Costs variations for percutaneous nephrolithotomy in the U.S. from 2003–2015: A contemporary analysis of an all-payer discharge database

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Abstract

Introduction: We sought to evaluate population-based cost variations and predictors of outlier costs for percutaneous nephrolithotomy (PCNL) in the U.S.
Methods: Using the Premier Healthcare Database, we identified all patients diagnosed with kidney/ureter calculus who underwent PCNL from 2003–2015. We evaluated 90-day direct hospital costs, defining high- and low-cost surgery as those >90th and <10th percentile, respectively. We constructed a multilevel, hierarchical regression model and calculated the pseudo-R^2 of each variable, which translates to the percentage variability contributed by that variable on 90-day direct hospital costs.
Results: A total of 114 581 patients underwent PCNL during the 12-year study period. Mean cost in the low-cost group was $5787 (95% confidence interval [CI] 5716–5856) vs. $38 590 (95% CI 37 357–39 923) in the high-cost group. Cost variations were substantially impacted by patient (63.7%) and surgical (18.5%) characteristics and less so by hospital characteristics (3.9%). Significant predictors of high costs included more comorbidities (≥2 vs. 0: odds ratio [OR] 1.81; p=0.01) and hospital region (Northeast vs. Midwest: OR 2.04; p=0.03). Predictors of low cost were hospital bed size of 300–499 beds (OR 1.35; p<0.01) and urban hospitals (OR 2.77; p=0.01). Factors less likely to be associated with low-cost PCNL were more comorbidities (Charlson Comorbidity Index [CCI] ≥2: OR 0.69; p<0.0001), larger hospitals (OR 0.61; p=0.01), and teaching hospitals (OR 0.33; p<0.0001).
Conclusions: Our contemporary analysis demonstrates that patient and surgical characteristics had a significant effect on costs associated with PCNL. Poor comorbidity status contributed to high costs, highlighting the importance of patient selection.

Introduction

About 10% of the American population is affected by kidney stones.[1] Stone disease, due to its high prevalence, high rate of recurrence, frequent need for surgical management, and impact on work absenteeism, has important economic repercussions. In the U.S., stone disease is associated with an annual cost greater than 2 billion dollars.[2] Various surgical interventions can be undertaken for the management of stone disease, namely shockwave lithotripsy (SWL), ureterscopy (URS), and percutaneous nephrolithotomy (PCNL). According to the most recent American Urological Association (AUA) guidelines, PCNL is indicated as first-line therapy for symptomatic patients with a total renal stone burden larger than 2 cm.[3] PCNL represents about 5% of stone procedures.[2] It is associated with the highest stone-free rate, but represents a more complex surgery with a steeper learning curve and higher complication rates, compared to the other procedures.[4] Given its potential morbidity, there has been interest to examine variations in care and outcomes. High-volume academic centres may perform better with decreased morbidity and higher stone-free rates, but it is unclear whether this is secondary to better surgeon technique, volume, or processes of care, and whether these ultimately translate to cost differences. A comprehensive population-level assessment of PCNL costs has not been performed. Therefore, we performed a study examining 90-day direct line-item hospital costs post-PCNL, hypothesizing that there exists substantial cost variation across surgeons and hospitals.

Methods

Data source

The Premier Healthcare Database (Premier, Inc., Charlotte, NC, U.S.), a nationally representative all-payer claims database, represents >75 million inpatient discharges, including ~20% of all hospitalizations at >700 hospitals in the U.S. This claims-based database provides billing information via ICD-9 codes and standardized billing items, including direct-item costs for most hospitalizations (e.g., medications, laboratory services, room and board, etc). ICD-9 codes were used to identify patients' diagnoses and procedures. As data are anonymized and HIPAA-compliant data, institutional review board waiver was obtained.

Hospital-specific projection weights are applied to each discharge. This allows for the projection of the sample to a national estimate of inpatient discharges. The projection methodology was developed by Premier and validated by the Food and Drug Administration (FDA).[5] Hospital-level projection weights are then applied to each discharge; all numbers reported herein refer to the weighted estimates.

Study population

Using ICD-9 codes, we identified individuals diagnosed with kidney or ureteric calculus (592.0, 592.1, 592.9) who underwent PCNL (55.04 or 55.03 with 55.21) between January 1, 2003 and December 31, 2015. Patients treated with PCNL were identified as previously described, using ICD-9 procedural codes 55.04 for percutaneous nephrostomy with fragmentation and 55.03 for percutaneous nephrostomy combined with 55.21 for nephroscopy.[6,7]

Our weighted cohort consisted of 236 999 individuals who underwent PCNL by 3531 surgeons at 458 unique hospitals. After excluding surgeons whose annual surgical volume is <3 PCNL, which is likely too small to perform a meaningful analysis (median annual surgeon volume was 3; 75th percentile: 6, 90th percentile: 12), our final cohort had 114 581 patients who underwent PCNL by 911 unique surgeons at 301 different hospitals in the U.S.

Study variables

Our outcome of interest was direct hospital costs, including that of the entire procedure, inpatient stay, and/or readmissions up to 90 days postoperatively. Costs were adjusted to 2016 U.S. dollars using the medical component of the Consumer Price Index.

We examined relevant patient, hospital, and surgical characteristics. Patient characteristics included age, race, marital status, insurance status, and Charlson Comorbidty Inex (CCI).[8] Hospital characteristics included teaching status, urbanicity, bedsize, hospital annual PCNL volume (high defined as >75th percentile; >24/year), and U.S. geographic region. Surgical characteristics included surgeon annual PCNL volume (defined as >75th percentile; >9/year) and year of surgery.

Statistical analyses

First, we sought to identify the scale of variation in non-adjusted direct hospital costs for all attending surgeons who performed ≥3 PCNL/year. To do this, we generated a ranked list of all providers (911 surgeons or 301 hospitals) ordered by 90-day direct hospital costs. Mean costs per provider were calculated by dividing the total direct hospital costs by the number of PCNLs performed by each provider across the study period. This yielded each provider's mean costs per PCNL, along with standard deviations (SD) and 95% confidence intervals (CI). This was then plotted according to each provider's rank from least to costliest (Supplementary Fig. 1).

Second, to assess for the relative contribution of patient-, hospital- and surgical-level variables on costs, we constructed a multilevel hierarchical regression model and calculated the pseudo-R^2 of each variable, which translates to its contribution to costs variability (%).

Finally, we assessed predictors of high- and low-cost PCNL, defined as those costing the most (>90th percentile: $23 615) and least (<10th percentile: $6511) per PCNL. Summary statistics were constructed using frequencies and proportions for categorical variables, as well as medians and interquartile ranges for continuous variables. Categorical values were compared using Chi-squared, and continuous variables were compared with the Mann-Whitney test. Subsequently, we developed a multivariate logistic regression model controlling for all aforementioned covariates in order to assess for independent predictors of low and high costs. There was no statistically significant collinearity among the covariates. All statistical analyses were performed using STATA 13 (College Station, T, U.S.) and SAS 9.3 (SAS Institute, N, U.S.). All tests were two-sided and a p value of <0.05 was considered statistically significant.

Results

We identified a total of 114 581 patients who underwent PCNL performed by 911 unique surgeons at 301 different hospitals in the U.S. from 2003–2015. Baseline cohort characteristics are listed in Table 1. The mean 90-day direct hospital cost for each PCNL patient was $14 498 (SD $83) and the median cost was $11 930 (interquartile range [IQR] $9016–16 517). The lowest decile of costs (<$6511) consisted of 405 surgeons at 194 hospitals with a mean cost per PCNL of $4968 (SD $52), while the top decile of costs (>$23 615) consisted of 269 surgeons at 147 hospitals with a

Table 1. Characteristics of all patients in the Premier Hospital Database who underwent percutaneous nephrolithotomy (PCNL) from 2003–2015, and of those in the lowest and highest 10th percentile of costs per PCNL

	Low costs	High costs	Overall (n=114 581)
Patient characteristics			
Mean age (SD)	53.8 (0.5)	54.9 (0.38)	54.5 (0.1)
Gender			
Male	4104 (47.7)	5697 (46.6)	55067 (48.1)
Female	4498 (52.3)	6537 (53.4)	59514 (51.9)
Race			
White	6008 (69.8)	9040 (73.9)	86751 (75.7)
Non-White	2595 (30.2)	3195 (26.1)	27831 (24.3)
Marital status			
Married	3302 (38.4)	4825 (39.4)	49035 (42.8)
Non-married	5300 (61.6)	7410 (60.6)	65546 (57.2)
Insurance status			
Medicare	3051 (35.5)	5828 (47.6)	45774 (39.9)
Medicaid	1049 (12.2)	2355 (19.2)	14396 (12.6)
Private	3925 (45.6)	3618 (29.6)	46302 (40.4)
Other	577 (6.7)	433 (3.5)	8109 (7.1)
Charlson Comorbidity Index			
0	4721 (54.9)	4642 (37.9)	55053 (48.0)
1	2124 (24.7)	2946 (24.1)	28830 (25.2)
≥2	1757 (20.4)	4646 (38.0)	30698 (26.8)
Hospital characteristics			
Hospital teaching status			
Teaching	1524 (62.6)	7135 (58.3)	67170 (58.6)
Non-teaching	7079 (82.3)	5099 (41.7)	47411 (41.4)
Hospital bed size			
<300 beds	1946 (22.6)	2370 (19.4)	27409 (23.9)
300–499 beds	4797 (55.8)	4199 (34.3)	47280 (41.3)
≥500 beds	1859 (21.6)	5665 (46.3)	39892 (34.8)

SD: standard deviation.

Table 1 (cont'd). Characteristics of all patients in the Premier Hospital Database who underwent percutaneous nephrolithotomy (PCNL) from 2003–2015, and of those in the lowest and highest 10th percentile of costs per PCNL

	Low costs	High costs	Overall (n=114 581)
Hospital characteristics (cont'd)			
Hospital location			
Urban	8468 (98.4)	11867 (97.0)	111056 (96.9)
Rural	135 (1.6)	367 (60.3)	3526 (3.1)
Hospital region			
Midwest	1063 (12.4)	2029 (16.6)	22764 (19.9)
Northeast	1107 (12.9)	5208 (42.6)	26305 (22.9)
South	5306 (61.7)	3468 (28.3)	26305 (43.1)
West	1126 (13.1)	1529 (12.5)	26305 (14.1)
Hospital volume			
≤75th percentile (≤19/yr)	7612 (88.5)	7614 (62.2)	92254 (80.5)
>75th percentile (>19/yr)	990 (11.5)	4621 (37.8)	22327 (19.5)
Surgical characteristics			
Surgeon volume			
≤75th percentile (≤6/yr)	6838 (79.5)	7531 (61.6)	92555 (80.8)
>75th percentile (>6/yr)	1764 (20.5)	4703 (38.4)	22027 (19.2)
Year of surgery			
2003–2006	2736 (31.8)	2814 (23.0)	30698 (26.8)
2007–2010	2673 (31.1)	4569 (37.3)	37449 (32.7)
2011–2015	3193 (37.1)	4852 (39.7)	46434 (40.5)

SD: standard deviation.

mean cost per PCNL of $36 061 (SD $435). There was over a seven-fold difference in mean costs between the least and costliest groups. Mean costs per surgeon and hospital were ranked in ascending order and plotted along with 95% CI (Supplementary Fig. 1). Overall, annual mean cost per PCNL remained stable over the period of the study (Supplementary Fig. 2). Costs breakdowns by category are shown in Fig.1 and further subdivided into high-cost vs. low-cost PCNL and high-volume vs. low -volume surgeons. We found that the room and board costs and operating room costs were higher among the high-cost PCNLs compared to the low-cost PCNLs. This was confirmed to be true when the mean length of stay of the high-cost PCNLs was 8.79 days compared to 2.83 days among the low-cost PCNLs (p<0.00).

Our multilevel hierarchical regression pseudo-R^2 model showed that patient characteristics greatly contributed to variations in costs (63.7%). CCI had an important impact on cost variation (41.1%), similar to insurance status (39.3%). Concerning surgeon characteristics, surgical volume was the most important contributor to variability in PCNL costs (15.8%) (Table 2).

On multivariable logistic regression, we identified several patient, surgical, and hospital characteristics that predicted high- (Table 3A) and low-cost (Table 3B) surgeries.

Predictors of high-cost PCNL

Patients with a poorer health status, classified as CCI ≥2, were more likely to have a higher cost PCNL (CCI ≥2 vs. CCI=0; odds ratio [OR] 1.81; p=0.01). Performing PCNL in a hospital located in Northeast U.S. was also a predictor of a higher-cost surgery. (Northeast vs. Midwest OR 2.04; p=0.03). On the other hand, patients with private insurance were less likely to have a higher-cost PCNL procedure (private vs. Medicare OR 0.41; p=0.01).

Predictors of low-cost PCNL

Middle-sized hospital (300–499 vs. <300 beds OR 1.35; p<0.0001) and urban medical centres (rural vs. urban OR 2.77; p=0.01) were both predictors of low-cost PCNL. Once again, our analysis showed that poorer health status had an

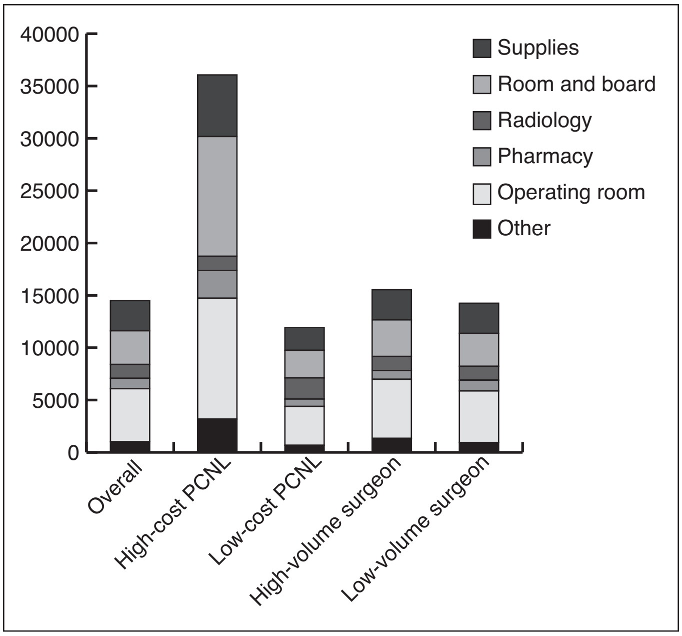

Fig. 1. Breakdown of 90-day direct hospital costs for percutaneous nephrolithotomy (PCNL) in the U.S. from 2003–2015.

impact on PCNL costs. In fact, patients with a CCI of 1 (CCI 0 vs. CCI 1 OR 0.85; p=0.01) and CCI ≥2 (CCI 0 vs. CCI ≥2 OR 0.69; p<0.0001) were less likely to undergo low-cost PCNL. Patients operated in a teaching hospital were approximately three-fold less likely to have a PCNL in the low-cost group (non-teaching vs. teaching hospital OR 0.33; p<0.0001).

Table 2. Contribution of patient, hospital, and surgical characteristics of postoperative outcomes to variability in costs of PCNL

	% variability in PCNL costs
Patient characteristics	63.7%
Age	4.9%
Gender	1.9%
Race	0.9%
Marital status	1.6%
Insurance status	39.3%
Charlson Comorbidity Index	41.1%
Hospital characteristics	3.9%
Teaching status	0.3%
Location (urban vs. rural)	0.0%
Bed size	0.4%
Region	1.3%
Annual hospital volume	1.5%
Surgical characteristics	18.5%
Annual surgeon volume	15.8%
Year of surgery	2.2%

PCNL: percutaneous nephrolithotomy.

Table 3A. Multivariable logistic regression for patient-, sugical-, and hospital-level predictors of high-cost (>90th percentile) PCNL

	OR	95% CI		p
Patient characteristics				
Age	0.990	0.979	1.002	0.09
Gender				
Male	Ref			
Female	0.95	0.72	1.25	0.72
Race				
White	Ref			
Non-White	0.96	0.67	1.36	0.82
Marital status				
Married				
Non-married	1.09	0.78	1.53	0.59
Insurance status				
Medicare	Ref			
Medicaid	0.96	0.52	1.79	0.90
Private	0.52	0.34	0.80	0.00
Other	0.41	0.20	0.83	0.01
Charlson Comorbidity Index				
0	Ref			
1	1.19	0.88	1.61	0.27
≥2	1.81	1.18	2.79	0.01
Hospital characteristics				
Hospital teaching status				
Teaching	1.39	0.86	2.24	0.18
Non-teaching	Ref			
Hospital bed size				
<300 beds	Ref			
300–499 beds	1.04	0.58	1.89	0.89
≥500 beds	1.48	0.73	3.00	0.28
Hospital location				
Urban	0.75	0.24	2.36	0.63
Rural	Ref			
Hospital region				
Midwest	Ref			
Northeast	2.04	1.09	3.81	0.03
South	0.79	0.39	1.59	0.51
West	1.25	0.58	2.73	0.57
Hospital region				
Midwest	Ref			
Northeast	2.04	1.09	3.81	0.03
South	0.79	0.39	1.59	0.51
West	1.25	0.58	2.73	0.57
Hospital volume				
≤75th percentile (≤19/yr)	Ref			
>75th percentile (>19/yr)	0.98	0.54	1.77	0.94

CI: confidence interval; OR: odds ratio; PCNL: percutaneous nephrolithotomy.

Table 3A (cont'd). Multivariable logistic regression for patient-, sugical-, and hospital-level predictors of high-cost (>90th percentile) PCNL

Surgical characteristics				
Surgeon volume				
≤75th percentile (≤6/yr)	Ref			
>75th percentile (>6/yr)	1.33	0.89	1.99	0.16
Year of surgery				
2003–2006	Ref			
2007–2010	1.40	0.86	2.28	0.18
2011–2015	1.09	0.61	1.96	0.76

CI: confidence interval; OR: odds ratio; PCNL: percutaneous nephrolithotomy.

Discussion

Due to the high prevalence of kidney stones and the increasing costs associated with its management,[2] we decided to examine variations in PCNL cost and contemporary predictors of high- and low-cost PCNL procedures. We first determined that mean cost of PCNL has remained stable throughout the study period (2003–2015). Second, we identified patient health status, classified by CCI, type of health insurance, and surgeon's experience (defined by annual surgical volume) as significant factors contributing to the cost variation of PCNL. Using multivariable logistic regression, we examined the predictors of high- and low-cost PCNL procedures. Results demonstrated that patients with a CCI ≥2 and those treated in the Northeast part of the U.S. were more likely to undergo high-cost PCNL. On the other hand, privately insured patients had lower odds of incurring high-cost PCNL. Predictors of low-cost PCNLs were identified as middle-sized hospitals (300–499 beds) and urban medical centres. However, patients with a CCI ≥1 and those who underwent PCNL in a teaching hospital were less likely to be part of the low-cost group. Several of these results require further comment.

First, our results demonstrate that the mean cost of PCNL has not changed in over 10 years. This is interesting since technological advancements and stone complexity have changed over the study period; however, it would seem that the impact is minimal. That said, there exists a large variability between the low- ($6511) and high-cost PCNLs ($23 615).

Second, our results showed that in addition to contributing significantly to cost variation of PCNL, poor health status (CCI ≥2) was a predictor of high-cost surgery and a negative predictor of low-cost PCNL. As is the case with most types of surgery, increased treatment costs are mainly secondary to complications, which can lead to a prolonged length of hospital stay (LOS). This appears to be true in our cohort of patients, where we found that higher room and board costs (owing to longer hospitalization) was a main driver of higher costs. Various studies have examined the predictors of outcomes post-PCNL. Comorbidities and poor health

Table 3B. Multivariable logistic regression for patient-, sugical-, and hospital-level predictors of low-cost (<10th percentile) PCNL

	OR	95% CI		p
Patient characteristics				
Age	1.003	0.987	1.020	0.682
Gender				
Male	Ref			
Female	0.99	0.73	1.34	0.96
Race				
White	Ref			
Non-White	0.77	0.48	1.24	0.29
Marital status				
Married				
Non-married	0.85	0.57	1.26	0.42
Insurance status				
Medicare	Ref			
Medicaid	1.39	0.68	2.84	0.37
Private	1.33	0.80	2.22	0.27
Other	1.00	0.60	1.69	0.99
Charlson Comorbidity Index				
0	Ref			
1	0.85	0.63	1.15	0.01
≥2	0.69	0.43	1.09	<.0001
Hospital characteristics				
Hospital teaching status				
Teaching	0.33	0.17	0.63	0.00
Non-teaching	Ref			
Hospital bed size				
<300 beds	Ref			
300–499 beds	1.35	1.15	1.60	0.00
≥500 beds	0.61	0.49	0.75	<.0001
Hospital location				
Urban	2.77	1.27	6.03	0.01
Rural	Ref			
Hospital region				
Midwest	Ref			
Northeast	1.54	0.53	4.44	0.42
South	2.06	0.95	4.47	0.07
West	1.11	0.50	2.50	0.79
Hospital volume				
≤75th percentile (≤19/yr)	Ref			
>75th percentile (>19/yr)	0.62	0.30	1.30	0.20
Surgical characteristics				
Surgeon volume				
≤75th percentile (≤6/yr)	Ref			
>75th percentile (>6/yr)	1.74	0.88	3.41	0.11
Year of surgery				
2003–2006	Ref			
2007–2010	0.82	0.38	1.75	0.60
2011–2015	0.88	0.39	1.97	0.76

CI: confidence interval; OR: odds ratio; PCNL: percutaneous nephrolithotomy.

status have been identified as common predictors of poor outcomes following PCNL.[8-14] Labate et al reported a 20.5% post-PCNL complication rate, with health status (defined using the American Society of Anesthesiologists [ASA] classification) and operative time being the two main predictors of poor outcomes.[12] Similar results were confirmed in three recent studies, which demonstrated that a higher CCI score was correlated with increasing odds of severe complications and prolonged LOS following PCNL.[8,13,14] Similar to our study (median PCNL costs of $11 930 (Q1–Q3: $9016–16 517), PCNL median cost has been shown to be variable in different studies, ranging from around $5000–25 000 per PCNL.[15-17] A study by Bagrodia et al showed the different components of direct cost per PCNL and identified operating room services, surgical supplies, and room costs as the most important contributors to direct expenditures.[15] Patients with multiple comorbidities tend to have longer LOS and operative time, hence increases in direct costs associated with their procedure. To our knowledge, Bagrodia's study is the only other study looking at the predictors of cost of PCNL. Interestingly, the only predictor of higher cost that they identified on multivariable analysis was stone burden; there was no correlation between patient characteristics and PCNL cost.[15] This may be secondary to a different health status classification (ASA vs. CCI), and their small cohort of 200 patients from a single academic teaching hospital. In contrast, our population-based cohort of over 114 000 patients represents a variety of hospital settings (teaching status, bed size, urban city, and geographic region).

Our results are important for the urological community, especially in this era of high medical cost and budgetary constraints. This study underlines the importance of careful patient selection and, if possible, modifications in patient habits preoperatively to make them more suitable for surgery.[9]

PCNL is the most complex intervention related to kidney stone management. Its steep learning curve has been examined in various studies. It has been demonstrated that 60 PCNLs is the cutoff for the performance of a safe procedure.[18-21] It has also been established that high-volume centres and surgeons have better outcomes post-PCNL.[11,22-24] Opondo et al demonstrated that after adjusting for patient and stone characteristics, high-volume centres had lower complication rates and shorter LOS.[22] Similarly, another study showed that for identical procedures, high-volume surgeons had significantly better outcomes than less experienced colleagues. However, high-volume surgeons, in general, had the same complication rates as their less experienced colleagues because of the more complex cases they had to perform. High-volume surgeons and high-volume/tertiary hospitals receive transfers from general urologists to perform complex PCNL cases.[15,22,25] These include cases with substantial stone burden, staghorn calculi, and anatomic abnormalities.[26,27] Even in the hands of experts, such cases are associated with increased rates of complications, need for multiple punctures, longer operative times, longer LOS, and need for secondary procedures. These complexity factors have been associated with increased cost of PCNL.[15] High-volume hospitals where high-volume surgeons work often are teaching hospitals. It can be hypothesized that these teaching hospitals have a higher propensity of complex cases being referred to them. It is also probable that in these centres, the implication of trainees can lead to even longer operative times and higher rates of complications, as they have not completed their learning curve.[22] This may explain the negative correlation between teaching hospitals and low-cost PCNL we found in our study. However, when adjusting for case complexity, Huang and colleagues found that high-volume surgeons had lower cost related to PCNL, mainly because of shorter LOS and lower intensive care unit transfers.[28]

Our study did not identify surgeon or hospital volume as predictors of low- or high-cost PCNLs. It did, however, show that surgeon volume was a predictor of cost variability. This absence of correlation could be explained by the lack of stone characteristics in our analysis; hence, adjustments for cases complexity could not be ascertained from our database. Finally, the cutoff we established for surgical volume was annual and not total, which probably does not adequately represent the surgeon's true experience.

Despite its strengths, our study is not devoid of limitations. Firstly, there may be residual differences at the hospital-by-hospital level or even at the surgeon-by-surgeon level in cost estimation, which may contribute to some of the observed variations in costs. Secondly, as with any secondary analysis of an administrative database, it may be prone to coding errors leading to misclassification bias. Thirdly, the retrospective design of our study subjects it to selection bias and unmeasured variables — such as prior surgery,[29] obesity,[30-32] stone complexity,[33] burden, location of calculi, number of punctures,[34] approach (supine/prone),[35] exit strategy (tube or tubeless),[36] and need for secondary procedures — which may impact outcomes and costs. Fourthly, we were only able to capture inpatient hospitalization requiring at least one night of hospital stay. Therefore, we were unable to determine which patients had a secondary procedure after PCNL (e.g., SWL or URS done typically as a day surgery procedure). This has implications on the estimation of the true cost of PCNL. Finally, in our estimation of individual surgeons' volume, we were only able to calculate the number of operations performed within the Premier hospital network. Thus, some surgeons who perform surgery at both Premier and non-Premier hospitals may have a higher true surgical volume than that reflected in our analysis.

Conclusion

PCNL is considered the most invasive, complex, and costly stone procedure in the endoscopy era of stone management. Its cost is influenced mainly by patient and surgeon characteristics. We identified that the main predictor of high cost is patient's poor health status. It is an important reminder that surgeons need to carefully select their patients for surgery, as much for patient safety as well as from a socioeconomic point of view.

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This paper has been peer-reviewed.

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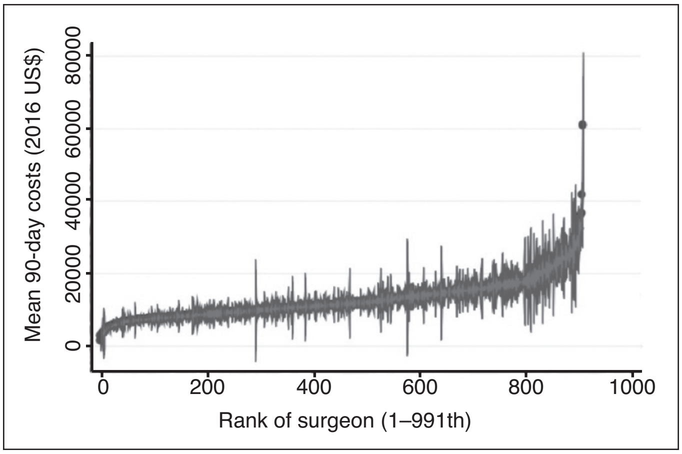
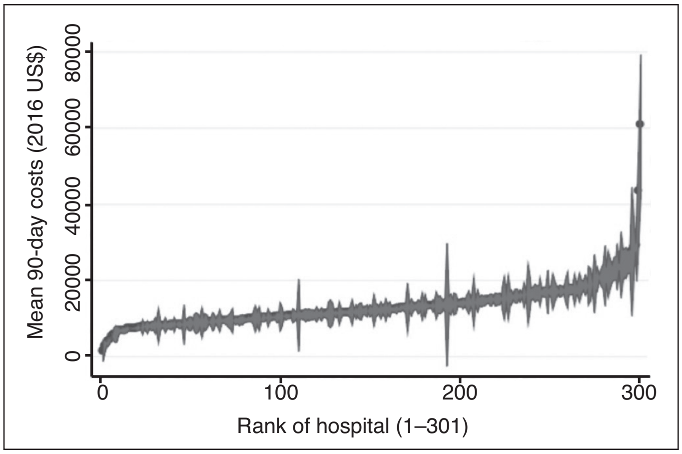
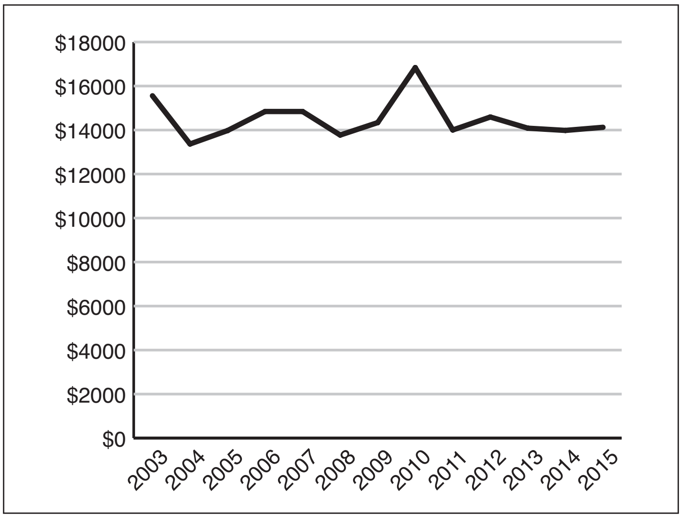


Supplementary Fig. 1A. Distribution of 991 surgeons in Premier Healthcare Database, who performed at least three percutaneous nephrolithotomy (PCNL) each year, ranked by average costs per surgery (with 95% confidence intervals).



Supplementary Fig. 1B. Distribution of 301 hospitals in Premier Healthcare Database performing percutaneous nephrolithotomy (PCNL) each year, ranked by average costs per surgery and 95% confidence intervals.



Supplementary Fig. 2. Trend in mean costs of percutaneous nephrolithotomy in the U.S. from 2003–2015.