*Original research article*

JVA The Journal of Vascular Access

The Journal of Vascular Access
1–7

DOI: 10.1177/11297298221122118
journals.sagepub.com/home/jva
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# Predictors of ultrasound-guided peripheral intravenous catheter failure: A secondary analysis of existing trial data

**Amit Bahl[1], Michael Millard[2], Mahmoud Hijazi[3] and Nai-Wei Chen[4]**


## Abstract

**Objectives:** Ultrasound-guided (US) peripheral intravenous catheters (PIVC) have a high failure rate with many failing prior to completion of therapy. Risk factors associated with catheter failure are poorly delineated. This study aimed to assess risk factors related to catheter failure including patient, procedure, catheter, and vein characteristics to further elucidate which variables may impact catheter longevity.

**Methods:** This was a secondary analysis using an existing trial dataset that primarily compared survival of two catheters: a standard long (SL) and an ultra-long (UL) US PIVC. Adult emergency room patients with difficult intravenous access at a tertiary care suburban academic center were study participants. Kaplan-Meier was employed to estimate the median catheter survival time. Cox regression univariable and multivariable analyses were used to evaluate the primary outcome of catheter survival.

**Results:** Among 257 subjects, 63% of PIVCs survived until completion of therapy. In a multivariable Cox regression model, length of catheter in vein $>2.75$ cm (adjusted hazard ratio [aHR] 0.58, 95% confidence interval [CI] 0.37–0.90, $p=0.01$) was associated with improved survival. First stick success decreased the risk of catheter failure (aHR 0.68, 95% CI 0.44–1.06, $p=0.09$) but was not statistically significant. Factors associated with the increased risk of catheter failure included: depth of vein $>1.2$ cm (aHR 1.68, 95% CI 1.06–2.66, $p=0.03$) and PIVC placement in right extremity (aHR 1.64, 95% CI 1.07–2.51, $p=0.02$).

**Conclusions:** This study demonstrated that catheter length in vein ($>2.75$ cm) was associated with improved US PIVC survival highlighting the value of longer catheters in US PIVC survival. Choosing targets in the non-dominant extremity with shallower depths ($\leqslant 1.2$ cm) may also increase catheter survival.



### Keywords

Peripheral catheterization, vascular access devices, ultrasonography, vascular systems injuries, difficult vascular access, difficult intravenous access

Date received: 8 May 2022; accepted: 29 July 2022


## Introduction

The most common invasive procedure performed worldwide in the hospital setting is the placement of peripheral intravenous catheters (PIVC) with nearly 300 million PIVCs placed annually in the United States alone.[1,2] With nearly 90% of hospitalized patients requiring intravenous access for treatment, establishing functional PIVCs consistently and reliably becomes paramount for providing quality patient care.[1,3–5] Though PIVCs have proven

[1]Department of Emergency Medicine, Beaumont Hospital, Royal Oak, MI, USA
[2]Western University of Health Sciences, Pomona, CA, USA
[3]Oakland University William Beaumont School of Medicine, Rochester, MI, USA
[4]Beaumont Health Research Institute, Royal Oak, MI, USA

**Corresponding author:**
Amit Bahl, Department of Emergency Medicine, Beaumont Hospital, Royal Oak, 3601 W 13 Mile Road, MI 48073-6769, USA.
Email: Amit.bahl@beaumont.edu

integral to health care, up to 50% of traditionally placed IVs fail prior to completion of treatment.[2,3,6,7]

Patients may suffer a multitude of sequelae from PIVC failure, including the need for repeat invasive procedures, venous depletion from repeated needlesticks, escalation to more invasive central venous access devices with associated higher risk profiles, extravasation with skin necrosis, catheter associated bloodstream infections, interruption of medical therapies, and longer hospital stays.[2,8–10] While the spectrum of patient impact ranges from simple re-insertion to much more severe complications such as sepsis, there is a high likelihood that PIVC inadequacies directly impact the quality of care of most hospitalized patients.

This problem has challenges in the growing vulnerable difficult vascular access (DIVA) population (up to one-third of hospital patients) in which successful re-insertions in the inpatient wards often require specialized nursing personnel or vascular access teams proficient in ultrasound.[11] In the DIVA patient population, ultrasound-guided (US) PIVC placement has proven to be a viable and superior alternative with high first-stick insertion success.[5,12–14] Despite successful PIVC placement achieved in 76%–100% of DIVA patients with US guidance, these IVs have an even higher failure rate (45%–56%) and limited dwell compared to traditionally placed PIVCs.[3,5,14–18] Notably, it has been shown up to 56% of US PIVCs fail before completion of therapy with nearly half failing within the first 24 h (median range 15–26 h).[15,16,19,20] In order to develop successful strategies to combat this expansive problem, it is necessary to understand the risk factors that lead to US PIVC failure, particularly modifiable variables.

There is a paucity of evidence that describes predictors of US PIVC failure. Several variables including demographics, clinical, procedural, and line/vein characteristics may influence survival and require investigation. Thus, the goals of this analysis are to identify risk factors that are predictive of US PIVC survival and help develop practical actionable recommendations to improve outcomes.

## Methods

### Study sample

This was a secondary analysis of a previous randomized trial at an 1100 bed tertiary care center with an annual emergency department census of approximately 130,000 visits that compared two catheters: (1) a standard long (SL) 20-gauge 4.78 cm Becton Dickinson (BD) Insyte™ Autoguard™ PIVC and (2) an ultra-long (UL) 20-gauge 6.35 cm B. Braun Introcan Safety® PIVC.[21] Briefly, the primary study was approved for adult subjects over the age of 18 with self-reported DIVA and at least one of the following: history of requiring 2 or more intravenous attempts on a previous visit, previous requirement for a rescue catheter (US PIVC, midline catheter, or central venous access), end-stage renal disease and receiving dialysis, injection drug use, or sickle cell disease. Patients were excluded if previously enrolled, withdrew from the study, or if patient presented when specifically trained line inserters were unavailable. Ultimately 257 patients were included in the dataset. The primary outcome of the original trial was duration of PIVC survival. This secondary exploration of predicators of catheter failure independent of catheter type was approved by the Institutional Review Board of Beaumont Health.

### Outcome measure

The primary endpoint was ultrasound-guided PIVC failure.

### Independent variables

To identify the potential predictors in the association with PIVC failure in spite of catheter type, we included the following variables: demographic, clinical, insertion/catheter, and vein factors. Demographic/clinical variables included: age, gender, BMI, vital signs, and medical history of end stage renal disease. PIVC insertion related data included: location/side of vein of placement, vein depth/diameter, catheter to vein ratio, distance from antecubuital fossa (cm), length of catheter in vein, angle of insertion into vein, and time to completion (first needlestick to securement with dressing).

### Primary data analysis

Continuous and categorical variables were expressed as means (standard deviations; SD) and frequencies (percentages), respectively. Kaplan-Meier was employed to estimate the median survival time with the corresponding 95% confidence interval (CI) on the comparison of catheter survival time. A Cox proportional hazards regression model was used to evaluate the effect of the UL catheter on line survival adjusting for covariates as well. To explore the association between risk factors and PIVC failure, Cox regression was used for univariable and multivariable analyses. Missing measures were imputed by the procedure of multiple imputation and the effects of risk factors were pooled from 20 imputed datasets, accounting for the additional variability introduced by the multiple imputation. Following an univariable analysis, variables with a $p$-value $< 0.2$ or variables determined by clinicians based on clinical rationale were subjected to a multivariable modeling strategy. There was no violation of proportional hazards assumption based on the Schoenfeld residuals. The corresponding c-statistic and a bootstrap cross-validation were used to evaluate the performance of modeling in multivariable analysis. All tests with a $p$-value $< 0.05$ were

**Table 1.** Patient and clinical characteristics.

| Variables[a] | |
|---|---|
| *n* | 257 |
| *Patient characteristics* | |
| Age, years | |
| <35 | 29 (11.3%) |
| ⩾35 | 228 (88.7%) |
| Gender | |
| Male | 73 (28.4%) |
| Female | 184 (71.6%) |
| BMI, kg/m$^2$ | |
| <30 | 133 (51.8%) |
| ⩾30 | 124 (48.2%) |
| ESRD | |
| No | 214 (83.3%) |
| Yes | 43 (16.7%) |
| Systolic blood pressure, mmHg | 141.1 (27.9) |
| Diastolic blood pressure, mmHg | 75.2 (14.9) |
| Heart rate, bpm | 88.9 (19.3) |
| *IV line characteristics* | |
| Location | |
| Basilic | 103 (40.1%) |
| Brachial | 93 (36.2%) |
| Cephalic | 55 (21.4%) |
| Unknown | 6 (2.3%) |
| Side | |
| Left | 129 (50.2%) |
| Right | 128 (49.8%) |
| Depth of vein, cm | |
| ⩽1.2 | 182 (70.8%) |
| >1.2 | 71 (27.6%) |
| Unmeasured | 4 (1.6%) |
| Catheter-vein ratio | |
| ⩽0.25 | 55 (21.4%) |
| >0.25 | 200 (77.8%) |
| Unmeasured | 2 (0.8%) |
| Length of catheter in vessel, cm | |
| ⩽2.75 | 65 (25.3%) |
| >2.75 | 135 (52.5%) |
| Unmeasured | 57 (22.2%) |
| Angle of insertion, degree | |
| ⩽30 | 144 (56.0%) |
| >30 | 78 (30.4%) |
| Unmeasured | 35 (13.6%) |
| Distance from antecubital fossa, cm | |
| <2.5 | 56 (21.8%) |
| ⩾2.5 | 199 (77.4%) |
| Unmeasured | 2 (0.8%) |
| First-stick success | |
| No | 60 (23.3%) |
| Yes | 197 (76.7%) |
| Time to completion, min | |
| ⩽7 | 202 (78.6%) |
| >7 | 55 (21.4%) |
| *Outcome* | |
| Line failure | |
| Yes | 94 (36.6%) |
| No | 163 (63.4%) |

ESRD: end-stage renal disease; BMI: body mass index; PIVC: peripheral intravenous catheter; IV: intravenous.
[a]Data are mean (SD) or *n* (%) in 257 patients.

considered to indicate statistical significance. All statistical analyses were performed with SAS v9.4 (SAS Institute, Inc., Cary, NC).

## Results:

Among 257 subjects, average age was ⩾35 in 89% of subjects and 72% were female. Over half (52%) had a BMI under 30 and 17% had end-stage renal disease. Half of all catheters were placed in the right arm, 28% placed at a depth >1.20 cm, and 53% had >2.75 cm catheter in vein. First-stick success was 77% and 63% of PIVCs survived until completion of therapy. The site of PIVC placement was basilic vein 40.1%, brachial vein 36.2%, cephalic vein 22.4%, and unknown vein 2.3% (Table 1).

In univariable Cox regression analysis, factors associated with increased risk of PIVC failure included: right arm insertion (hazard ratio [HR] 1.68, 95% CI 1.10–2.56, $p=0.02$) and depth of vein (HR 1.95, 95% CI 1.28–2.99, $p=0.002$). BMI ⩾ 30 increased risk of failure but was not statistically significant (HR 1.49, 95% CI 0.99–2.25, $p=0.06$). Catheter length in vein >2.75 cm was associated with improved PIVC survival (HR 0.53, 95% CI 0.34–0.82, $p=0.005$). First stick success decreased the risk of failure but was not statistically significant (HR 0.68, 95% CI 0.44–1.06, $p=0.09$) (Table 2). Additionally, in Kaplan-Meier analysis, catheter length in vein with >2.75 cm had median survival of 129 h (95% confidence interval [CI] 104–186 h) compared with 75 h (95% CI 52–119 h), for a difference of 54 h (95% bootstrapped CI 10–110 h); for depth of vein, catheters with >1.2 cm depth had median survival of 74 h (95% CI 58–90 h) compared with 136 h (95% CI 117–202 h), for a difference of −62 h (95% bootstrapped CI −129 to −38 h) (Figure 1). Results of median PIVC survival time were robust to complete case analysis (Supplemental Figure 1). Multivariable Cox regression analysis further showed that right arm insertion (adjusted hazard ratio [aHR] 1.64, 95% CI 1.07–2.51, $p=0.02$), depth of vein >1.2 cm (aHR 1.68, 95% CI 1.06–2.66, $p=0.03$), and catheter length in vein >2.75 cm (aHR 0.58, 95% CI 0.37–0.90, $p=0.01$) were identified as significantly independently associated with PIVC survival (Table 2).

**Table 2.** Univariable and multivariable analysis for intravenous catheter failure.

| Variables[a] | Univariable model | | Multivariable model[c] | |
|---|---|---|---|---|
| | HR (95% CI) | *p* Value | HR (95% CI) | *p* Value |
| *Patient characteristics* | | | | |
| Age, years | | | | |
| $<35$ | 1 [Reference] | | 1 [Reference] | |
| $\geqslant 35$ | 1.68 (0.61−4.61) | 0.31 | 1.85 (0.67−5.13) | 0.24 |
| Gender | | | | |
| Male | 1 [Reference] | | | |
| Female | 1.15 (0.72−1.84) | 0.56 | | |
| BMI, kg/m$^2$ | | | | |
| $<30$ | 1 [Reference] | | 1 [Reference] | |
| $\geqslant 30$ | 1.49 (0.99−2.25) | 0.06 | 1.37 (0.89−2.13) | 0.15 |
| ESRD | | | | |
| No | 1 [Reference] | | | |
| Yes | 0.85 (0.49−1.48) | 0.56 | | |
| Systolic blood pressure, mmHg | 1.00 (0.99−1.00) | 0.34 | | |
| Diastolic blood pressure, mmHg | 1.00 (0.98−1.01) | 0.60 | | |
| Pulse, beats/min | 1.01 (1.00−1.02) | 0.21 | | |
| *IV line characteristics* | | | | |
| Location[b] | | | | |
| Basilic | 1 [Reference] | | | |
| Brachial | 1.33 (0.83−2.15) | 0.24 | | |
| Cephalic | 1.10 (0.61−1.97) | 0.75 | | |
| Side | | | | |
| Left | 1 [Reference] | | 1 [Reference] | |
| Right | 1.68 (1.10−2.56) | 0.02 | 1.64 (1.07−2.51) | 0.02 |
| Depth of vein, cm | | | | |
| $\leqslant 1.2$ | 1 [Reference] | | 1 [Reference] | |
| $>1.2$ | 1.95 (1.28−2.99) | 0.002 | 1.68 (1.06−2.66) | 0.03 |
| Catheter-vein ratio | | | | |
| $\leqslant 0.25$ | 1 [Reference] | | 1 [Reference] | |
| $>0.25$ | 0.79 (0.49−1.28) | 0.35 | 0.83 (0.51−1.36) | 0.46 |
| Length of catheter in vein, cm | | | | |
| $\leqslant 2.75$ | 1 [Reference] | | 1 [Reference] | |
| $>2.75$ | 0.53 (0.34−0.82) | 0.005 | 0.58 (0.37−0.90) | 0.01 |
| Angle of insertion, ° | | | | |
| $\leqslant 30$ | 1 [Reference] | | | |
| $>30$ | 0.85 (0.53−1.35) | 0.49 | | |
| Distance from antecubital fossa, cm | | | | |
| $<2.5$ | 1 [Reference] | | | |
| $\geqslant 2.5$ | 0.96 (0.58−1.59) | 0.87 | | |
| First-stick success | | | | |
| No | 1 [Reference] | | 1 [Reference] | |
| Yes | 0.68 (0.44−1.06) | 0.09 | 0.68 (0.44−1.06) | 0.09 |
| Time to completion, min | | | | |
| $\leqslant 7$ | 1 [Reference] | | | |
| $>7$ | 1.20 (0.76−1.90) | 0.44 | | |

BMI: body mass index; ESRD: end-stage renal disease; IV: intravenous; PIVC: peripheral intravenous catheter; HR: hazard ratio; CI: confidence interval.

[a]Missing measures on depth of vein, catheter-vein ratio, length of catheter in vein, and angle of insertion described in Table 1 were imputed.

[b]Unknown insertion location was treated as a category in analysis and not shown.

[c]The model assessment indicated the predictive ability (c-statistic) on PIVC failure was 0.66. The bootstrap cross-validation with 1000 bootstrap samples per imputed dataset, the estimate of c-statistic was 0.68 (95% CI 0.61–0.74).

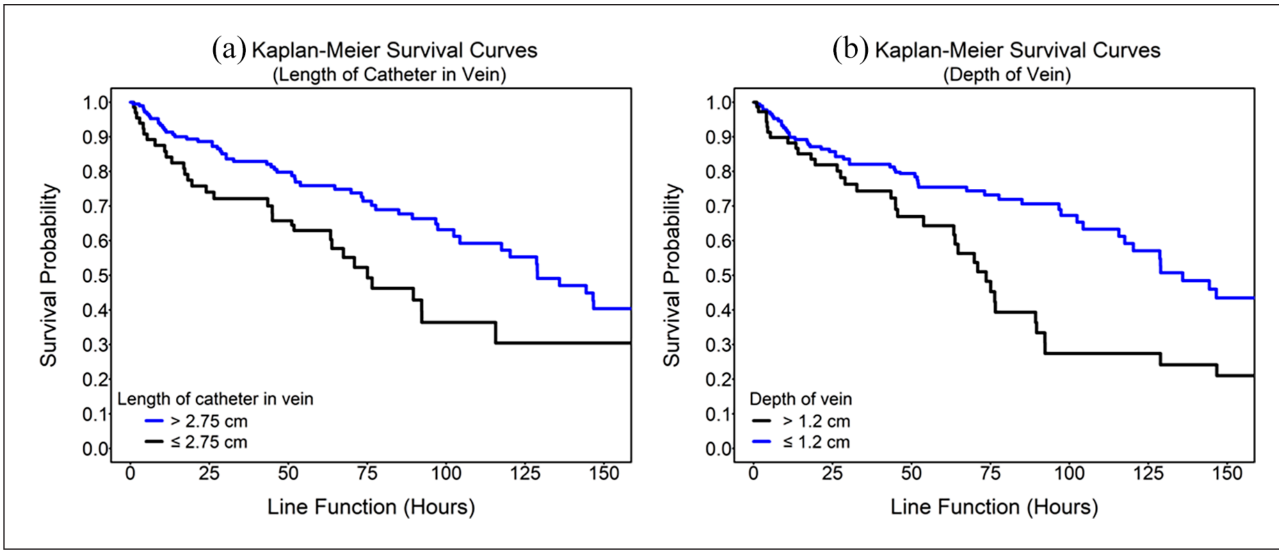


**Figure 1.** Kaplan-Meier survival estimates for intravenous catheter. Estimated survival curves were pooled from 20 imputed datasets. (a) The association of catheter length in vein with the line function was presented. (b) The association of depth of vein with the line function was presented.

## Discussion

The primary study was the first large randomized controlled trial demonstrating significant survival improvement of US PIVCs. This research has broad implications for clinicians and patients alike and it is necessary to explore the factors that impacted PIVC survival with the goal of improving best practice standards. This manuscript outlines actionable strategies to address risk factors related to US PIVC survival.

Previously, it has been shown that catheter survival is dependent on the amount of catheter residing in the vein with an increasing failure rate when <30% of the catheter resided in the vein.[20] This study evaluated this premise further by assessing the risk of failure at a cutoff for catheter length in vein. It was found that for catheters of any length with a length in vein >2.75 cm had a greater median survival compared to catheters with a length in vein ≤2.75 cm (6 days compared to 3.8 days, respectively).[21] A potential explanation for this finding is that the additional amount of catheter in vein may stabilize the PIVC and decrease the likelihood of dislodgement. This overall improved survival may also be related to vein location as all PIVCs were proximal to the antecubital fossa as Murayama et al. demonstrated that PIVCs inserted near the antecubital fossa had a higher propensity of bending, kinking, and premature failure, though this was not adequately assessed in this study.[22] Furthermore, additional catheter length in vein may also provide a more parallel lie of the PIVC within the vein, thus minimizing the potential for mechanical irritation of the posterior vein wall from the catheter tip.[23–25]

The depth of vein was shown to be another contributing factor to survival, a finding consistent with Fields et al. which demonstrated that catheters placed in veins deeper than 1.2 cm had a higher failure rate than those placed in shallower veins.[26] This is most likely related to decreased catheter length in vein due to increased distance traveled prior to reaching the vein. However, it may also be potentially due to a more convoluted path of the catheter to the vein, increasing the risk for bends or kinks. Importantly, the depth or the vein is critical in helping clinicians choose the right catheter length to achieve 2.75 cm in the vein. As most inserters enter the skin at an angle of 30° or less, we recommend choosing the UL (6.35 cm) PIVC for cases in which the vein depth is greater than 1 cm (see 2.75 rule—Supplemental Table 1).[21]

Placement of PIVC in the right arm was also shown to be associated with increased risk of failure. This may be related to hand dominance as up to 90% of the world's population is right hand dominant and continued use and bending of the arm with the PIVC may lead to kinks, bends, and dislodgement.[27] Given these results, we recommend placement of PIVCs in nondominant arms of patients.

Other variables that trended toward statistical significance and may impact catheter survival included first-stick success and obesity. Previous laboratory models have demonstrated that the release of inflammatory and prothrombotic markers begins as early as the initial needlestick.[28] Therefore, each subsequent needle poke has the potential to cause further damage to the vein and increase inflammation, increasing risk of catheter failure. Minimizing the number of needle insertions may maintain the integrity of the vein and reduce the associated inflammatory cascade, optimizing PIVC dwell time. Obese patients (BMI > 30) also had a higher risk of catheter failure. This may be related to increased depth of vein (which has been linked to failure), though further research addressing the question of BMI and arm circumference on PIVC failure is warranted.[26]

Catheter-to-vein ratio is another variable postulated to influence survival, particularly as an increased ratio has a higher risk of developing catheter-associated thrombosis.[29,30] Tanabe et al. demonstrated a ratio of 33% optimized catheter survival in PIVCs. However, in our study catheter-to-vein ratio was not related to failure. A potential explanation for this was the vein location of the PIVCs. The majority of the PIVCs were placed in veins with higher average blood flow rates (250 mL/h in basilic and proximal cephalic) compared to veins more distal to the antecubital fossa (40 mL/h in median vein and 10 mL/h in metacarpal veins).[31] The higher velocities could minimize blood stasis and risk of thrombosis making catheter-to-vein ratio less relevant in upper arm insertions.

## Limitations

This study had some limitations. First, this investigation was performed at a single, large academic suburban tertiary care center with a patient population that had difficult vascular access and demographics that may not be generalizable to other sites. Second, as this was a secondary analysis from an existing trial dataset, the potential actionable strategies need to be further substantiated through a larger well-designed evidence-based experimental or observational study. Third, catheter inserters were unable to be blinded, however, research staff evaluating outcomes were not aware of assignments, which may have negated earlier biases. Fourth, the location of the catheter was placed at sites only proximal to the antecubital fossa, thus the results may be specific to these veins and not applicable to PIVCs placed in the forearm or antecubital fossa. Finally, the timing and cause of catheter failure were extracted from nursing documentation, which may have had inaccuracies that may or may not have translated into skewing the results.

## Conclusions

As the population of DIVA patients continues to increase, need for US PIVC access for treatment is rising accordingly. Given the high risk of US PIVC failure, it is important to understand what factors contribute to early demise and take steps to mitigate failure. This study provides clinicians with actionable recommendations to improve PIVC survival: Use the right catheter to establish >2.75 cm of the catheter in the vein, insert in the non-dominant extremity, and choose a vein depth less than 1.2 cm when possible.

### Acknowledgements

None

### Author contributions

AB designed the study, had full access to all data in the study, and takes responsibility for the integrity and accuracy of the data analysis. AB, MM, MH, and NWC contributed to patient recruitment, data collection, data analysis. NWC conducted the formal statistical analysis. All authors contributed to the writing and editing of the manuscript. All authors contributed to data acquisition, data analysis, or data interpretation, and all reviewed and approved the final version of the manuscript. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

### Availability of supporting data

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

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: B has research grant support from B. Braun Medical, Becton-Dickinson, Teleflex, Adhezion, Medline Industries, and Access Vascular. AB is a paid consultant for B. Braun Medical, Teleflex, and Interad Medical.

### Ethical approval

The investigation was approved by the Beaumont Institutional Review Board.

### Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Research was funded via and educational grant for research by B. Braun Medical. The funder had no role in the study design, subject enrollment, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all study data in the study and had final responsibility for the decision to submit for publication.

### ORCID iD

Amit Bahl https://orcid.org/0000-0001-9495-1293

### Supplemental material

Supplemental material for this article is available online.

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