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Cost effectiveness of ultrasound-guided long peripheral catheters in difficult vascular access patients

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Abstract

Objective: Peripheral intravenous catheter (PIVC) placement is a routinely performed invasive procedure in hospital settings with an unacceptably high failure rate that can result in significant costs. This investigation aimed to determine the cost-effectiveness of using long peripheral catheters (LPC) versus standard short peripheral catheters (SPC) in the difficult vascular access (DVA) population.

Methods: A secondary analysis was performed of a randomized control trial that compared a 20-gauge 4.78 cm SPC to a 20-gauge 6.35 cm SPC for the endpoint of survival. This study assessed cost-effectiveness of the comparative interventions. Costs associated with increased hospitalization length of stay due to PIVC failure, including labor, materials, equipment, and treatment delays were estimated by utilizing healthcare resource utilization data. Cost-effectiveness of the LPC was analyzed through the incremental cost-effectiveness ratio, the cost-effectiveness acceptability curve, and the incremental net benefit. A sensitivity analysis was conducted to evaluate the robustness of the results during the time interval of PIVC insertion.

Results: Among the 257 patients, the average total cost for therapy was lower in the LPC group compared to the SPC group ($400 vs $521; mean difference −$121, 95% bootstrapped CI −$461 to $225). A marginally significant absolute difference of complication averted was found for LPC versus SPC (10.8%, $p = 0.07$). The estimated incremental cost-effectiveness ratio (ICER) for LPC as compared with SPC was −$1123 (95% bootstrapped CI −$8652 to $5964) per complication averted. In a willingness to pay (WTP) analysis, as WTP = $0, the incremental net benefit (INB) $121 was positive, indicating LPC was less costly. Analysis of PIVCs that survived ⩽48 h ($n = 134$) demonstrated a lower average total cost for therapy among the LPC group ($418 vs $531; mean difference −$113, 95% bootstrapped CI −$507 to $282). Forty-seven of 66 (71.2%) LPCs did not experience a complication, compared with 37 of 68 (54.4%) SPCs, resulting in a significant absolute difference of complication adverted of 16.8% ($p = 0.04$). In addition, with a positive slope, the INB $113 was positive as WTP = $0, indicating LPC was estimated to be cost-effective.

Conclusions: When using ultrasound guidance for vascular access, LPCs are potentially a cost-effective strategy for reducing PIVC complications in DVA patients compared to SPCs. Given this finding, ultrasound-guided LPCs should be routinely considered as first-line among the DVA population in order to improve their overall care and wellbeing.

Keywords

Peripheral intravenous catheter, long peripheral catheter, cost effectiveness, willingness to pay, incremental net benefit

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Introduction

Recent estimates indicate that over 350 million peripheral intravenous catheters (PIVC) are placed annually in the United States, with over 90% of hospitalized patients requiring some form of intravenous (IV) access during their hospitalization.[1–3] Although PIVC placement is the most commonly performed invasive medical procedure worldwide, complications are common, and first attempt procedural success is poor.[4–6] In fact, estimates indicate that up to 2.35 insertion attempts are required per PIVC placed, with first stick success as low as 44%. This problem is compounded by the fact that even after a successful insertion, up to 63% of PIVCs develop complications that lead to catheter failure prior to completion of therapy.[7] This unacceptably high failure rate and low first stick success contributes to significant patient harm in the form of repeated painful insertion attempts, treatment delays, venous depletion, prolongation of hospital stay, psychological and physical stress from needlesticks, and increased rates of nosocomial infections.[4–6]

Beyond poor patient outcomes, PIVCs contribute to a financial burden of $1.5 billion annually in the US healthcare system.[8,9] These substantial costs related to PIVC deficiencies include the labor and materials required for insertion as well as rescue devices, infectious complications, and increased hospital length of stay due to treatment delays.[8–10] New advancements in PIVC devices and placement techniques have been developed to help reduce patient discomfort, failure rates, treatment delays, and overall healthcare costs related to the procedure.[11,12] Despite these advancements, there are still many individuals with difficult venous access (DVA). Bahl et al. recently conducted a study that focused on this particularly vulnerable population and found that deploying a long peripheral catheter (LPC; 6.35 cm) via ultrasound guidance to augment vein purchase improved survival when compared to the short peripheral catheter (SPC; 4.78 cm).[13] While this study demonstrated that the LPC improved PIVC survival, it is unclear if the intervention reduced overall costs and enhanced patient comfort. Therefore, this investigation aims to determine the cost-effectiveness of using the LPC versus the SPC for DVA patients.

Methods

Clinical trial design and results

This is a secondary analysis of an existing single-site, randomized control trial that directly compared two catheters: (1) a 20-gauge 4.78 cm Becton Dickinson (BD) Insyte™ Autoguard™ SPC and (2) a 20-gauge 6.35 cm B. Braun Introcan Safety® LPC (ClinicalTrials.gov: NCT03655106). The study was conducted at an 1100 bed tertiary care center with an annual emergency department census of approximately 130,000 visits. The initial study consisted of adult patients at least 18 years of age with self-reported DVA and at least one of the following: history of requiring two or more intravenous attempts on a previous visit, end-stage renal disease and receiving dialysis, injection drug use, sickle cell disease, or previously requiring a rescue catheter. A rescue catheter was defined as any of the following: ultrasonographically guided intravenous catheter, midline catheter, or central venous access. Patients were excluded if they were previously enrolled, withdrew from the study, or presented when trained intravenous line inserters were unavailable. The final analysis consisted of 257 patients. Both the primary and this secondary analysis were approved by the Institutional Review Board of Beaumont Health. Kaplan-Meier estimate of catheter median survival time in the LPC group was 136 h (95% confidence interval [CI] 116–311 h) compared with 92 h (95% CI 71–120 h) in the SPC group, for a difference of 44 h (95% CI 9–218 h).

Catheter function was assessed at the time of insertion and each day thereafter for the life of the catheter. Functionality was determined by the ability of the research staff to flush the line with 5 mL of normal saline without resistance and complication. The research staff then noted whether the catheter survived to completion of therapy or failed prematurely. If the catheter failed before the follow-up, the date, time, and reason for failure were collected from the patient's medical record. If a patient was discharged before their follow-up, the line was presumed functional unless stated otherwise and the line removal date and time were collected from the patient's chart. Complications were classified as: phlebitis, infiltration, dislodgment, occlusion, and leaking.

Resource use measurement

Healthcare resource utilization data were collected alongside the trial. These resources included insertion-related equipment with labor estimates, rescue device equipment with labor estimates, and costs attributed to added hospital length of stay due to PIVC failure.

A literature review was conducted to establish the cost of placement for each catheter and the cost of treatment delay. We assumed the estimated total cost of insertion per attempt was $50 for the 6.35 cm catheter and $45 for the 4.78 cm catheter. We estimated the total cost of insertion of traditional PIVC, ultrasound-guided PIVC, peripherally-inserted central catheters, central venous catheters, and midline catheters was $35, $45, $249, $319, and $149, respectively.[10,14–18] The assumptions were applied to any rescue insertions. Rescue catheters were defined as lines that were placed to establish venous access when no other forms of access were available. Information regarding all subsequent lines placed after the trial device, including placement and removal time, catheter type, and line survival was collected from the patient's chart. The cost

Table 1. Costs of peripheral intravenous catheter-related therapy for all 257 patients.

Variables[a]	Ultrasound-guided PIVC		SPC		Mean difference (95% CI)
	LPC				
n	131		126		
Total costs of IV therapy ($US)	400.4	(1306.1)	521.7	(1480.3)	−121.3 (−460.7 to 224.9)
Cost associated with IV failure					
n	41		53		
Total costs of IV failure ($US)	1119.5	(2159.0)	1133.2	(2123.4)	−13.7 (−874.5 to 776.5)
Rescue device costs ($US)	90.3	(175.0)	86.2	(161.6)	4.1 (−68.4 to 68.6)
Treatment delay costs ($US)	1029.2	(2045.1)	1047.1	(2005.4)	−17.9 (−925.2 to 769.9)

PIVC: peripheral intravenous catheter; LPC: long peripheral catheter; SPC: short peripheral catheter; IV: intravenous; CI: confidence interval.
[a]Data are presented as mean US$ (SD). Nonparametric bootstrapping with 1000 replicates was used to assess the mean differences between ultrasound-guided LPC and SPC.

assumptions are based on published literature when possible.

In addition, for catheters that failed, treatment delay was quantifiable and represents a cost. The time interval was time of failure of the study catheter until the next catheter was established from hospital admission to hospital discharge. If a patient had multiple lines at once, the failure of one line did not constitute a delay in care. The Agency for Healthcare Research and Quality reported a cost of $11,728 for a hospital admission with an average length of stay of 4.6 days.[19] Using these assumptions to quantify the cost of treatment delay, each hour of delay due to premature catheter failure results in an additional $106 in cost.

Statistical analysis

The economic evaluation was performed to estimate the level of cost-effectiveness (CE) of LPCs and SPCs from existing trial data. The mean cost difference between LPCs and SPCs and the corresponding non-parametric bootstrapped 95% confidence interval (CI) were calculated. The effective index defined for the cost-effectiveness analysis was the rate of complication avoided (i.e. 1 − complication rate). We estimated the incremental cost-effectiveness ratio (ICER) and the bootstrap approach was applied to assess the 95% CI of ICER. We also plotted the bootstrapped samples on the cost-effectiveness plane to evaluate whether any uncertainty of cost-effectiveness occurred between LPCs and SPCs.[20]

Subsequently, the cost-effectiveness acceptability curve (CEAC) was used to characterize the relationship between cost-effectiveness and the willingness to pay (WTP) parameter to assess for avoidance of additional complications. We depicted CEAC to show the probability of the LPC being cost-effective across a range of possible WTP thresholds.[21] We also defined the net benefit (NB) as a function of the WTP parameter to analyze the incremental net benefit (INB), the difference between the NBs of LPCs and SPCs, representing the net gain from the LPC.[22] Moreover, we conducted a sensitivity analysis to evaluate the robustness of the results during the time interval of PIVC insertion in CE analysis for patients with the index-catheter insertion ⩽48 and >48 h, respectively. All statistical analyses were performed with SAS v9.4 (SAS Institute, Inc., Cary, NC).

Results

Cost

Cost results are reported in Table 1. For all 257 patients, the lower average total cost for therapy was found in LPC ($400 vs $521; mean difference −$121, 95% bootstrapped confidence interval [CI] −$461 to $225). Among 94 patients who experienced catheter failure, compared with SPC, the LPC showed the lower average cost for the treatment delay ($1029 vs $1047; mean difference −$18, 95% bootstrapped CI −$925 to $770).

Cost-effectiveness and incremental net benefit analyses

Ninety of 131 (68.7%) randomized to LPC did not experience a complication, compared with 73 of 126 (57.9%) in SPC. A marginally significant absolute difference of complication averted was found for LPC versus SPC (10.8%, $p = 0.07$). The estimated incremental cost-effectiveness ratio (ICER) for LPC as compared with SPC was −$1123 (95% bootstrapped CI −$8652 to $5964) per complication averted (Table 2). Figure 1(a) shows that the cost-effectiveness (CE) plane plotted all 10,000 bootstrapped estimates of the incremental costs and the incremental effects between LPC and SPC. Point estimates were situated in all four quadrants of the cost-effectiveness plane, reflecting the uncertainty. LPC dominated the majority (74.4%) of these point estimates situated in the cost-saving plane (quadrant IV in the bottom right corner), and 21.6% situated in the LPC were more effective but also more costly

Table 2. Incremental analysis for all 257 patients.

	Ultrasound-guided PIVC	
	LPC (n = 131)	SPC (n = 126)
Total costs of IV therapy ($US)	400.4	521.7
Incremental cost ($US)	−121.3	
Effective index (non-complication rate)	68.7%	57.9%
Incremental effective index (complication averted)	10.8%	
Incremental cost effectiveness ratio, ICER	−$1123.2	

PIVC: peripheral intravenous catheter; LPC: long peripheral catheter; SPC: short peripheral catheter.

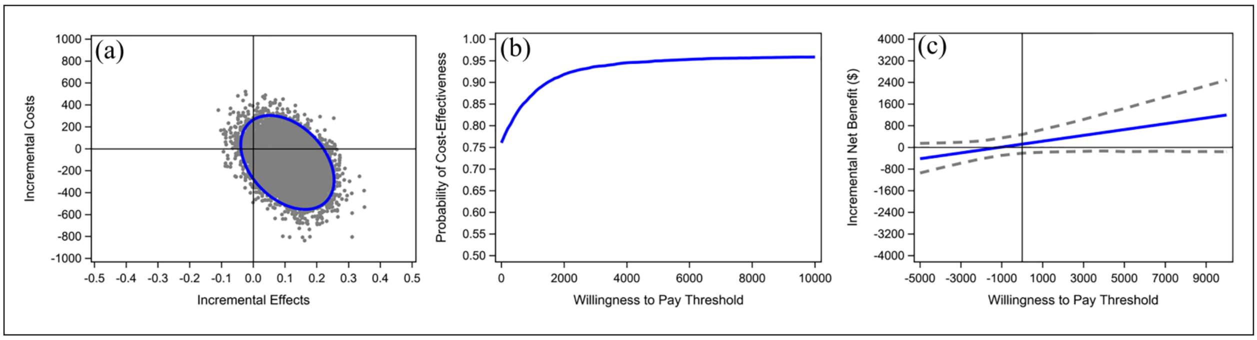

Figure 1. Cost-effectiveness of LPCs compared with SPCs for all 257 patients: (a) the incremental costs (y-axis) and the incremental effects (x-axis) of 10,000 bootstrapped estimates on the cost-effectiveness plane along with the 95% confidence ellipse depicted that point estimates were distributed in potentially economically attractive and uncertain areas, (b) the cost-effectiveness acceptability curve showed the probability of the LPC being cost-effective across willingness to pay thresholds, and (c) estimates of the incremental net benefit were assessed as a function of willingness to pay along with the 95% confidence interval based on 1000 bootstrapped replicates.

(quadrant I in the upper right corner). Moreover, the cost-effectiveness acceptability curve (CEAC) shown in Figure 1(b) indicates that if the decision-maker was willing to pay $100 per complication averted, there was a 78% chance that LPC is cost-effective compared with SPC. If the decision-maker was willing to pay approximately $3000 per complication averted, then the chance that LPC was cost-effective increased to 94%. On the other hand, Figure 1(c) illustrates that as willingness to pay (WTP) increases along the horizontal axis, the positive slope indicates LPC was more effective; as WTP = $0, the incremental net benefit (INB) $121 was positive, indicating LPC was less costly. The INB estimate was always positive for WTP > $0, suggesting LPC was estimated to be cost-effective, regardless of the decision-maker's willingness to pay.

Sensitivity analyses

When considering only catheters with an insertion not greater than 48 h, for those 134 patients, the lower average total cost for therapy was found in LPC ($418 vs $531; mean difference −$113, 95% bootstrapped CI −$507 to $282) (Table 3). Forty-seven of 66 (71.2%) in LPC did not experience a complication, compared with 37 of 68 (54.4%) in SPC, resulting in a significant absolute difference of complication adverted of 16.8% (p = 0.04). The estimated ICER (LPC vs SPC) was −$676 (95% bootstrapped CI −$4205 to $5058) per complication averted (Table 4). With 10,000 bootstrapped replicates, LPC dominated 71.5% of pairs of incremental costs and incremental effects in the cost-saving plane (quadrant IV in the bottom right corner), while 26.6% situated in the LPC were more effective but also more costly (quadrant I in the upper right corner). In CEAC, if the decision-maker was willing to pay $100 per complication averted, there was a 74% chance that LPC is cost-effective compared with SPC. If the decision-maker was willing to pay approximately $3000 per complication averted, then the chance that LPC was cost-effective increased to 94% (Figure 2(a) and (b)). In addition, with a positive slope, the INB $113 was positive as WTP = $0, indicating LPC was estimated to be cost-effective, regardless of the decision-maker's willingness to pay (Figure 2(c)).

On the other hand, when considering only the insertion greater than 48 h, for those 123 patients, the lower average total cost for therapy was found in LPC ($383 vs $510; mean difference −$127, 95% bootstrapped CI −$728 to $464) (Table 3). Forty-three of 65 (66.2%) in LPC did not experience a complication, compared with 36 of 58

Table 3. Costs of peripheral intravenous catheter-related therapy by the time interval of catheter insertion.

Variables[a]	Catheter insertion ⩽48 h					Catheter insertion >48 h				
	Ultrasound-guided PIVC					Ultrasound-guided PIVC				
	LPC		SPC		Mean difference (95% CI)	LPC		SPC		Mean difference (95% CI)
n	66		68			65		58		
Total costs of IV therapy ($US)	417.7	(1255.7)	531.3	(1104.8)	−113.6 (−507.0 to 281.7)	382.8	(1364.9)	510.4	(1835.8)	−127.6 (−728.0 to 464.2)
Cost associated with IV failure										
n	19		31			22		22		
Total costs on IV failure ($US)	1277.3	(2113.5)	1066.6	(1444.5)	210.7 (−712.8 to 1346.8)	983.1	(2237.9)	1227.1	(2858.0)	−244.0 (−1874.3 to 1247.2)
Rescue device costs ($US)	77.5	(106.7)	79.7	(85.0)	−2.2 (−49.9 to 58.6)	101.4	(219.7)	95.3	(232.7)	6.1 (−130.7 to 140.7)
Treatment delay costs ($US)	1199.8	(2093.4)	986.9	(1391.0)	212.9 (−739.1 to 1415.3)	881.8	(2039.9)	1131.8	(2679.8)	−250.0 (−1620.5 to 1127.6)

PIVC: peripheral intravenous catheter; LPC: long peripheral catheter; SPC: short peripheral catheter; IV: intravenous; CI: confidence interval.

[a]Data are presented as mean US$ (SD). Nonparametric bootstrapping with 1000 replicates was used to assess the mean differences between ultrasound-guided LPC and SPC.

Table 4. Cost-effectiveness analysis by the time interval of catheter insertion.

	Catheter Insertion ⩽48 h		Catheter Insertion >48 h	
	Ultrasound-guided PIVC		Ultrasound-guided PIVC	
	LPC (*n* = 66)	SPC (*n* = 68)	LPC (*n* = 65)	SPC (*n* = 58)
Total costs of IV therapy ($US)	417.7	531.3	382.8	510.4
Incremental cost ($US)	−113.6		−127.6	
Effective index (non-complication rate)	71.2%	54.4%	66.2%	62.1%
Incremental effective index (complication averted)	16.8%		4.1%	
Incremental cost effectiveness ratio, ICER	−$676.2		−$3112.2	

PIVC: peripheral intravenous catheter; LPC: long peripheral catheter; SPC: short peripheral catheter.

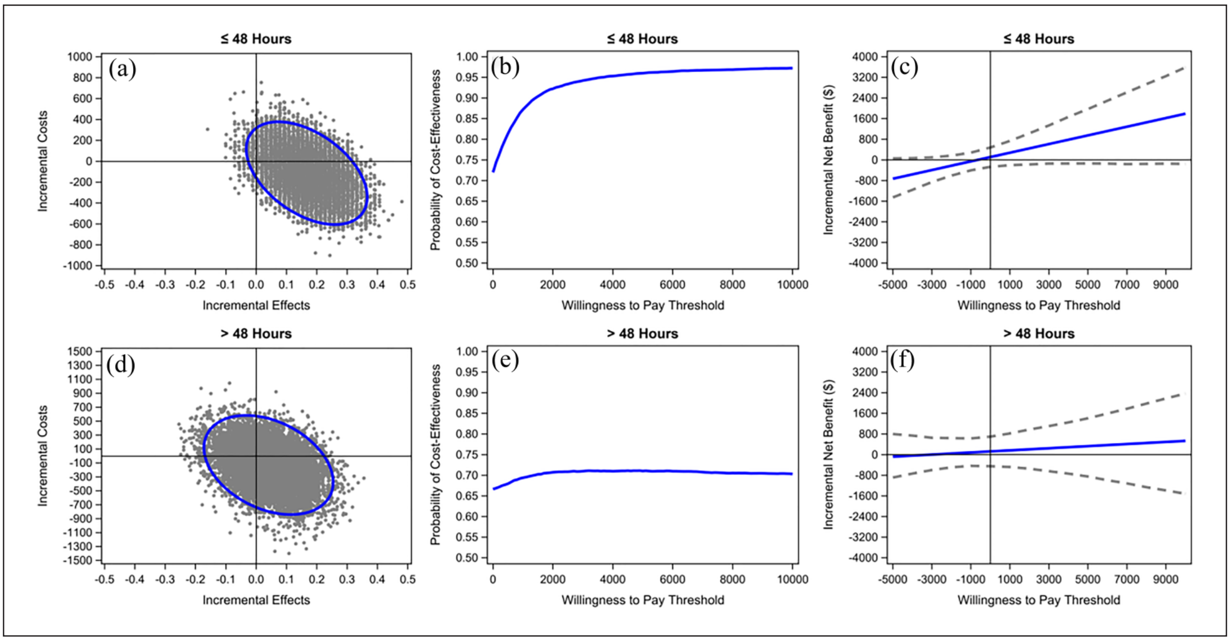

Figure 2. Cost-effectiveness of LPCs compared with SPCs for 134 patients with the index-insertion ⩽ 48 h (the upper panel; (a–c)) and 123 patients with the index-insertion > 48 h (the lower panel; (d–f)), respectively. (a and d), the incremental costs (y-axis) and the incremental effects (x-axis) of 10,000 bootstrapped estimates on the cost-effectiveness plane along with the 95% confidence ellipse depicted that point estimates were distributed in potentially economically attractive and uncertain areas. (b and e), the cost-effectiveness acceptability curve showed the probability of the LPC being cost-effective across willingness to pay thresholds. (c and f), estimates of the incremental net benefit were assessed as a function of willingness to pay along with the 95% confidence interval based on 1000 bootstrapped replicates.

(62.1%) in SPC, resulting in an absolute difference of complication adverted of 4.1% ($p = 0.64$). The estimated ICER (LPC vs SPC) was −$3112 (95% bootstrapped CI −$36,697 to $30,246) per complication averted (Table 4). With 10,000 bootstrapped replicates, LPC dominated 50.2% of pairs of incremental costs and incremental effects in the cost-saving plane (quadrant IV in the bottom right corner) and 18.2% situated in the LPC were more effective but also more costly (quadrant I in the upper right corner). In CEAC, if the decision-maker was willing to pay $100 per complication averted, there was a 67% chance that LPC is cost-effective compared with SPC. If the decision-maker was willing to pay approximately $3000 per complication averted, then the chance that LPC was cost-effective increased to 71% (Figure 2(d) and (e)). In addition, the INB $127 was positive as WTP = $0, however, the flatted positive slope revealed that the cost-effectiveness of LPC might be diminished while the catheter insertion was greater than 48 h (Figure 2(f)).

Discussion

While our original trial demonstrated that the LPC improved PIVC survival during hospitalization of DVA patients, it was unclear if this survival benefit occurred alongside an economically favorable model.[13] Limited existing data suggests that ultrasound-guided PIVC placement programs are cost-effective, but the incremental value of any specific catheter type has not been previously described.[23] When examining the overall efficacy of comparing the LPC and SPC devices, we found the LPC to be the cost-effective option. Importantly, our cost-effectiveness analysis accounts for both direct costs (index and rescue device insertions), treatment delays, and complications. This current analysis not only demonstrates that there is no increased direct financial cost from using the LPCs, but the enhanced survival leads to a significant benefit when evaluating overall cost-effectiveness. Additionally, while the difference in direct catheter-related costs was not found to be statistically significant, the mean difference favored the LPC group by $121.

When evaluating the individual components of the cost equation, both the cost of the PIVC failure and treatment delay favor the LPC. The only element whose mean difference favors the SPC is the rescue device cost. A closer look at the original study cohort shows that 13 of the 53 patients from the SPC group experienced PIVC failure and did not have a rescue device placed. This was likely secondary to multiple co-existing PIVCs in these cases. Thus, when the study catheter failed, other PIVCs may still have been functional and a rescue device was not required. Unfortunately, due to the unacceptably high rate of PIVC failure currently, many nurses maintain several PIVCs for admitted patients in anticipation of a failure event.[3,24] Therefore, it is possible that the cost savings of the LPC may be amplified even further in cases in which PIVCs are placed more judiciously. Additionally, it should not be overlooked that beyond direct costs, we demonstrate a significant cost savings by using the LPC when factoring complications.

Another interesting finding of this analysis was that among catheters that survived less than 48 h, there was an increase in cost-effectiveness for the LPC group. While this difference may be attributable to other factors, such as additional vascular access device already in place, it is also possible that it reflects the natural progression of catheter failure. Previous data demonstrate that a substantial percentage of ultrasound-guided PIVCs fail often and early within the clinical course. Two studies found median time to failure for ultrasound-guided PIVCs was 15.6 and 30 h, respectively, for the SPC.[25,26] Another analysis investigating inflammatory changes within a catheterized vessel and surrounding soft tissue demonstrated that PIVCs which showed early inflammatory signs on ultrasound at or before 48 h resulted in significantly less dwell time than catheters that showed these signs $>$48 h after insertion.[27] Nevertheless, further research is needed to elucidate why some catheters fail so quickly while others do not.

There are some limitations to our study. First, the cost of additional co-existing "back-up" PIVCs was not considered in our analysis. It was challenging to discern if additional catheters were placed for other clinical indications, and therefore this cost was not quantified for either study arm. Next, we are reliant on documentation in the medical record for the date and time of index device removal and for rescue device insertion and removal. These timings may not reflect the exact time of the activity and could have introduced some inaccuracy to the cost analysis. Additionally, these results apply exclusively to the LPC used in the clinical trial and cannot be generalized to category of LPCs as a whole. Finally, additional patient factors such as pain with insertion or maintenance of the PIVC could have been added the composite calculation. However, pain assessment data was often incomplete and possibly unreliable.

Conclusions

Given our overall findings that LPCs are potentially cost-effective and our prior findings that these catheters have increased rates of survival, we feel that standard use of ultrasound-guided LPCs among DVA inpatients is a safe and effective way of improving PIVC performance amongst these hospitalized patients. Further research is needed to clarify if using LPCs in only a certain subset of these patients may provide additional cost savings.

Author contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Data sharing statement

The data that support the findings of this study are available via a data access agreement. Please contact the corresponding author (AB) for this request.

Declaration of conflicting interests

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Ethics committee approval

This study was approved by the Beaumont Health Institutional Review Board.

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