty, admission the day prior to surgery, anaesthesia type and ICU stay, all are known to impact resource utility. If differences on these variables are due to BMI, the adjusted analysis will underestimate any cost differences. In fact, although there was a higher proportion of patients with degenerative joint disease in the morbidly obese group, patients with this indication had mean costs $1002 lower than other surgical indications. Additionally, there were higher proportions of obese and morbidly obese patients in years since 2000, but the costs of more recent years were $2319 less expensive. These results suggest that, despite baseline factors that were more prevalent in the obese and morbidly obese patient groups, the analysis appropriately adjusted for these variables to isolate the impact of BMI on costs. We relied on the definitions of obesity recommended by the WHO, as opposed to those based on life-insurance tables or older methodologies. Previous studies have determined that obese patients have 50 % higher health-care costs than 'normal' weight patients; hence we wished to determine the costs in accordance to this BMI category[46].

Although BMI is a widely used surrogate for the degree of adiposity, it not only overestimates adiposity in patients with increased musculature, but more importantly underestimates adiposity amongst the elderly, who have age-related reductions in lean mass[47,48]. Recent data demonstrate the lower correlation coefficients between BMI and lean mass, and between BMI and percentage body fat, in the 65+ years age group compared with patients below the age of 65 years[49]. Hence we may have underestimated the true impact of adiposity on resource utilization. Finally, our analysis was limited to the inpatient stay and thus we cannot determine resource utilization past dismissal. As much of the costs are shifted to post-acute care venues, rehabilitation, home-health services and skilled nursing facility costs are factors which contribute to overall resource utilization, and are not reflected in our results, leading our results to have underestimated the impact of obesity on overall resource use[50]. This study was undertaken from a hospital perspective as opposed to a societal perspective, thereby omitting potential non-medical costs which are incurred by patients and others related to the surgical intervention.

Our results cannot be extrapolated to patients with a BMI $< 18{\cdot}5\,\text{kg/m}^2$ as we had excluded this subgroup of patients from this analysis. Furthermore, indications for arthroplasty are usually different in this cohort as they are less likely to develop osteoarthritis, can be considered frail and thus may not either be candidates for the intervention or may not obtain its benefits. In addition, the inherent selection bias by both primary care providers in referring these patients for surgery and orthopaedic surgeons in operating on them is real. The scope of these issues would need to be fully ascertained to better understand them.

Our findings have significant implications for physicians, policy makers and others interested in the impact of obesity in the hospitalized patient. Using this large cohort of patients, our data suggest that there is no difference in LOS or in overall costs. Identification of measures to optimize health-care delivery in obese patients may reduce inpatient costs but would likely impact all groups alike. Little attention has been given towards the 'ageing obese' population, the need for arthroplasty and its fiscal consequences. Prospective evaluation of the impact of obesity on patient-related outcomes and costs are needed to ascertain areas where clinical pathways or interventions can be implemented to sustain efficiency and fiscal responsibility.

Acknowledgements

The authors obtained funding through the Small Grants Program, Mayo Clinic Rochester. No authors have any conflicts of interests. The work was performed primarily while J.A.B. was at Mayo Clinic Rochester. J.A.B. was involved in conceptualization and design of the study, analysis and interpretation of the data, manuscript writing and approval of the final submitted manuscript. J.M.N. and A.E.W. were involved in the conceptualization and design of the study, analysis and interpretation of the data, statistical expertise, critical revisions of the manuscript, and approved the final submitted version. M.T.K. and P.M.H. were involved in conceptualization and design of the study, analysis and interpretation of the data, critical revision of the manuscript, and approved the final submitted version. J.M.H. was involved in conceptualization and design of the study, analysis and interpretation of the data, supervision, responsible for obtaining funding, and critically reviewed the manuscript, also approved the final submitted version. We thank Donna K. Lawson, LPN, for her assistance in data collection and management.

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