Cost-effectiveness analysis of arterial catheter insertion on robotic-assisted laparoscopic prostatectomy

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Introduction: *To evaluate the utility, outcomes, and cost of arterial line placement in a single institution cohort of patients undergoing robotic-assisted laparoscopic prostatectomy (RALP).*
Materials and methods: *A retrospective chart review was performed at a large tertiary care center from July 2018 through January 2021. Hospital costs and cost-effective analysis was performed on patients with and without arterial line placement. Means with standard deviations were used to report continuous variables, while numbers and percentages were utilized to describe categorical variables. T-tests and Chi-square tests compared categorical and continuous variables across study cohorts, respectively. Multivariable analyses were used to examine the association between A-line placement and outcomes as mentioned above adjusting for the effect of other co-variables.*
Results: *Among the 296 included patients, 138 (46.6%) had arterial lines. No preoperative patient characteristic predicted arterial line placement. Rates of complications and re-admissions were not statistically significant between the two groups. Arterial line use was associated with higher volumes of intraoperative fluid administration, as well as a longer hospital length of stay. Total cost and operative time did not significantly differ between cohorts, but arterial line placement increased variability of these factors.*
Conclusion: *The use of arterial lines in patients undergoing RALP is not necessarily guideline-driven and does not decrease the rate of perioperative complications. However, it is associated with longer length of stay and increases variability in charge. These data show that the surgical team and anesthesia team should critically evaluate the need for arterial line placement in patients undergoing RALP.*

Key Words: arterial line, cost analysis, prostate cancer, peripheral catheterization, prostatectomy, robotic-assisted laparoscopic prostatectomy

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Introduction

Prostate cancer remains the second most common malignancy in men and the fourth leading cause of death worldwide.[1] The estimated cost for prostate cancer treatment in the United States grew from $11.8 million in 2010 to $18.5 million in 2020.[2] Historically, radical retropubic prostatectomies (RRP) were performed open, with estimated blood loss (EBL) ranging from 500 cc-1000 cc, necessitating blood transfusion in 25%-50% of patients.[3] In the setting of high EBL and associated fluid shifts, arterial catheter (A-line) use was common.[4] Over the past decade, the standard of care for prostatectomy has shifted to favor robotic-assisted laparoscopic prostatectomy (RALP), further highlighting the decreased rate of blood loss and transfusion rates, while minimizing operative time compared to laparoscopic radical prostatectomy (LRP) and open radical prostatectomy (ORP).[5]

A-line placement is a common practice for monitoring critically ill patients because it allows an uninterrupted display of pulse contour with real-time monitoring of heart rate and blood pressure.[6] Indications for arterial line placement include the need for continuous beat-to-beat blood pressure monitoring, frequent blood draws, and arterial administration of medications.[7] However, placement of A-lines is not without morbidity; A-line placement can cause hemorrhage, infection, vascular insufficiency, ischemia, thrombosis, embolization, and neuronal or adjacent structure injury.[8] The presence of an A-line itself has been associated with increased frequency of blood testing and total volume of blood sent to the lab per person.[9] In addition to significant morbidity, A-line placement may also add cost. Arterial lines are typically placed in the operating room (OR) after induction of general anesthesia, and each minute in the OR time costs an estimated $62.[10]

Despite decades of effectiveness research, there are numerous interventions used in medical practice for which there are no data directly addressing how they influence relevant patient or societal outcomes. Fitting with this pattern, there is no previous effectiveness or cost analysis research addressing the utility of arterial line placement during RALP. Our study aims to identify patient characteristics that influence A-line placement. Secondary aims include analysis of the financial structure surrounding RALP procedures to ascertain which factors could trigger additional variable costs.

We hypothesize that A-line placement increases the cost of robotic prostatectomy, without decreasing total duration of hospitalization or complication rate.

Materials and methods

Patient cohort

After Institution Review Board (IRB) approval, we evaluated cost effectiveness of arterial line placement during RALP between July 2018 and January 2021 using health utility values and medical costs. All cases included in the analysis were performed at a single high-volume center. Specific data points were selected a priori and included age, prostate-specific antigen (PSA), body mass index (BMI), Charleston Comorbidity Index (CCI), history, electrocardiogram, age, risk factors, and troponin (HEART) score, operative estimated blood loss (EBL), administered albumin alone, administered fluids (including albumin), operative time, number of lymph nodes obtained, number of lymph nodes involved by malignancy, prostate volume, length of hospital stay, complications, costs, and A-line placement. We chose to assess patient comorbidity status utilizing CCI to improve the granularity of comorbidities. For more accurate prediction, regression algorithms have advocated use of CCI and demographic variables than American Society of Anesthesiologists (ASA) score.

Calculation of costs

Hospital costs were obtained from the institution with direct costs denoting hospital expenditure directly required to perform a RALP surgery while indirect costs were general expenses related to operational functions. Mean values were used for costs in the analysis. Due to the proprietary nature of the information, we compared the costs to the mean value. The hospital direct and indirect costs include: fixed (robotic acquisition, maintenance with associated costs) and variable costs, expenses for RALP that depended on the frequency of RALP surgeries performed. All costs were adjusted to 2021 using consumer price index for medical costs measured in United States (US) dollars. Because of the proprietary nature of the institution, actual costs were used for the analysis but normalized to scale for reporting and figures from the analysis. Costs were assigned to patients on the basis of mean difference for a patient with arterial line compared to a patient without one, both undergoing RALP with bilateral pelvic lymph node dissection.

Cost-effectiveness analysis

We ran 10,000 iterations for each profile. From these, we estimated the incremental cost-effectiveness ratio of RALP with and without arterial line. Calculation of incremental cost-effectiveness ratios (ICERs) was performed.

Sensitivity analysis

A sensitivity analysis addressed model uncertainty, and evaluated the effect of plausible changes in key variables on the ICER, including age, fluid

TABLE 1. **Independent samples t-test and chi-square test of patient characteristics by arterial line placement**

	Arterial line	**No Arterial line**	**p value**
Patients (n = 296)	n = 138	n = 158	
Patient characteristics			
Age (years)	63.05	63.44	0.79
BMI (kg/m^2)	30.28	28.67	0.01
PSA (ng/mL)	8.2	8.85	0.43
CCI*	2.82	2.53	0.06
HEART score†	2.84	2.64	0.08
Intraoperative values			
EBL (cc)	197.23	181.57	0.77
Administered fluids (including albumin) cc	2050.91	1849.24	0.01
Administered albumin (cc)	103.95	59.12	0.06
Total operative time (min)	248.18	229.96	0.23
Pathology			
Total lymph nodes obtained (n)	9.38	9.84	0.33
Lymph nodes involved by malignancy (%)	0.14	0.59	0.55
Prostate volume (g)	53.53	52.75	0.99
Postoperative course			
Hospital LOS (days)‡	1.72	1.31	0.02
	90-day Clavien-Dindo complication rate N (%)		
None	113 (81.8)	130 (82.82)	0.25
Grade I	17 (12.31)	19 (12.02)	0.9
Grade II	4 (2.89)	5 (3.16)	0.19
Grade III	4 (2.89)	4 (2.53)	0.12
Grade IV/V	0	0	
Hospital costs			
Total charges	+5710	Reference	< 0.001
Total direct cost	+395	Reference	0.004
Actual fixed direct cost	+40	Reference	0.16
Actual variable direct cost	+389	Reference	0.004
Actual fixed indirect cost	+61	Reference	0.43

*Charlson Comorbidity Index predicts the 10-year survival of patients with multiple comorbidities. It assigns a composite weighted value based on age (0-4), history of Myocardial infarction (0-1), history of cerebrovascular accident (0-1), congestive heart failure (0-1), peripheral vascular disease (0-1), dementia (0-1), chronic obstructive pulmonary disease (0-1), connective tissue disease (0-1), peptic ulcer disease (0-1), liver disease (0-3), diabetes mellitus (0-2), hemiplegia (0-2), chronic kidney disease (0-2), presence of a solid tumor (0-6), leukemia (0-2), lymphoma (0-2), and AIDS (0-6).
†HEART score for major cardiac events predicts the 6-week risk of a major adverse cardiac event. It is a composite weighted value that factors the degree of suspicion of a cardiac event based on patient's history (0-2), electrocardiogram (0-2), Age (0-2), risk factors for atherosclerotic disease (0-2), and troponin levels (0-2).
‡Length of stay of one hospital day is defined as discharge the day after surgery.
BMI = body mass index; PSA = prostate-specific antigen; CCI = Charlson Comorbidity Index; EBL = estimated blood loss; LOS = length of stay

and albumin resuscitation, arterial line placement, comorbidity status, HEART score, length of stay, total lymph node yield and involvement, operative time, PSA, prostate volume. Probabilistic sensitivity analysis was conducted using Monte Carlo stimulation on all parameters, which were randomly and simultaneously sampled from defined probability distributions over 10,000 iterations.

The top influences of RALP cost-effectiveness were determined via tornado analysis. One-way and two-way sensitivity analysis was conducted.

Statistical analysis

Statistical analysis was completed on each patient characteristic and potential cost factor for A-line placement, and the results were analyzed for significant correlations. Means with standard deviations were used to report continuous variables, while numbers and percentages were utilized to describe categorical variables. T-tests and Chi-square tests were used to compare categorical and continuous variables across study variables, respectively. Multivariable analyses were used to examine the association between A-line placement and the outcomes as mentioned above adjusting for the stage, PSA, Gleason core, prostate volume, BMI, HEART score, CCI, year of surgery, and surgeon. All tests were 2-sided, and p values < 0.05 were considered clinically significant.

Results

Of the 296 patients from June 2018 to February 2021 who had RALP performed at our single institution and had corresponding anesthesia and pathology reports, 138 patients (46.6%) underwent arterial line placement, Table 1. All arterial lines were placed in the operating room during the recorded intraoperative period. Patients who had RALP along with a concurrent surgery or procedure were excluded from the study. There were no significant demographic differences between the patients who underwent arterial line vs. standard blood pressure cuff monitoring (including age, Charleston comorbidity score, PSA, HEART score). Patients with a higher BMI were more likely to have A-lines during RALP (p < 0.01).

Complications, transfusions, and readmissions were not significantly different between the groups. Patients with A-line placement were more likely to have a higher volume of intraoperative crystalloid fluid and albumin resuscitation (2.1 L vs. 1.8 L, p < 0.01 and 103.95 cc vs. 59.12 cc, p = 0.06, respectively), and an increased length of stay (1.72 vs. 1.31, p = 0.02). The A-line group had significantly higher total charges (+ $5,710, p < 0.001), total direct costs (+ $395, p = 0.004), and variable costs (+ $389, p = 0.004); no changes were seen in fixed cost between the groups, as expected. None of the complications listed were directly related to placement of the arterial line.

When assessing factors predictive for arterial line placement among the cohort (after adjusting for CCI, HEART score, year, BMI, prostate volume and surgeon), no single predictive factor was predictive for arterial line placement, Table 2.

TABLE 2. **Multivariable analysis on predictors of arterial line placement**

Variable	p value	Odds ratio [95% CI]
Year	0.53	0.74 [0.53-1.8]
Age (year)	0.23	0.97 [0.87-1.54]
BMI (kg/m^2)	0.16	1.04 [0.32-1.89]
CCI	0.14	1.18 [0.78-1.23]
HEART score	0.28	1.22 [0.89-1.54]

model adjusted for prostate volume and surgeon.
BMI = body mass index; CCI = Charlson Comorbidity Index

After adjusting for patient age and performing surgeon, prostate volume, total operative time, surgeon-specific variation, and patient characteristics, factors affecting variable direct cost in RALP included BMI [OR 1.22, p = 0.04], CCI [OR 1.67, p = 0.03], total operative time [OR 3.45, p < 0.001], hospital length of stay [OR 2.02, p < 0.001]. Placement of arterial line increased total charges, total direct and variable costs; however, this was not significant (p = 0.06) after adjusting for patient factors, Table 3.

The results of the deterministic (one-way) sensitivity analysis displayed as a tornado diagram demonstrate the influence of extreme variations in each key parameter on cost of RALP per patient. Total OR time

TABLE 3. **Multivariable analysis on drivers of variable direct cost for patients undergoing robotic prostatectomy**

Intercept	p value	Odds ratio [95% CI]
Year	0.3	1.62 [0.63-1.3]
BMI	0.04	1.22 [1.02-2.4]
CCI	0.03	1.67 [1.3-1.90]
HEART score	0.46	5.17 [0.89-6.59]
Arterial line placement	0.06	1.25 [0.96-1.46]
Total operative time (min)	< 0.001	3.45 [1.94-4.01]
Hospital length of stay (day)	< 0.001	2.02 [1.45-2.69]

†model adjusted for age and surgeon. Arterial line placement coded as binary variable (present/absent)

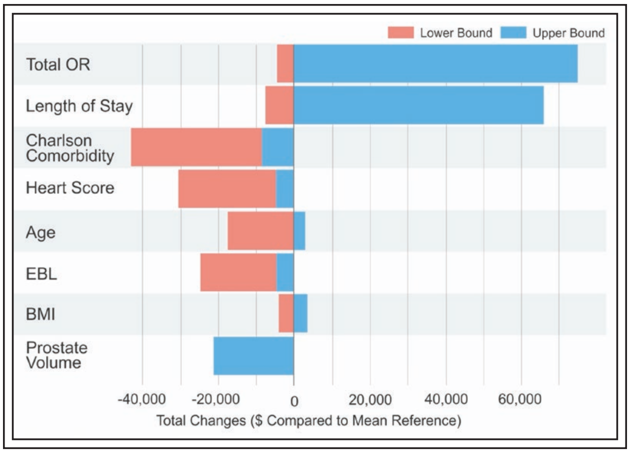

Figure 1. Deterministic sensitivity analysis Tornado diagram of Variable Contribution to Total Hospital Charges. Total OR = operative time in minutes; BMI = body mass index, EBL = estimated blood loss. Note: Blue bar represents the degree of total charge increase per patient as parameter value increases. Red bar represents the degree of total charges decrease per patient as the parameter value decreases.

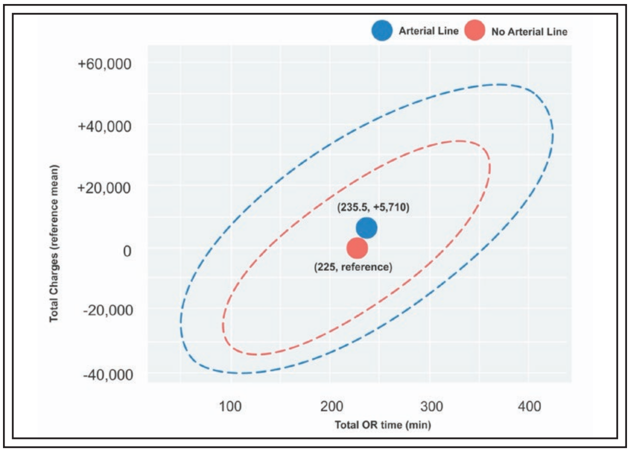

Figure 3. Graphical representation of cost effectiveness probabilistic sensitivity analysis. The graph shows 1000 samples resulting from the probabilistic sensitivity analysis and 95% confidence ellipse, function of total charges ($) and operative time, by arterial line placement. Arterial line placement overall resulted in an increase of 10.5 minutes and total cost 5,710$ from mean values for patients without arterial lines placed.

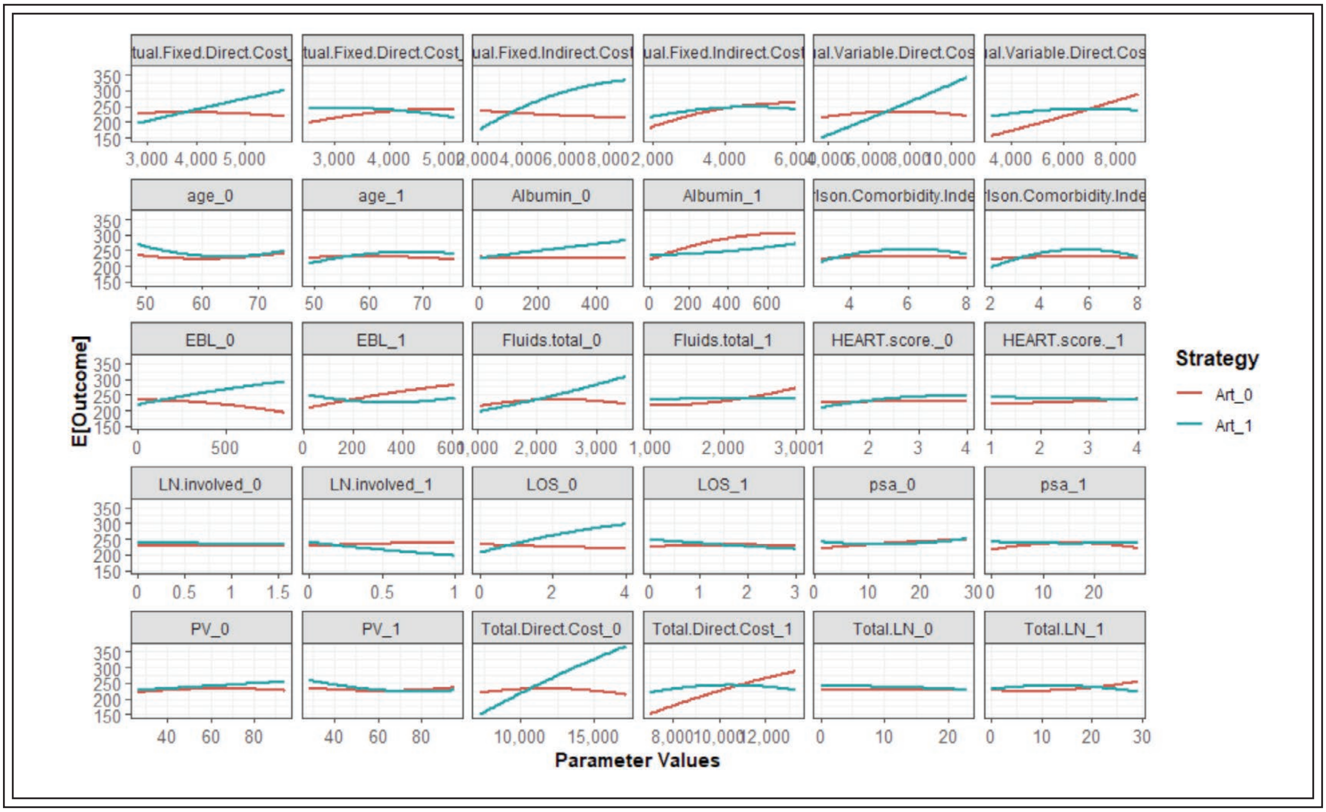

Figure 2. Additional one-way sensitivity analysis of variables affecting cost of robotic-assisted laparoscopic prostatectomy.

and length of stay had the most influence on increasing total costs, Figure 1, while BMI, patient age and EBL had the least effect. In contrast, decreasing CCI and HEART score had the most influence in lowering total costs per patient. Additional one-way sensitivity analysis can be seen in Figure 2, illustrating predictors of cost among patients undergoing RALP.

On our probabilistic sensitivity analysis modeling evaluating variance in total charges based on operative time and A-line placement, A-line placement showed an increase of total of 10.5 minutes in operative duration and an increased total charge to the patient ($5,710), Figure 3.

Discussion

While the use of A-lines was common in the era of open RRP, this practice is relatively antiquated and may no longer be necessary for most patients undergoing RALP. To date, no studies have evaluated the use of A-lines for patients undergoing RALP. Here, we review baseline characteristics, intraoperative variables, and cost of RALP for patients who had A-lines placed at a large tertiary care center. We show that patients with A-lines are likely to receive more intraoperative fluids, have a longer LOS, and may have increased total charges and cost associated with A-line placement. While A-line placement potentiates higher cost of RALP, no improvement in complication rates were seen.

At present there is little guidance for anesthesiologists on the appropriate use of A-line during RALP. Current recommendations for A-line placement are vague and open to interpretation.[7] While A-line use was relatively common during the era of RRP, the advent of new technology and ubiquitous use of robotic surgery for prostatectomies have resulted in decreased blood loss, shorter length of stays, and lower complication rates, which necessitates re-evaluation of arterial line use.[11] In our study, there was no single clinical characteristic that predisposed patients to A-line placement.

Previous studies investigating the cost of prostatectomy have found that for every 1 unit increase in BMI, there is a subsequent increase of $129 on the total cost.[12] Additionally, carrying the diagnosis of DM, and having a higher CCI, increased the adjusted direct cost by $1860.[13] These findings are in concordance with our study, which found similar predictive factors on the total cost of RALP, including BMI, CCI, and operative time.

We found that A-line use during RALP was associated with higher costs. Charges for patients in our cohort with A-line placement was nearly $6,000 higher in total cost and $400 higher in corresponding direct variable cost. While this was not statistically significant within the cohort setting ($p = 0.06$), A-line placement increased variation and thus increased the upper limit of cost, increasing the financial burden for individual patients.

This cost inflation due to A-line placement is likely multifactorial in nature, driven by factors presented here as well as factors not fully captured. For example, although patients with A-lines were associated with increased intraoperative fluid resuscitation (+200 cc), this alone likely had very little effect on total cost per patient. This statistically significant difference, however, may be indicative of a broader alteration in care that patients with A-lines receive that collectively influence total cost. These may take place as varying degrees of postoperative resuscitation, transfusions, level of care assigned, and increased use of intravenous antihypertensive medications to name a few.

The two observed factors that had the largest influence on total cost with RALP were total operative time and hospital length of stay. Similar to total cost, difference in operative time was not significant when comparing cohorts. However, A-line placement again increased variation and thus increased the upper limit of RALP operative time. Nevertheless, a statistically significant association between A-line placement and increased hospital length of stay was observed even in the cohort setting.

The only appropriate justification for invasive intervention is benefit for the patient, society, or both. In the context of operative care, A-line placement would be justified if improvement in survival, complication rate, or quality of life could be observed. Even if the said intervention provided no benefit to patients, it can benefit society in the form of lower cost or producing better cost-effective care.[14] Every intervention has risk and cost; therefore, interventions without such benefit should not be routinely used. Our data does not show any benefit of A-line placement to the patient, showing no decrease in complication rates, while potentially increasing the expense of surgical procedure. In addition, our data does not demonstrate any impact of patient preoperative clinical factors on A-line placement, signifying high-rate variability and inconsistency of its use based on poorly defined subjective assessment.

Many studies have evaluated perioperative factors in relation to cost of prostatectomy. Our study is unique, as cost of A-line placement has not previously been assessed in a prostatectomy cohort. While it is understood that the complexity of a patient's medical history may necessitate A-line placement, its widespread use without evidence for benefit is likely due, in part, to the fact that clinical practice patterns are often based on "expert opinion, historical practice, and blind acceptance, rather than on adequate evidence base".[15] As the safety and feasibility of same-day discharge after RALP is becoming better understood, these patients especially may not require A-line monitoring. A commonly held, but erroneous, belief is that A-line systolic and diastolic blood pressure measurements are more accurate than non-invasive values. In vivo and in vitro studies have shown this to be false; both types of blood pressure measurements have > 95% sensitivity.[14] A-line placement facilitates easier laboratory testing, which is associated with higher cost, risk of anemia, and consequent blood transfusion, without difference in improved clinical outcomes.[16,17] As we strive to improve the health of patients and decrease societal cost, it is a slippery slope to justify the use of A-line placement during RALP, which may no longer be justified based on convenience to caregivers.[14]

Limitations to this study include its retrospective nature. Since data are from a single tertiary care institution, the cost metrics may be institution specific. Our data is limited to a single hospital encounter and 30-day complications without oncologic data, so we are unable to assess delayed complications or outpatient visits. Furthermore, our study did not adjust for the anesthesiologist. As A-line placement is at the jurisdiction of the anesthesiologist, variations across years of practice and attending anesthesiologist may be seen. Despite the above listed limitations, this is the first study to show limited clinical utility of A-line placement in robotic prostatectomy patients, with an exaggerated cost of treatment. □

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