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Ultrasound Guidance Reduces Percutaneous Nephrolithotomy Cost Compared to Fluoroscopy

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Abstract

Objective—To examine the cost factors associated with ultrasound and fluoroscopic guidance for percutaneous nephrolithotomy (PCNL) and determine which method can be performed at a lower cost per case.

Methods—A cost comparison study was performed utilizing clinical data from a prospectively maintained research database. We included the most recent 33 consecutive ultrasound-guided PCNL cases in 2016 and the most recent 40 consecutive fluoroscopy-guided PCNL cases before the operative surgeon transitioned to ultrasound guidance in May 2014. Total operative time and clinical outcomes were examined. Costs were extracted from the institution accounting systems and given a uniform multiplier to protect institutional financial reporting confidentiality. Comparisons were made using Student's t-test and Chi-squared.

Results—After excluding outliers, 71 PCNL procedures were included in the analysis. Demographic data and stone characteristics were not different between ultrasound-guided and fluoroscopy-guided groups. However, mean operative time for ultrasound-guided PCNL was significantly shorter (99.8±27.0 vs. 144.9±55.1 minutes, $p < 0.05$). Including capital equipment costs, the mean total cost per case of ultrasound-guided PCNL was approximately 30% less than fluoroscopy-guided PCNL (simulated costs with a uniform multiplier; $5,258.90±957.12 vs. $7,508.60±1,163.83, $p < 0.05$). Postoperative clinical outcomes were comparable between the two groups.

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Conclusion—Including capital costs, ultrasound-guided PCNL can produce comparable clinical outcomes to fluoroscopy-guided procedures at a lower cost to the institution. Shorter operative time drives significant savings with the adoption of ultrasound guidance, which may be magnified with increasing case volume. Using ultrasound imaging during PCNL may be more cost-effective compared to fluoroscopy and warrants further study.

Keywords

percutaneous nephrolithotomy; ultrasound; fluoroscopy; cost

Introduction

Percutaneous nephrolithotomy (PCNL) is a procedure most commonly performed to treat larger sized kidney stones and those not amenable to ureteroscopic or shockwave lithotripsy.[1] Most institutions usually perform this procedure under fluoroscopic guidance,[2] however, concerns have risen regarding the long-term effects of ionizing radiation exposure sustained by the surgeon, medical personnel, and patient during the operation. Several studies have shown that some degree of radiation exposure can be detected despite the routine use of protective aprons and thyroid shields.[3,4]

Recently, ultrasound guidance is increasingly utilized because it potentially decreases or even obviates radiation exposure during PCNL procedures.[5,6] Real-time ultrasonographic imaging helps surgeons gain access into the collecting system via a posterior calyx, guide tract dilation, and confirm stone clearance after lithotripsy is completed. Moreover, it facilitates an assessment of the renal parenchyma, renal vasculature, and surrounding visceral organs.[7,8]

Several studies have shown a similar clinical efficacy between ultrasound and fluoroscopy guidance for PCNL supporting the transition from one technique to the other for the practicing urologist,[9-14] but little is known about the impact of ultrasound use on procedural cost. Increasingly, health care costs are a source of concern for patients, government agencies, health economists, and medical professional worldwide. For example, the United states has the highest health care expenses compared to other countries globally – approaching 18% of gross domestic product.[15] Thus, efforts for cost-conscious care with assessment of the benefits, harms, and costs of all procedures should be explored. This study aimed to examine the cost factors associated with ultrasound and fluoroscopy guidance for PCNL and determine which method could be performed at a lower cost per case.

Patients and Methods

After obtaining institutional review board approval, a cost comparison study was performed across two academic medical centers: University of California, San Francisco (UCSF) and Zuckerberg San Francisco General Hospital and Trauma Center (ZSFG). Cases were selected from a prospectively maintained PCNL research database. All procedures were performed by a single surgeon (TC), who transitioned from fluoroscopy to ultrasound guidance for PCNL in May 2014 and is proficient in both surgical techniques. To minimize any effect from learning curve on cost, we identified the most recent 33 patients who underwent totally x-ray-free ultrasound-guided PCNL,[16] and the most recent 40 patients who underwent fluoroscopy-guided PCNL prior to the transition to ultrasound. Power calculations indicated that a sample size of at least 11 patients in each group would be required to detect a difference in cost equivalent to the difference in capital cost per case, which we hypothesized might be a primary driver in overall difference in cost between modalities. We included patients age 18 or older with renal or proximal ureteral stones presenting for PCNL. We excluded patients who underwent procedures other than PCNL during the same operation, which may have significantly altered procedural costs and total operative time.

Costs were calculated for all procedures performed at UCSF. Overhead costs of the operating room, costs of disposable equipment, and capital equipment costs were extracted from the existing institution accounting system. Disposable equipment costs were specific to each individual case. Operating room overhead costs were comprised of fixed and variable direct costs such as personnel costs for nursing and anesthesia, anesthesia supplies, medications, and indirect costs such as room maintenance and electricity. Fluoroscopy-guided PCNL included the additional personnel cost of a radiology technician, present for the entirety of each procedure. Because radiology technicians are paid a variable hourly fee based on their seniority and level of experience, an average hourly cost of a radiology technician was obtained from the Department of Radiology. This cost was determined by multiplying operative time by the average hourly cost for the technician.

For this study, the entire capital cost of the fluoroscopy machine used for PCNL was assigned to the Department of Urology as it is not a resource shared between departments at our institution. In contrast, ultrasound equipment is a shared resource between departments. The capital cost for ultrasound equipment was adjusted by the fraction of urology cases out of the total annual number of cases across all departments that share the ultrasound machine (23% of total annual cases). Capital costs included the purchase cost of the machine, plus the annual cost of the service contract, but did not account for machine depreciation or amortization. Capital cost per case assumed a volume of 75 PCNL cases per year. A sensitivity analysis that varied the fluoroscopy capital cost assignment was also performed to determine how allocation of fluoroscopy capital costs contributes to the difference in total costs between modalities. All costs presented in this study are actual costs that have been adjusted by a uniform multiplier to maintain institutional financial reporting confidentiality.

Patient demographic data including age, gender, body mass index (BMI), and baseline health status based on American Society of Anesthesiologists classification[17] were obtained preoperatively. Either renal ultrasound or non-contrast computed tomography (CT scan) was used to identify stone characteristics prior to surgery. Stone burden was determined by measuring the total stone size at the greatest dimension and was a summation of all stones present on imaging in the ipsilateral collecting system. Preoperative laboratory results including hematocrit and serum creatinine were also collected.

Our surgical technique has been previously published.[18,19] Briefly, under general anesthesia, a 5-french externalized ureteral catheter was placed into the ipsilateral ureter via a flexible cystoscope for retrograde instillation of iodinated contrast agent or saline as needed. The patient was then repositioned prone and safely secured to the operative table. For fluoroscopy-guided PCNL, retrograde pyelography with iodinated contrast agent was performed using a fluoroscopy unit (OEC 9800 Mobile C-arm, GE Healthcare, Aurora, OH) to outline the renal collecting system, and a triangulation technique was used to gain renal access. For ultrasound-guided PCNL, a 3.5-MHx convex abdominal transducer (Hitachi Aloka Medical America, Wallingford, CT) was used to localize the stone and visualize the anatomy of the collecting system. In non-hydronephrotic kidneys, saline instillation via the pre-placed ureteral catheter was performed as needed to dilate the system. Renal access was gained freehand, without a needle guide, using an 18-gauge EchoTip needle (Cook Medical, Bloomington, IN) under real-time ultrasound monitoring. The remainder of the procedure was similar for both renal access techniques. Tract dilation was accomplished with a 10-French fascial dilator (Cook Medical) and a 24-French high-pressure balloon dilator and sheath (BARD X-Force, Bard Medical, Covington, GA). Nephroscopy was performed with a 20.8-French rigid offset nephroscope, and stone fragmentation was accomplished using either CyberWand Dual Ultrasonic (Olympus America, Center Valley, PA) or UreTron (Med-Sonics America, Erie, PA) Lithotriptor System. Flexible nephroscopy was performed in all procedures to look for residual fragments. After stone clearance was completed, we routinely placed a 10-French Cope loop nephrostomy tube (Cook Medical) for renal drainage.[16]

Clinical outcome measures, including postoperative serum creatinine and hematocrit change, estimated blood loss, total operative time, and length of hospital stay were recorded. Perioperative complications occurring within 30 days were collected and classified by the Clavien-Dindo system.[20] A combination of plain KUB (Kidneys, Ureters, and Bladder) radiograph and renal ultrasound was performed thirty days after surgery to evaluate stone-free status, which was divided into 3 categories: stone-free, insignificant residual fragment (less than 4 mm) and significant residual fragment. Student's t-test and Chi-squared test were used to compare the costs, demographics, and clinical outcomes associated with both PCNL techniques. Simple linear regression was performed to determine the effect of sequential case number on operative time. Statistical analyses were performed using STATA/IC version 13.1 (StataCorp, College Station, TX). Data are expressed as mean ± standard deviation or percentage with a significance level of $p < 0.05$.

Results

We excluded the greatest outlier from each group based on operative time and disposable costs. After exclusions, 39 and 32 consecutive PCNL procedures were used in the analysis of perioperative characteristics and outcomes for fluoroscopy-guided and ultrasound-guided PCNL, respectively. A total of 51 procedures performed at UCSF (27 procedures for ultrasound-guided PCNL and 24 procedures for the fluoroscopy-guided PCNL) were used in the cost analysis. For patients in the ultrasound group, the mean age was 49.2±19.9 years, 15 (47%) patients were males, 17 (53%) were female, and mean BMI was 28.7±7.8 kg/m^2. Age, gender, BMI, ASA status, stone laterality, stone type, and total stone burden did not significantly differ between the ultrasound-guided and fluoroscopy-guided groups (Table 1).

Mean operative time for ultrasound-guided PCNL was significantly shorter than fluoroscopy-guided PCNL (99.8±27.0 vs. 144.9±55.1 minutes, $p<0.05$). Simple linear regression for the ultrasound and fluoroscopy groups did not demonstrate a significant change in total operative time with increasing sequential case number over time. Mean hospital length of stay, change in serum creatinine and hematocrit, stone-free status, and postoperative complication rate were comparable between the two groups (Table 2).

Mean operating room cost was significantly less expensive for ultrasound-guided PCNL compared with fluoroscopy-guided PCNL ($2,073.45±447.81 vs. $2,488.85±770.72 respectively, $p<0.05$). Mean disposable costs were $2,737.46±917.03 for ultrasound and $2,362.48±576.13 for fluoroscopy ($p=0.09$) (Figure 1). Excluding capital equipment costs, the mean cost of each procedure was $4,754.50±957.12 for ultrasound and $4,999.22±1,163.83 for fluoroscopy ($p=0.43$). Calculated as a shared resource among several departments, ultrasound capital cost per case was $504.40. Fluoroscopy, as an unshared resource at our institution, had a capital cost per case of $2,509.38. Including capital equipment costs, the mean total cost per case of ultrasound-guided PCNL was 30% less than fluoroscopy-guided PCNL. Including our uniformly applied multiplier to all costs, this amounted to a $2,249.70 difference between the two surgical approaches ($5,258.89±957.12 vs. $7,508.59±1,163.83 respectively, $p<0.05$), and this cost difference was statistically significant (Table 3). To simulate sharing a fluoroscopy unit across multiple services, a sensitivity analysis assigning the same percentage of capital costs (23%) to fluoroscopy equipment as to ultrasound equipment resulted in a total fluoroscopy-guided PCNL cost of $5,571.60±1,163.83, $312.71 more expensive than ultrasound-guided PCNL ($p=0.31$). Assigning the entire cost of both ultrasound and fluoroscopy equipment to the Department of Urology resulted in total costs of $7441.22 ± 957.12 and 7508.59±1,163.83 for ultrasound-guided and fluoroscopy-guided PCNL, respectively ($p=0.83$).

Discussion

This study demonstrated that adopting ultrasound guidance for PCNL may decrease operative time and eliminate radiation exposure for patients and intraoperative staff, particular as the surgeon gains proficiency in this operator-dependent technique.[21-23] Prospective trials have demonstrated comparable clinical outcomes achievable using ultrasound versus traditional fluoroscopic methods, confirmed by our study results.[7,24] These clinical benefits are important, but in today's environment of value-driven clinical care, a provider's decision in transitioning to a new technique should depend on a number of factors, including differences in cost between the traditional and new modalities.

While cost has been examined for other aspects of the PCNL procedure,[25-29] the differences in cost between ultrasound-guided and fluoroscopy-guided techniques have not been previously studied. As the surgeon's case volume increases, the two cost factors expected to change are operating room costs and, to a certain extent, disposable costs, particularly as the surgeon becomes faster and more efficient with ultrasound-guided PCNL. Our results demonstrate that one of the biggest drivers for cost savings with ultrasound-guided PCNL at our institution is the shorter total operative time. While our study did not find a trend in decreasing operative time with increasing case number, this may reflect the mature experience of the operative surgeon, well outside the learning curve of ultrasound-guided PCNL.[21] For the surgeon new to ultrasound-guided procedures, they may realize a savings in time and operating room cost as their experience matures. Several factors may account for the reduced operative time seen with ultrasound-guided procedures. Obviation of retrograde iodinated contrast injection and fluoroscopic C-arm adjustment by a radiology technician may contribute to the shorter operative time with the ultrasound-guided method. Time savings reflective of the nature of these units may also be realized. Ultrasound machines are smaller and can be more quickly moved around the operating room. The imaging transducer is also relatively small and totally under the surgeon's control. In addition, ultrasound guidance offers a wider range of renal access approaches to any posterior calyx, for establishing a secure percutaneous working tract. Moreover, multi-planar assessment of the collecting system can be promptly performed without rotating the C-arm. These characteristics of the ultrasound approach may result in time and cost savings in the operating room.

In addition, for ultrasound-guided PCNL, disposable equipment traditionally used in the fluoroscopy-guided technique is repurposed. Over time, a more refined set of disposable surgical instruments could be identified, potentially lowering average disposable cost per case. Interestingly, although disposable costs were similar between the two modalities, ultrasound costs appeared to have a higher variability. This may be explained by differences in the use of high-cost equipment, such as ultrasonic lithotripters and laser fibers, that are unrelated to whether ultrasound or fluoroscopy is used for renal access and tract dilation. A follow-up study with a larger sample size may demonstrate comparable variability in disposable costs between the two modalities, as the effect of a small number of high-cost items on mean disposable cost will be lessened.

Costs for ultrasound-guided PCNL remained lower than fluoroscopy-guided PCNL when the capital costs of ultrasound and fluoroscopy equipment were included in the comparison. The ability to share an imaging unit across surgical services as a communal resource provided a great cost advantage to ultrasound consoles over fluoroscopy units at our institution. Ultrasound equipment is increasingly useful intraoperatively across a number of disciplines. For example, at our institution, ultrasound consoles are used by the urology, gynecology, neurosurgery, endocrine surgery, and general surgery services. This spreads the capital cost of equipment over multiple departments. Fluoroscopy units, on the other hand, are often dedicated to one service or one room, given their larger size and more specialized use. At our institution, one fluoroscopy unit is dedicated to the cystoscopy suite where the vast majority of PCNL cases are performed. Other units are dedicated to the orthopedics services and vascular services. Thus, the burden of capital cost falls solely on a single department. In general, ultrasound consoles can be utilized for a number of applications for any number of surgical services. Given their relatively small size and portability, they are easily shared across services, reducing their cost per case from a capital equipment standpoint. These differences in resource allocation may not be the case at all institutions, however. From our sensitivity analysis, it was apparent that sharing a fluoroscopy unit across multiple services in a similar fashion to ultrasound can have a significant impact on reducing the total cost of fluoroscopy-guided PCNL.

We recognize that the difference in total cost per case in this study is dependent upon whether capital costs are included and how they are calculated. Institutions that share all imaging equipment between surgical departments may find that the total cost per case, excluding capital equipment, is a more accurate estimate in determining whether ultrasound-guided or fluoroscopy-guided PCNL costs less per case since the overall capital equipment cost of a high-end ultrasound console and fluoroscopy unit are about the same. That being said, greater variability in cost for ultrasound consoles exists that is not present for fluoroscopy units. Portable ultrasound machines used frequently in the emergency department and during overseas relief work cost on the order of tens of thousands of dollars whereas high-end machines with 3-dimensional imaging capabilities and higher resolution may cost somewhere in the hundreds of thousands of dollars range. Both ends of the spectrum are adequate for renal imaging to facilitate percutaneous renal access. On the other hand, fluoroscopic units will at the minimum start in the hundreds of thousands of dollars price range. Our current cost comparison reflects actual institutional costs. If a hospital or department environment is such that ultrasound consoles are not a shared resource, their potentially lower cost of purchase may still facilitate a capital equipment cost savings when compared to fluoroscopy.

Additional limitations must be acknowledged in this study. The observational nature of the study and the relatively small sample size may introduce bias into the clinical outcomes and cost results. There may also be hidden cost factors that were not accounted for, which may differentially affect ultrasound-guided PCNL and fluoroscopy-guided PCNL. We did not account for the lifespan of each imaging unit or depreciation. Our ultrasound and fluoroscopy units tend to be durable to 5-10 years before requiring replacement. Amortization accounting for durability of equipment would reduce calculated cost of capital and is worth considering. We also utilized renal ultrasound and plain KUB radiograph to confirm stone-free status and guide the decision for secondary procedures, in line with the current AUA guidelines[30] and our institutional standard of care. These imaging studies are generally less sensitive than CT scan for evaluating residual stone fragments. Further studies with larger sample sizes may minimize some of these limitations as data collection on ultrasound-guided PCNL continues.

Conclusion

Not accounting for capital costs, ultrasound-guided PCNL can produce comparable clinical outcomes to traditional fluoroscopy-guided procedures at a non-inferior cost to the institution. However, capital equipment costs can drive significant savings with the adoption of ultrasound guidance for PCNL, a savings that may be magnified with increased number of cases over time and more refined ultrasound-specific disposables. Our results suggest that the use of ultrasound imaging during PCNL may be a more cost effective means of performing PCNL compared to fluoroscopy use and warrant further study.

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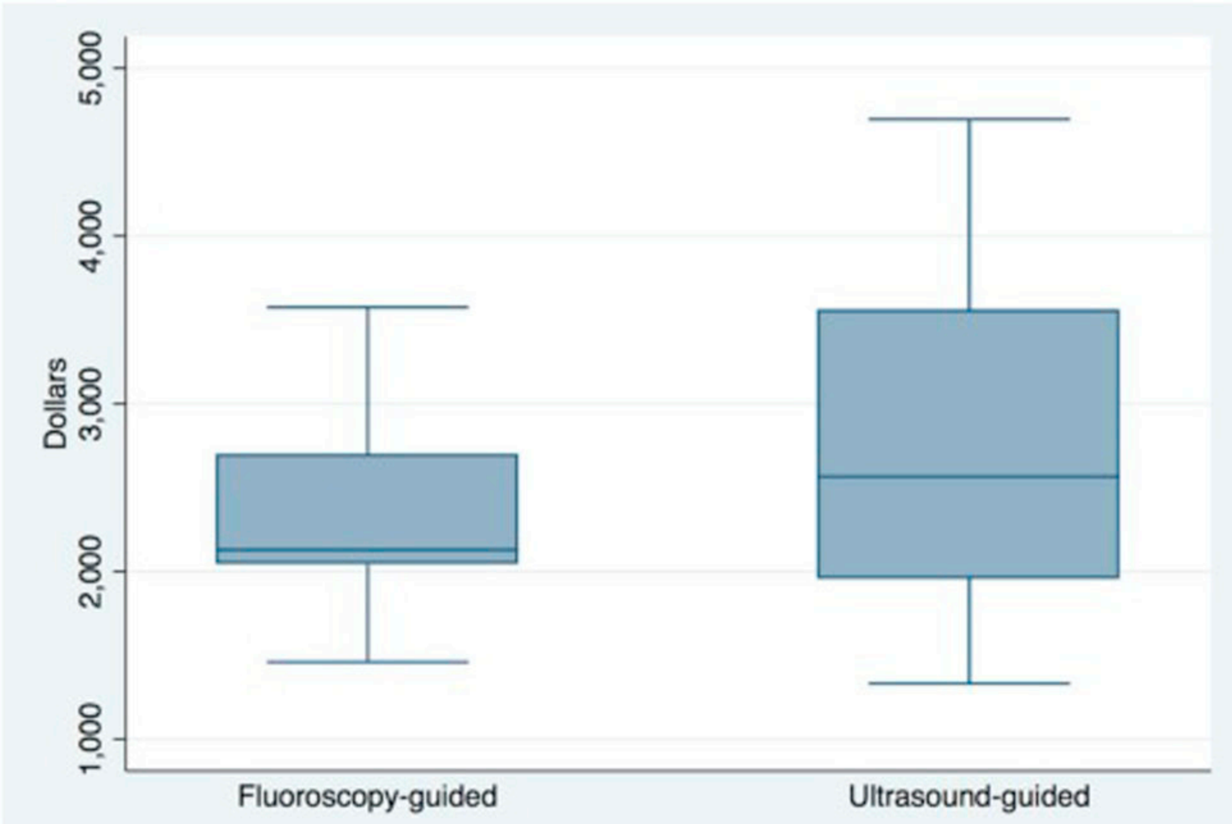

Figure 1.

Disposable costs by PCNL modality. The horizontal line within the boxplot represent the median disposable cost.

Table 1

Patient Characteristics

Parameter	Ultrasound *(n=32)*	Fluoroscopy *(n=39)*	Total Cohort *(n=71)*	*p*-value
Age, mean ± SD	49.2 ± 19.9	53.1 ± 12.6	51.3 ± 16.3	0.35
Gender, *n* (%)				
Male	15 (47%)	18 (46%)	33 (46%)	0.95
Female	17 (53%)	21 (54%)	38 (54%)	
BMI (kg/m^2), mean ± SD	28.7 ± 7.8	29.3 ± 7.3	29.0 ± 7.5	0.75
ASA status, *n* (%)				
Class 1	3 (9%)	6 (15%)	9 (13%)	0.45
Class 2	21 (66%)	28 (72%)	49 (69%)	
Class 3	7 (22%)	5 (13%)	12 (17%)	
Class 4	1 (3%)	-	1 (1%)	
Stone laterality, *n* (%)				
Left	16 (50%)	21 (54%)	37 (52%)	0.75
Right	16 (50%)	18 (46%)	34 (48%)	
Stone type, *n* (%)				
Caliceal	5 (16%)	10 (26%)	15 (21%)	0.35
Pelvic	9 (28%)	13 (33%)	22 (31%)	
Staghorn	7 (2%)	8 (21%)	15 (21%)	
Ureteral	2 (6%)	4 (10%)	6 (8%)	
Multiple	9 (28%)	4 (10%)	13 (18%)	
Total stone burden (mm), mean ± SD	33.7 ± 21.8	30.7 ± 14.4	32.1 ± 18.0	0.51

Table 2

Intraoperative Parameters and Postoperative Clinical Outcomes

Parameter	Ultrasound *(n=32)*	Fluoroscopy *(n=39)*	Difference (95% CI)	*p*-value
Operative time (minutes), mean ± SD	99.8 ± 27.0	144.9 ± 55.1	-45.1 (-65.6 to -24.6)	<0.05
Hospital stay (days), mean ± SD	2.4 ± 0.62	2.9 ± 1.9	-0.5 (-1.1 to 0.2)	0.15
Complication rate, *n* (%)	1 (3%)	3 (8%)	-	0.41
Grade 1	-	-		
Grade 2	1	1		
Grade 3a	-	-		
Grade 3b	-	2		
Change in creatinine (mg/dl), mean ± SD	-0.01 ± 0.13	0.03 ± 0.15	-0.04 (-0.11 to 0.03)	0.25
Change in hematocrit, mean ± SD	-4.34 ± 2.09	-3.30 ± 3.75	-1.05 (-2.48 to 0.38)	0.15
Stone free status, *n* (%)				0.54
Stone-free	29 (91%)	35 (89%)	-	
Insignificant fragments	2 (6%)	1 (3%)		
Significant fragments	1 (3%)	3 (8%)		

Table 3

PCNL Costs Per Case by Procedure Type

Cost Variable	**Ultrasound *(n=26)***	**Fluoroscopy *(n=23)***	**Difference (95%CI)**	***p*-value**
Operating room, mean ± SD	$2,073.45 ± 447.81	$2,488.85 ± 770.72	-$415.40 (-773.13 to -57.67)	<0.05
Radiology technician, mean ± SD	-	$128.88 ± 47.92	-	-
Operating room and radiology technician, mean ± SD	$2,073.45 ± 447.81	$2,636.74 ± 831.61	-$563.29 (-951.98 to -174.62)	<0.05
Disposable equipment, mean ± SD	$2,737.46 ± 917.03	$2,362.48 ± 576.13	$374.99 (-61.28 to 811.25)	0.09
Total cost, excluding capital equipment, mean ± SD	$4,754.50 ± 957.12	$4,999.22 ± 1,163.83	$-244.73 (-863.55 to 374.10)	0.43
Capital equipment	$504.40	$2,509.38	-	-
Total cost, mean ± SD	$5,258.90 ± 957.12	$7,508.60 ± 1,163.83	-$2,249.70 (1,630.88 to 2,868.53)	<0.05