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Should the Pareto Principle Be Applied as a Cost Savings Method in Hip and Knee Arthroplasty?

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ABSTRACT

Background: Understanding the most significant contributions to the cost of completing total hip arthroplasty (THA) and total knee arthroplasty (TKA) is essential to optimize costs and meet funding standards. The objectives of this study are to determine whether cost distribution of THA and TKA follows the Pareto Principle (80/20 rule) and factors predictive of costs that could be modified.

Methods: All inpatient, primary, elective, and unilateral THA and TKA patients from April 2008 to September 2017 were retrospectively reviewed. The Pareto Principle was tested by dividing patients into top 5% cost increments and calculating patient cost category ratio. Relationship between patient-related factors and acute care costs and relationship between cost categories and length of stay (LOS) were examined using multiple regression.

Results: The Pareto Principle does not apply for THA or TKA patients, with the top 20% of costly patients accounting for approximately 30% of total costs. LOS is the strongest independent driver of costs. Operating room services and supplies accounted for over 50% of total costs but with low variability (coefficient of variation < 0.25). Laboratory and allied health costs had high variability (coefficient of variation > 1.5), but their contribution to total costs was low (from 0.76% to 5.68%).

Conclusion: THA and TKA costs do not follow Pareto Principle, concluding that targeting top costly patients is not as effective as focusing on overall patient population. Efforts to decrease overall costs should focus on decreasing the LOS and improving operating room process efficiencies including human resources for supplies and instruments.

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In Canada, in 2016-2017, over 55,000 total hip arthroplasties (THAs) and 67,000 total knee arthroplasties (TKAs) were performed at an average inpatient cost of $9100 [1]. Over $1 billion is spent annually on these procedures, accounting for a significant portion of healthcare spending [2]. The Canadian healthcare system is a single-payer system, with most government funding coming from the provincial level. Hospital care is delivered by publicly funded hospitals, which are required by law to stay within a set out budget. With an aging population, the cost of healthcare is expected to continue to rise over the next several years [3]. In 2012, Health System Funding Reform was introduced in an effort to minimize cost while maintaining patient safety. Subsequently, funding has moved from a global funding approach, where the hospital used to receive lump sum funding, to a patient-based funding approach, where evidence-based models dictate funding with incentives to deliver the highest and most efficient care called (referred to as quality-based procedures) [4]. Understanding the most significant contributions to the cost of completing THA and TKA is essential to meeting funding standards.

This study was reviewed and approved by the Institutional Ethics Committee.

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One commonly used principle in economics to improve cost savings is the Pareto Principle. The Pareto principle states that a small number of patients and associated factors have a disproportionate impact on any outcome [5]. It is also referred to as the 80/20 rule in which 80% of impact comes from only 20% of potential causes. This principle has been shown to apply to many other sociological, economic, political, and natural phenomena. In mathematics, it is recognized as the power distribution. The Pareto Principle is useful in healthcare and quality improvement because it suggests that focusing on a small number of patients can result in a large improvement impact. These factors are referred to as the vital few [5].

In Ontario, Canada, the top 5% of highest costly patients account for 61% of total healthcare costs [6]. Previous literature on back pain has demonstrated that the majority of healthcare costs are attributable to a minority of the patients, following the Pareto Principle [7,8]. This has led to targeted funding and interventions to subsets of patients with low back pain in order to significantly decrease healthcare expenditures. No previous studies have looked at application of the Pareto Principle in THA and TKA patients. In recent years, there has been a notable reduction in length of stay (LOS) associated with THA and TKA procedures [9,10]. Because of these changes in practice, it is important to assess to what extent the Pareto Principle applies in a historical and contemporary timeframe at our institution. As such, the primary objective of this study is to determine whether the cost distribution of primary THA and TKA patients follows the Pareto Principle over 2 timeframes. The secondary objective is to determine if there are any modifiable factors that could be optimized that are predictive of increased costs.

Methods

All inpatient, primary, elective, and unilateral THAs and TKAs completed at a large tertiary care center from April 1, 2008 to September 30, 2017 were retrospectively examined. We excluded any bilateral cases, revision cases, or cases completed on an urgent basis (such as for fracture). Expenses pertaining to the surgery and acute hospital stay were retrieved from the hospital's data warehouse as per the Ontario Case Costing Initiative guidelines [11]. All cases were analyzed and compared on financial factors including the type of cost incurred during their stay, including direct and indirect costs associated with the patient encounter. Patient factors including age, gender, American Society of Anesthesiologists (ASA) grade, body mass index (BMI), Charlson Comorbidity Index (CCI), and LOS were evaluated as predictors of total cost. The distribution of costs was evaluated for 5% increments of patients, followed by the patient cost category ratio, which was calculated by taking the cost of each 5% increment and dividing it by the total cost for all patients, to determine whether the Pareto Principle applied. Given the emphasis on decreasing LOS and increased uptake of outpatient THA and TKA after 2015, we explored 2 time periods: 2008-2014 vs 2015-2017, to determine to what extent does the Pareto Principle apply during these timeframes. The average LOS reduced from a median of 3 (interquartile range [IQR] = 1) in 2008-2014 to 2 (IQR = 2) in 2015-2017 for hips ($P < .001$) and median 4 (IQR = 2) in 2008-2014 to 2 (IQR = 2) in 2015-2017 ($P = .003$) for knees.

Multiple regression analysis was then performed to assess relationships between patient-related factors and total cost, with the dependent variable being total cost and the independent variables including age, gender, ASA grade, BMI, CCI, and LOS. The costs of readmissions and complications such as wound healing issues, deep vein thrombosis, pulmonary embolism, and pneumonia were not included, as only the acute stay was evaluated. A subgroup analysis of individual cost categories was performed on patients between 2015 and 2017 which included drugs, food services, laboratories, medical imaging, medical/surgical nursing, operating room (OR) services and supplies, allied health (occupational therapy, physiotherapy, social work), and post-anesthesia care unit. Coefficients of variation (CVs) were calculated for each to determine which were more fixed or variable. Another multiple regression was performed to examine the relationship between different cost categories and LOS. A subgroup analysis of ASA grade was performed for cost categories that were not predictive of LOS.

Table 1
Demographic Breakdown of All Total Hip and Knee Arthroplasty Procedures Performed Between 2008 and 2017.

Continuous Variables	THA (n = 3802)	TKA (n = 4884)
	Mean ± SD (Range)	Mean ± SD (Range)
Age	64.8 ± 12.4 (16-95)	67.9 ± 10.1 (24-99)
BMI	29.0 ± 5.9 (0.16-63.1)	33.1 ± 7.1 (13-74)
CCI	0.31 ± 0.93 (0-11)	0.43 ± 0.981 (0-9)
LOS (median, IQR)	3.0 (2.0)	3.0 (2.0)
Categorical Variables	Count (%)	Count (%)
Gender (male)	1590 (41.8%)	1736 (35.5%)
ASA Grade		
1	134 (3.5%)	88 (1.8%)
2	1770 (46.5%)	1766 (36.2%)
3	1809 (47.5%)	2894 (59.3%)
4	89 (2.3%)	136 (2.8%)

THA, total hip arthroplasty; TKA, total knee arthroplasty; SD, standard deviation; BMI, body mass index; CCI, Charlson Comorbidity Index; LOS, length of stay; IQR, interquartile range; ASA, American Society of Anesthesiologists.

Results

Cost Ratios

From April 1, 2008 to September 30, 2017, 3802 primary unilateral THAs were performed at our institution and analyzed as part of this study (Table 1). Between April 2008 and December 2014, and between January 2015 and September 2017, 2501 and 1301 primary unilateral THAs were performed, respectively. Table 2 shows the cost distribution for the top 50% of most costly patients divided into 5% increments for the 2 timeframes. The top 5% of costliest THA patients accounted for 11.9% and 10.8% of costs between 2008-2014 and 2015-2017 respectively, with ratios of 2.37 and 2.17. The top 20% of most costly patients accounted for 30.7% and 30.6% respectively, with ratios of 1.53 and 1.53.

During the same time period, 3884 primary unilateral TKAs were performed at our institution and analyzed as part of this study

Table 2
Distribution of Most Costly Patients for Each 5% Cost Increment for Total Hip and Knee Arthroplasty Patients for 2 Timeframes.

Patient Cost Category	Total Cost (%)				Cost Category Ratio[a]			
	2008-2014		2015-2017		2008-2014		2015-2017	
	Hip	Knee	Hip	Knee	Hip	Knee	Hip	Knee
5%	11.9	11.8	10.8	13.1	2.37	2.35	2.17	2.62
10%	18.9	18.7	18.2	20.5	1.89	1.87	1.82	2.05
15%	25.0	24.8	24.6	27.0	1.67	1.65	1.64	1.80
20%	30.7	30.5	30.6	32.9	1.53	1.52	1.53	1.65
25%	36.1	35.9	36.2	38.5	1.44	1.43	1.45	1.54
30%	41.3	41.0	41.6	43.7	1.38	1.37	1.39	1.46
35%	42.7	46.0	46.7	48.8	1.22	1.31	1.33	1.39
40%	51.2	50.8	51.7	53.7	1.28	1.27	1.29	1.34
45%	55.9	55.6	56.5	58.3	1.24	1.23	1.26	1.30
50%	60.6	60.2	61.3	62.9	1.21	1.20	1.23	1.26

[a] % of total costs divided by patient cost category.

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Table 3
Multiple Regression With Total Cost as Dependent Variable for Total Hip Arthroplasty Patients Including Length of Stay as Major Cost Driver.

Variable	*P*-Value	Unstandardized β	95% Confidence Interval	Standardized β
Age	<.001[a]	−27.487	−32.956 to −22.017	−0.094
Gender	.445	−51.414	−183.488 to 80.659	−0.007
ASA (dichotomous)	.026[a]	157.333	18.772 to 295.894	0.022
BMI	.916	0.61	−10.731 to 11.951	0.001
CCI	<.001[a]	265.682	193.700 to 337.664	0.068
LOS	<.001[a]	956.538	935.831 to 977.245	0.866

$R^2 = 0.753$; adjusted $R^2 = 0.753$.
ASA, American Society of Anesthesiologists; BMI, body mass index; CCI, Charlson Comorbidity Index; LOS, length of stay.
[a] Significance is set at $P < .05$.

(Table 1). Between April 2008 to December 2014, and between January 2015 and September 2017, 3610 and 1274 primary unilateral TKAs were performed, respectively. Very similar trends were observed for TKA patients over same timeframes as for THA patients (Table 2). The top 5% of costliest TKA patients accounted for 11.8% and 13.1% of costs between 2008-2014 and 2015-2017 respectively, with ratios of 2.35 and 2.62. The top 20% of most costly patients accounted for 30.5% and 32.9% respectively, with ratios of 1.52 and 1.65.

Predictors of Total Cost

When examining the predictors of total costs, LOS is a major cost driver for both THA and TKA patients: standardized β = 0.866, *P*-value <.001* and standardized β = 0.796, *P*-value <.001*, respectively. In both THA and TKA multiple regression models, all variables including LOS resulted in a R^2 of 0.753 and 0.641, respectively (Tables 3 and 4). When LOS was removed, the R^2 dropped down to 0.085 and 0.047, respectively.

Cost Breakdown and Predictors of LOS

OR services and supplies encompass the highest percentage of patient direct and indirect costs for THA and TKA patients, at 59.39% and 52.74% of total costs respectively (Table 5). Although contributing the most to total costs, these costs were the least variable, with low CVs. Conversely, allied health and laboratory test costs were the most variable, but their contribution to total costs was low (3.34% and 1.12% respectively for hips and 5.68% and 0.76% respectively for knees). Medical imaging costs were much more variable for TKA than THA, with CVs of 3.33 and 0.77 respectively, but the contribution to total costs was very low (0.89% of total costs) (Table 6).

All cost categories were found to be statistically significantly predictive of LOS with the exception of laboratory costs ($P = .901$) for THA patients (Table 7) and laboratory costs ($P = .285$) and OR services and supplies ($P = .412$) for TKA patients (Table 7). The variability of laboratory costs can be attributed to patients' comorbidities. THA patients with ASA grade of 3 and 4 have higher mean laboratory costs ($150.9 ± $228) than those with ASA grade 1 and 2 ($95.3 ± $97) ($P < .001$). Similarly, TKA patients with ASA grade 3 and 4 have higher mean laboratory costs ($107.2 ± $291) than those with ASA grade 1 and 2 ($70.2 ± $65) ($P = .002$). Also, OR services and supplies costs were significantly higher for TKA patients with ASA grade 3 and 4 ($4392 ± $1022) vs ASA grade 1 and 2 ($4153 ± $774) ($P = .002$).

Discussion

Over the last 5-8 years there has been a strong focus on providing value care where value is defined as health outcomes divided by costs of providing that care. In Canada, this was first introduced with the so-called QBP funding to the hospital which is based solely on the acute in-hospital phase of treatment [12]. In the United States, this was brought to the forefront with bundle payments where its recent introduction has led to significant cost savings. Navathe et al reported an average decrease in expenditures of 20.8%, and prolonged LOS decreasing by 67%. Although patient illness severity remained stable, 51.2% of overall hospital savings came from internal cost reductions and 48.8% from post-acute spending reductions [13]. Historically, cost savings measures have been determined by identifying patient population at risk of increased costs. Although it has been estimated in Canada that 5% of the population accounts for 61% of healthcare costs [6], in our population of inpatient, primary, elective, and unilateral THA and TKA patients, this distribution was not replicated. Pareto's principle did not apply to this cohort of patients when considering the whole timeframe and both time periods. The top 20% of costly patients accounted for approximately 30% of total costs. Despite the average LOS halving in the latter timeframe, the cost ratios were very similar between both time periods.

To our knowledge, no previous study has investigated whether primary arthroplasty patients follow a Pareto distribution. In previous healthcare literature on patients with back pain, a small portion of patients (7.4% to 21%) accounted for 66%-74% of the cost expenditures [7,8]. As the THA and TKA patient population is targeted by healthcare reform with QBPs, knowing that the Pareto Principle does not apply is useful as it suggests that cost saving

Table 4
Multiple Regression With Total Cost as Dependent Variable for Total Knee Arthroplasty Patients Including Length of Stay as Major Cost Driver.

Variable	*P*-Value	Unstandardized β	95% Confidence Interval	Standardized β
Age	<.001[a]	−23.034	−34.665 to −11.404	−0.042
Gender	.012[a]	−291.159	−517.781 to −64.537	−0.025
ASA (dichotomous)	.51	81.177	−160.573 to 322.928	0.007
BMI	.154	12.246	−4.604 to 29.096	0.016
CCI	<.001[a]	282.553	169.185 to 395.921	0.05
LOS	<.001[a]	1206.215	1176.135 to 1236.295	0.796

$R^2 = 0.642$; adjusted $R^2 = 0.641$.
ASA, American Society of Anesthesiologists; BMI, body mass index; CCI, Charlson Comorbidity Index; LOS, length of stay.
[a] Significance is set at $P < .05$.

Table 5
Breakdown of Costs for Hips and Knees Between 2015 and 2017.

Direct and Indirect Costs of Patient Care	Drugs	Food Services	Laboratories	Medical Imaging	Surgical Nursing	Operating Room Services and Supplies	Allied Health	Post-Anesthesia Care Unit
Hips (%)	4.04%	1.31%	1.12%	2.26%	18.58%	59.39%	3.34%	9.32%
Knees (%)	5.10%	1.60%	0.76%	0.89%	22.00%	52.74%	5.68%	9.06%

strategies should focus on the population as a whole. There is however skewing of cost for certain patients, although not to the extent of the Pareto Principle, where the top 5% of patients cost twice as much as the average patient. The vast majority of costs have very low variability as demonstrated by the low CV for each cost category. The least variable costs were related to the highest cost contributors, showing that targeting individuals is not the best approach. Program-wide cost reduction targeting fixed costs will provide greater costs savings. Our previous work has shown that the preoperative and postoperative day 2 timed up and go can indicate hospital LOS, which has led to better planning of recovery times and discharge disposition [14]. Better understanding of patient's function prior to surgery and immediately after surgery has allowed us to discharge eligible patients sooner. Although age, ASA grade, and CCI are significant factors of total cost, LOS continues to be the major driver of total acute care cost as demonstrated by the multiple regression model. The relationship between comorbidities and total cost is expected, as the relationship between comorbidities and LOS has been previously demonstrated [15].

Increased LOS leads to a greater demand for nursing services, physiotherapy, hospital meals, and so on. Inpatient hospital stay is the standard of care following THA and TKA. However, several recent studies have demonstrated the potential cost savings possible by decreasing LOS by moving toward outpatient arthroplasty surgeries. Berger et al and Huang et al have shown that outpatient TKA is a safe and cost-effective alternative to inpatient TKA in selected individuals, with no increased rates of readmission and no increased likelihood of complications, demonstrating a 30% median cost savings [16,17]. Despite the increasing literature supporting the safety of outpatient arthroplasty surgeries as well as the significant cost savings, only 0.1% of THA and 0.3% of TKA were performed as day surgeries in Canada in 2016-2017 [1]. The factors that contribute to an increased LOS should also be explored to identify areas for cost saving for inpatient arthroplasty surgeries such as perioperative pathways and implants [18].

Based on our analysis, laboratory costs are highly variable for both THA and TKA patients but are not related to LOS which could indicate an opportunity for cost savings. However, the overall percent contribution of laboratory costs to total costs is very low, so targeting them as a means for overall cost reduction would have a marginal impact. Furthermore, a significantly higher cost in laboratory expenditures can be attributed to the higher ASA score for both THA and TKA patients, with increasing cost gradient the higher the ASA grade. The relationship between ASA grade and laboratory costs makes this variable difficult to modify. Similarly, the OR services and supplies costs for TKA patients may be difficult to modify given that costs increase with increasing ASA grade. Despite its very low variability, reducing costs of OR services and supplies may provide a promising cost reduction given its large percentage of overall costs. Improving OR processes including human resources for supplies and instruments should be considered a priority to decrease the costs of OR services and supplies which account for the majority of total costs. Furthermore, providers should work together to identify a list of lower cost OR supplies at a lower target implant price.

Although age and comorbidities are also nonmodifiable patient factors, knowledge that they contribute to higher case costs for patients undergoing THA and TKA can help physicians to advocate for increased lump sum funding for this patient population or for centers that treat this patient cohort. The physician can also use this information to identify patients preoperatively at increased risks for higher costs and optimize the patient prior to undergoing surgery. Prehabilitation efforts to improve patient health prior to surgery may decrease necessity for more resources during the operation. There is a certain degree to which comorbidities (such as ASA grade and high BMI) can be modified prior to surgery; however, recent evidence speculates that increasing efforts to reduce risk factors to avoid high costs of the procedure must be balanced with patient autonomy [19].

There are some limitations to our study. We only included cost of the acute care period and did not consider costs prior to surgery or after discharge from the hospital, and societal costs. Our costing data were also based on Ontario Case Costing Initiative guidelines, which follow traditional hospital cost accounting systems. However, there is literature that suggests that time-driven activity-based costing may more accurately reflect the costs associated with arthroplasty surgery [20]. This study is a single-center study accomplished in the context of the Canadian healthcare system, a unique single payer publicly financed system, and these findings may differ to other multipayer public/private systems, with differential costs [21]. Replication of this study in other healthcare systems is warranted.

Table 6
Coefficient of Variation (CV = SD/Mean) for Total Hip and Knee Surgical and In-Hospital Expenses.

Expenses	CV Hip	CV Knee
Drugs	0.85	1.17
Food services	1.03	1.30
Laboratories	1.56	3.53
Medical imaging	0.77	3.33
Surgical nursing	1.06	0.86
OR services and supplies	0.24	0.22
Allied health	1.91	1.94
Post-anesthesia care unit	0.86	0.86

CV, coefficient of variation; SD, standard deviation; OR, operating room.

Table 7
Multiple Regression With Length of Stay as Dependent Variable and Cost Categories as Independent Variables for Total Hip and Knee Arthroplasty Patients.

Variable	Hips		Knees	
	P-Value	Standardized Beta	*P*-Value	Standardized Beta
Drugs	<.001	0.037	<.001[a]	0.035
Food services	<.001	0.996	<.001[a]	0.994
Laboratories	.901	<0.001	.285	−0.006
Medical imaging	<.001	0.012	.044[a]	0.01
OR services and supplies	<.001	−0.12	.412	0.003
Allied health	<.001	−0.062	<.001[a]	−0.052
PACU	.011	0.007	.030[a]	0.009

$R^2 = 0.998$; adjusted $R^2 = 0.998$.
OR, operating room; PACU, post-anesthesia care unit.
[a] Significance is set at $P < .05$.

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Conclusion

THA and TKA hospital costs do not follow Pareto Principle, concluding that targeting top costly patients is not as effective as focusing on the overall patient population. Cost saving strategies for elective THA and TKA should be focused on the population as a whole, as opposed to the subset of patients that are most costly. Efforts to decrease overall costs should focus on decreasing the LOS and improving OR process efficiencies including human resources for supplies and instruments.

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