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ORIGINAL ARTICLE

Development of a paediatric central venous access device database: A retrospective cohort study of practice evolution and risk factors for device failure

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Aim: To describe practice evolution, complications and risk factors for multiple insertion attempts and device failure in paediatric central venous access devices (CVADs).

Methods: A paediatric retrospective cohort study using prospectively collected data from CVAD database 2012–2014. Data included were patient (i.e. age, condition), insertion (i.e. indication, device, technique) and removal (complications, dwell). Descriptive statistics and incidence rates were calculated per calendar year and compared. Risk factors for multiple insertion attempts and failure were explored with logistic regression and cox regression, respectively.

Results: A total of 1308 CVADs were observed over 273 467 catheter-days in 863 patients. Multiple insertion attempts remained static (14%) and significantly associated with non-haematological oncology (odds ratio 2.19; 95% confidence interval (CI) 1.08–4.43), respiratory (3.71; 1.10–12.5), gastroenterology (4.18; 1.66–10.5) and other (difficult intravenous access) (2.74; 1.27–5.92). CVAD failure decreased from 35% (2012) to 25% (2014), incidence rate from 1.50 (95% CI 1.25–1.80) to 1.28 (1.06–1.54) per 1000 catheter-days. Peripherally inserted CVAD failure was significantly associated with lower body weight (per kilogram decrease, hazard ratio (HR) 1.02; 95% CI 1.00–1.03), cephalic vein (1.62; 1.05–2.62), difficult access (1.92; 1.02–3.73), suboptimal tip placement (1.69; 1.06–2.69) and gastroenterology diagnosis (2.27; 1.05–4.90). Centrally placed CVAD failure was significantly associated with younger age (per year, HR 1.04; 95% CI 1.00–1.07), tunnelled device (3.38; 2.41–4.73) and gastroenterology diagnosis (1.70; 1.06–2.73).

Conclusions: While advancement in CVAD practices improved overall CVAD insertion and failure outcomes, further improvements and innovation are necessary to ensure improved vessel health and preservation for children requiring CVAD.

Key words: central venous catheter; clinical registry; paediatrics; peripherally inserted central catheter; quality care; vascular access.

What is already known on this topic

1 One in four central venous access devices (CVADs) fail.
2 Vessel insufficiency threatens the survival of vascular-access-dependent children.
3 CVAD complications and failure are often preventable with a coordinated, multifactorial and interdisciplinary approach to improve device insertion and care.

What this paper adds

1 Interdisciplinary practice changes are challenging; however, this study demonstrates that CVAD complications and failure are preventable, but require a multifactorial (surveillance, education, uptake of new technology) and interdisciplinary (insertion, vascular access specialist, infectious diseases) approach to achieve this.
2 The shift to ultrasound-guided vascular access involves a challenging learning curve, which might initially be met with resistance from clinicians previously expert at their preferred technique due to the associated risk of failed insertion attempts and increased complications associated with learning a new technique.
3 Analysis of a large paediatric vascular access data set for clinicians to benchmark outcomes and evaluate similar quality initiatives and improve practice.

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Approximately 25% of hospitalised children receive a central venous access device (CVAD), for treatment administration.[1] Insertion of CVADs can be challenging, and 25% of CVADs fail prior to the completion of therapy,[2] due to mechanical, infectious and vascular complications.[1,3] The prevalence of complications such as central line-associated blood stream infection (CLABSI; 1.63 per 1000 catheter-days) and device occlusion or blockage (e.g. peripherally inserted central catheters (PICCs); 2.2 per 1000 catheter-days) are especially concerning.[2] The economic costs of CVAD failure and complications are multifaceted, having both direct (need for replacement, depletion of access sites, therapy delays), and indirect health-care costs (staff and resource utilisation). The Healthcare Cost and Utilization Project data estimate a mean increase in costs of US$50 621 per device failure.[4,5] The patient costs of CVAD failure include multiple and painful reinsertion procedures, extended inpatient stays and long-term vessel insufficiency.[6]

There is growing body of evidence on which we should base our CVAD practices to reduce failure rates and associated patient harm. This includes the incorporation of enhanced decontamination products (including chlorhexidine gluconate (CHG)),[7] novel catheter materials and designs,[8] ultrasound guidance (USG),[9] interventional radiology techniques[10] and alternative sites.[10] Advances in medical and surgical care have meant children are surviving previously fatal illnesses, but with long-term health-care needs, consequently maintaining vessel health into adulthood is increasingly important.[11] Increased survivorship and a growing interest in vessel health and preservation has driven an increased focus on interventions, which reduce catheter failure and complications, such as catheter lock solutions[12] and catheter salvage,[13,14] rather than replacement of catheters affected by infection, occlusion and thrombosis.[10,14] Despite this renewed focus, little is known about how well these CVAD practices have been implemented into practice, and their impact on vessel health and preservation in the acutely unwell child.

Internationally there are few data platforms to benchmark and monitor CVAD practice. With the exception of bloodstream infection (BSI)[15,16] few CVAD outcomes are routinely reported to external organisations. This means clinically significant outcomes such as occlusion are potentially under-recognised and lack benchmarking across health services. Consequently clinicians, patients and organisations lack data to transform patient care and optimise outcomes.[16] In recognition of this gap, in 2012 we established a local CVAD quality database within a tertiary referral paediatric hospital. Database variables included patient, device and insertion variables, as well as complication data, for all children requiring a CVAD. The primary objective of this study was to describe changes in CVAD insertion practices, and examine change in failure (incidence and rate) over time. A secondary objective was to identify modifiable and non-modifiable risk factors for multiple insertion attempts and device failure. These data may support practice changes to mitigate modifiable risk factors for CVAD failure.

Methods

Study design

A retrospective cohort study was undertaken, using data prospectively entered into a paediatric hospital vascular access database between calendar years 2012 and 2014.

Setting and population

The database was established in 2012 in a tertiary paediatric facility (Royal Children's Hospital, Brisbane, Australia), which provided a full suite of paediatric inpatient and outpatient services (excluding cardiothoracic surgery and neonatal intensive care) to children and adolescents from birth to 18 years. Any child (0–18 years) who attended the operating theatre suite for insertion of a CVAD (i.e. PICCs, centrally inserted CVADs) was included in the database. CVADs inserted outside the operating theatre (e.g. emergency department, intensive care unit (ICU)) were excluded as the database included only insertions in the operating suite. The study received ethical approval from the Children's Health, Queensland, Human Research Ethics Committee (HREC/16/RCH/67).

Data collection and measures

From January 2012 to November 2014, CVAD-related data were collected and entered into a standard data collection form by the inserting clinician. Insertion data were collected on insertion. Complication and removal data were collected during routine clinical care by a vascular access specialist (VAS). Clinical staff from subspecialty paediatric wards contributed data to the master database with data linked with Microsoft Excel spreadsheets (Microsoft Corporation, Washington, DC, USA).

Database variables were developed based on outcomes and quality measures previously reported in quality improvement initiatives,[17,18] and included patient demographic and clinical variables, CVAD insertion, complication and removal data. Variables were reviewed by multidisciplinary stakeholders, including VAS, surgeons and infectious diseases, and were included in the final data set if they were: (i) known to be associated with the outcome and (ii) feasible to collect.[16] Practices that contradicted current evidence were identified by the VAS, and attempts to influence practice change were made through a continuous cycle of feedback. CVAD complication and failure outcomes were defined in line with best practice and current evidence as per Table S1 (Supporting Information).[16,19] The confirmation of venous thrombosis was made by an independent radiologist using standard department protocols when a symptomatic patient was referred for vascular imaging. Clinical staff obtained blood and CVAD tip cultures on suspicion of infection, as per standard hospital and pathology protocols.[19] Diagnosis of CLABSI and CVAD-related BSI was made by an independent infectious diseases specialist, using the definition recommended at the time.[20,21]

Statistical analysis

Data were exported to Stata 14 (StataCorp; LLC, College Station, TX, USA) for linkage and statistical analysis. Data cleaning was performed in Excel and Stata. Lost-to-follow-up and censored data (device removed for reasons other than failure) were marked in Stata syntax as required. Missing data were not imputed. Participant demographic and clinical characteristics over 12-month time periods were presented using descriptive statistics. The changes in clinical and device characteristics, over time were tested with χ^2 tests. Incidence rates for device failure were calculated, and Kaplan–Meier survival curves were generated. PICCs

and other centrally placed CVADs were analysed separately to allow for natural variation between the two procedures. Infrequent catheter insertions such as non-tunnelled CVC and haemodialysis catheters were excluded from regression analyses. Covariates (independent variables) were re-categorised and dummy-coded as necessary. Covariates were selected and entered in multivariable models at univariable $P < 0.20$ level. Multivariable models were generated manually, by stepwise removing covariates at $P \geq 0.05$ (backward method). The final model was confirmed by re-entering the removed covariates one-by-one (forward method). The proportional hazards assumption was tested, and the Nelson-Aalen estimates were graphed by the Cox-Snell residuals (graph not presented). The results of hypothesis testing and regression analyses were compared with the results of the same analyses on a reduced data set (first insertion per patient). Results of these sensitivity analyses were reported only if the polarity or statistical significance was found to be affected by including multiple devices per patient in the main analysis. Statistical significance was declared at $P < 0.05$ (two-sided).

Results

Patient and device characteristics

There were 1308 CVADs, in 863 patients, involving 273 467 catheter-days over 35 months. Table 1 describes patient characteristics.

Temporal changes in CVAD insertion practices

There was no significant increase in the use of USG vessel puncture over the study period; 53% in 2012 to 58% in 2014 ($P = 0.133$). The number of attempts required to successfully insert CVADs did not change, 14–15% of patients continued to require multiple insertion attempts. PICCs were the most commonly inserted device across the study period, increasing from 34 to 47% ($P = 0.002$), while tunnelled CVAD use decreased from 32 to 20%. The use of single lumen catheters increased from 60 to 72%, while the use of double lumen catheters decreased from 33 to 21% ($P < 0.001$). Overall, 2% CHG in 70% alcohol was the most commonly used skin preparation.

Risk factors associated with multiple insertion attempts

As described in Table 2, the diagnostic groups; non-haematological oncology (odds ratio (OR) 2.19; 95% confidence interval (CI) 1.08–4.43), respiratory (OR 3.71; 95% CI 1.10–12.5), gastroenterology (OR 4.18; 95% CI 1.66–10.5) and other (e.g. difficult intravenous access) (OR 2.74; 95% CI 1.27–5.92) were significantly associated with an increased risk of multiple insertion attempts in comparison to haematological malignancy for centrally placed devices. For PICCs, use of the cephalic vein (OR 1.90; 95% CI 1.12–3.22) and other non-specified vein locations (OR 2.6; 95% CI 1.38–5.24) were associated with a greater risk for multiple insertion attempts. Additionally, dual lumen PICCs had an increased risk for multiple insertion attempts compared with single lumen devices (OR 0.21; 95% CI 0.06–0.68).

Temporal trends in CVAD complications and failure

Table 3 describes device outcomes by insertion period. Overall 27% of CVADs were removed due to device failure, which decreased over time from 35 to 25% ($P < 0.001$; χ^2 test). Occlusion and suspicion of infection were consistently the most common causes of device failure, where reasons for failure were recorded. Catheter removal due to suspected infection halved over the study from 11 to 5% ($P = 0.006$; χ^2 test). Catheters requiring salvage due to infection also reduced from 12 to 5% ($P = 0.010$; χ^2 test).

Associations with PICC failure

As per Table 4, multivariable Cox regression identified several patient-, provider- and device-related factors associated with increased PICC failure. Lower body weight had a significantly higher risk of PICC failure (per kilogram, hazard ratio (HR) 1.02; 95% CI 1.00–1.03; inverted for consistency). Non-modifiable risk factors such as a gastroenterology diagnosis had a twofold increase in failure (HR 2.27; 95% CI 1.05–4.90). Catheter tip outside the cavo-atrial junction (CAJ) was associated with increased risk for PICC failure (HR 1.69; 95% CI 1.06–2.69). Venepuncture of the cephalic vein, compared to basilic, was associated with increased PICC failure (HR 1.62; 95% CI 1.05–2.62). Children requiring PICC insertion due to difficult intravenous access, compared to those without difficult access, had higher risk of PICC failure (HR 1.92; 95% CI 1.02–3.73). The Kaplan–Meier curve (Fig. 1a) demonstrates an increased rate of PICC failure in the latter years of the study.

Associations with centrally inserted catheter failure

The association between device failure, and patient and device insertion characteristics are described as per Table S2 (Supporting Information). Tunnelled cuffed CVAD were more than three times more likely to fail compared to totally implanted venous port devices (TIVPDs) (HR 3.38; 95% CI 2.41–4.73; $P < 0.001$). For every 1-year increase in age, a significant reduction in risk of device failure was evident (HR 0.97; 95% CI 0.90–1.00). A gastroenterology diagnosis, when compared to haematology, non-cancer, was positively associated with device failure (HR 1.70; 95% CI 1.06–2.73). The Kaplan–Meier curve (Fig. 1b) demonstrates a reduction in failure over time.

Discussion

This study describes significant changes in CVAD insertion practices, and the associated CVAD insertion and failure over time in a paediatric population at a single children's hospital. Significant changes in use of, skin antisepsis and judicious use of multilumen catheters at insertion were seen. A reduction in CVAD failure, from 35 to 24%, was evident (average 27%); however, overall CVAD failure remains unacceptably high, and predominantly related to occlusion or suspected infection. Over time, PICC failure increased which might be related to the increased acuity of patients receiving PICC, as evidenced by the reduction in centrally inserted CVADs. Reasons for failure were poorly

Table 1 Patient and device characteristics†

	n	2012, *n* (%)	2013, *n* (%)	2014, *n* (%)
Number of patients	863	209	317	337
Age group at last insertion, years	863			
0–4		14 (7)	35 (11)	40 (12)
5–9		86 (41)	111 (35)	123 (36)
10–14		42 (20)	56 (18)	66 (20)
>15		14 (7)	21 (7)	24 (7)
Males	857	117 (56)	189 (60)	197 (59)
Weight at last insertion, kg, median (IQR)	804	19.0 (23.9)	20.0 (19.0)	18.0 (18.9)
Number of insertions	1308	349	494	465
Multiple insertion attempts	1286	49 (14)	68 (14)	67 (15)
Vein location	1284			
Internal jugular		136 (39)	180 (37)	145 (32)
Basilic		76 (22)	118 (24)	118 (26)
Subclavian		76 (22)	84 (17)	72 (16)
Cephalic		22 (6)	43 (9)	51 (11)
Other		35 (10)	63 (13)	65 (14)
Insertion technique	1279			
Ultrasound		183 (53)	283 (58)	261 (58)
Blind puncture		70 (20)	106 (22)	80 (18)
Surgical cut down		53 (15)	53 (11)	65 (15)
Rewire		24 (7)	26 (5)	24 (5)
Other		15 (4)	19 (4)	17 (4)
Catheter type and class	1290			
Peripherally inserted central catheter		120 (34)	202 (41)	213 (47)
Totally implanted venous port device		85 (24)	122 (25)	120 (27)
Tunnelled CVC		112 (32)	109 (22)	90 (20)
Non-tunnelled CVC (Other)		11 (3)	38 (8)	17 (4)
Other		20 (6)	19 (4)	12 (3)
Insertion team	1306			
Surgical		199 (57)	240 (49)	207 (45)
Anaesthetic		143 (41)	251 (51)	251 (54)
Other		6 (2)	3 (1)	6 (1)
Diagnosis	1290			
Haematology (Malignancy)		76 (22)	109 (22)	129 (28)
Oncology		86 (25)	114 (23)	90 (19)
Respiratory		50 (15)	67 (14)	73 (16)
Infection		29 (9)	70 (14)	56 (12)
Gastroenterology		42 (12)	29 (6)	26 (6)
Other		55 (16)	100 (20)	89 (19)
Number of lumens	1279			
One		205 (60)	322 (66)	326 (72)
Two		113 (33)	126 (26)	93 (21)
Three		22 (6)	37 (8)	31 (7)
Four		0 (0)	2 (0)	2 (<1)
Skin preparation	1279			
2% CHG in 70% alcohol		148 (43)	252 (52)	230 (51)
10% Povidone iodine in aqueous		193 (57)	26 (5)	183 (41)
10% Povidone iodine in alcohol		0 (0)	209 (43)	27 (6)
Other		0 (0)	0 (0)	11 (2)
Tip placement	1282			
Cavo-atrial junction		193 (56)	296 (61)	102 (23)
Superior vena cava		119 (35)	147 (30)	319 (71)
Other		32 (9)	44 (9)	30 (7)
Indication: Antibiotics	1280	98 (29)	165 (34)	141 (32)
Indication: Blood products	1280	9 (3)	22 (4)	0 (0)

(*Continues*)

Table 1 (Continued)

	n	2012, *n* (%)	2013, *n* (%)	2014, *n* (%)
Indication: Chemotherapy	1280	162 (47)	224 (46)	207 (47)
Indication: Dialysis	1280	9 (3)	5 (1)	3 (1)
Indication: Difficult access	1280	10 (3)	51 (10)	25 (6)
Indication: Infusion	1280	15 (4)	34 (7)	41 (9)
Indication: Total parenteral nutrition	1280	54 (16)	50 (10)	38 (9)
Indication: Other(s)	1280	21 (6)	27 (5)	24 (5)

†Column frequencies (%) were calculated using the number of non-missing observations as denominator. CHG, chlorhexidine; CVC, central venous catheter; IQR, interquartile range.

recorded in the database ('other' being the default option), so more comment cannot be made regarding reasons for failure. The data set included multiple (up to 12) outcomes per participant, which did not appear to have influenced the findings of this study in a meaningful way.

As evident in previous international literature,[2] the risk of CVAD complication was greatest for younger children with complex, chronic pathology such as a gastroenterology diagnosis for PICC (HR 2.27; 95% CI 1.05–4.90) and for centrally inserted central catheter (HR 1.70; 95% CI 1.06–2.73), respectively. Innovations to reduce complications and improve techniques of catheter salvage in this vulnerable patient cohort, rather than removal and replacement, are urgently required to allow preservation of alternative access sites for future use.[22] In 2014 the hospital introduced taurolidine citrate for children with recurrent CVAD BSI. Taurolidine citrate was indicated for patients with a history of more than one CABSI, residing within the hospital and did not have any medication infusion for at least 6 h. Longterm sequelae for CVAD failure and complications for children with chronic, vascular-access-dependent conditions are severe. In its

Table 2 Associations between multiple insertion attempts and patient/device insertion characteristics (logistic regression)

	Central (*n* = 744), OR (95% CI)		Peripheral (*n* = 531), OR (95% CI)	
	Univariable	Multivariable	Univariable	Multivariable
Age (1 year increase)	0.95 (0.90–1.01)†	*	0.98 (0.93–1.02)	†
Female (Reference: Male)	0.96 (0.57–1.59)	†	1.37 (0.90–2.08)†	*
Vein location				
Internal jugular	Reference	†	NA	†
Subclavian	0.95 (0.55–1.67)	†	NA	†
Femoral	0.88 (0.20–3.87)	†	NA	†
External jugular	1.79 (0.50–6.35)	†	NA	†
Basilic	NA	†	Reference	Reference
Cephalic	NA	†	1.83 (1.09–3.09)‡	1.90 (1.12–3.22)‡
Brachial	NA	†	1.61 (0.79–3.30)†	1.57 (0.76–3.23)
Other	NA	†	2.70 (1.40–5.23)‡	2.69 (1.38–5.24)‡
Ins. technique (Reference: Ultrasound)				
Blind puncture	1.03 (0.54–1.96)	*	1.38 (0.63–3.06)	†
Surgical cut down	1.89 (1.03–3.46)‡	*	NA	†
Ins. team: anaesthetics (Reference: Surgical)	0.68 (0.30–1.52)	†	1.87 (0.23–15.4)	†
Diagnosis (Reference: Haematological malignancy)				
Oncology	2.19 (1.08–4.43)‡	2.19 (1.08–4.43)‡	0.55 (0.17–1.84)	‡
Respiratory	3.71 (1.10–12.5)‡	3.71 (1.10–12.5)‡	1.29 (0.67–2.48)	*
Infection	NA	NA	0.59 (0.29–1.23)†	*
Gastroenterology	4.18 (1.66–10.5)‡	4.18 (1.66–10.5)‡	0.70 (0.26–1.88)	*
Other	2.74 (1.27–5.92)‡	2.74 (1.27–5.92)‡	0.61 (0.28–1.33)	*
Number of lumens (Reference: One)				
Two	0.99 (0.59–1.67)	*	0.33 (0.13–0.85)‡	0.21 (0.06–0.68)‡
Three	0.42 (0.15–1.21)†	*	NA	NA

*Statistically significant at $P < 0.20$; **Statistically significant at $P < 0.05$. †Not eligible for multivariable analysis at $P \geq 0.20$. ‡Excluded from the multivariable model at $P \geq 0.05$. CI, confidence interval; ins, insertion; NA, not applicable or cannot be calculated, OR, odds ratio; Reference, reference category.

Table 3 Device outcomes

	n	2012, *n* (%)	2013, *n* (%)	2014, *n* (%)
Number of removals	1308	349	494	465
Reason for removal†	1296			
End of treatment		212 (63)	339 (69)	295 (63)
Occlusion (including fibrin sheath)		31 (9)	36 (7)	44 (9)
Still *in situ*		7 (2)	41 (8)	56 (12)
Suspected infection		37 (11)	41 (8)	22 (5)
Other		50 (15)	37 (7)	48 (10)
Failure (at removal): All groups†‡	1296	118 (35)	114 (23)	114 (25)
Failure (at removal): Tunnelled/Implanted†‡	626	87 (47)	63 (27)	51 (24)
Failure (at removal): PICC†‡	535	19 (16)	41 (20)	54 (25)
Failure (at removal): Other types†‡	135	12 (38)	10 (16)	9 (21)
Dwell time (Total), device-days	12 888	78 030	109 322	86 115
Dwell time, days, median (IQR): All groups	12 888	64 (14–273)	33 (10–278)	26 (10–261)
Dwell time, days, median (IQR): Tunnelled/Implanted	623	224 (98–467)	294 (131–819)	305 (116–674)
Dwell time, days, median (IQR): PICC	533	14 (9–26)	13 (8–22)	12 (7–17)
Dwell time, days, median (IQR): Other	132	7 (2–30)	5 (2–8)	7 (1–17)
IR of failure at removal§¶	339	1.50 (1.25–1.80)	1.02 (0.85–1.23)	1.28 (1.06–1.54)
Devices with any linked (non-removal) complications†	1010	226	429	355
Devices with CLABSI†	1010	28 (12)	41 (10)	19 (5)
Devices with medically significant bacteria†	1010	14 (6)	17 (4)	5 (1)
Devices with breakage†	1010	16 (7)	16 (4)	4 (1)
Devices with occlusion†	1010	14 (6)	6 (2)	12 (3)
Devices with thrombosis†	1010	5 (2)	7 (2)	3 (1)
Devices with pulled out†	1010	4 (2)	8 (2)	0 (0)
Devices with other†	1010	4 (2)	8 (2)	6 (2)

†Frequencies and column percentages shown. ‡Coded as 1 for occlusion, suspected infection, dislodgement, breakage, thrombosis or other, and 0 for end of treatment and censored events. §Per 1000 device-days. ¶Including 95% confidence interval. CLABSI, central line associated blood stream infection; IQR, interquartile range; IR, incidence rate; PICC, peripherally inserted central catheter.

most extreme scenario, loss of central venous catheter or absence of an accessible central venous pathway can mean loss of life.[23]

Multifactorial influences are likely responsible for the 50% reduction in catheter removal due to suspected infection, as until 2014, catheter removal to treat CLABSI was considered necessary. Now the microorganism responsible for CLABSI influences the decision to remove the catheter or attempt catheter salvage with a prolonged course of empiric and direct antibiotic therapy, supplemented by catheter lock.[24,25] The Infectious Disease Society of America guidelines recommend long-term catheters be removed from patients with CLABSI associated with severe sepsis; suppurative thrombophlebitis; endocarditis; CLABSI that continues despite 72 h of targeted antimicrobial therapy; or infections due to *Staphylococcus aureus*, *Pseudomonas aeruginosa*, fungi or *Mycobacteria* spp.[25] Catheter salvage is crucial for preservation of long-term venous access in paediatric patients with complex and chronic disease.[26]

For the past two decades, CLABSI prevention has received increased attention with several quality improvement studies demonstrating how simple and practical interventions markedly reduce infection-related complications.[27] A reduction in CLABSI from 12 to 5% ($P = 0.010$; χ^2 test) was observed from the start of this study in 2012 to its conclusion in 2014. Current efforts to maintain low CVAD-related BSI include surveillance and CLABSI benchmark targets.[21] Much of the 2014 CLABSI reduction may be credited to the introduction of Taurolock (TauroPharm GmbH,Waldbüttelbrunn, Germany) (taurolidine 1.34% with citrate 4%), a catheter lock solution introduced in that year for patients at high CLABSI risk.[12]

Insertion practices naturally evolved over the course of the study, including the preferential use of 2% CHG in 70% alcohol compared to the traditional 10% aqueous povidone iodine for skin disinfectant. The Centers for Disease Control and Prevention guidelines[20] prompted the initial practice change, which were actioned by the VASs and disseminated to the hospital departments through education sessions. The initial delay in practitioner uptake may have been related to the quality of the evidence supporting CHG as a superior skin antisepsis.[28] However, a recent trial by Mimoz *et al*.[7] demonstrated CHG in alcohol significantly reduced the incidence of catheter-related infections (0.28 vs. 1.77 per 1000 catheter-days), in comparison to povidone iodine in alcohol, in adult ICUs. To increase generalisability, further research comparing the use of antiseptic solutions prior to CVAD insertions, in adults and children in non-ICU settings is needed.

The use of real-time ultrasound to gain vessel access for CVAD insertion did not increase significantly over the study, and there was no reduction in the number of attempts to successful vein cannulation. Internationally, ultrasound is considered gold standard technique to guide vessel puncture, compared to traditional

Table 4 Associations between peripherally inserted central catheter failure and patient/device insertion characteristics (Cox regression)

	Hazard ratio (95% CI)	
	Univariable	Multivariable (n = 480)
Age (1 year increase)	0.94 (0.91–0.98)†	‡
Female (Reference: Male)	0.75 (0.51–1.10)†	§
Weight (1 kg increase)	0.98 (0.97–0.99)†	0.98 (0.97–1.00)¶
Multiple insertion attempts (Reference: No)	1.57 (1.00–2.47)†	§
Vein location (Reference: Basillic)†		
Cephalic	1.40 (0.88–2.24)	1.62 (1.05–2.62)¶
Brachial	0.68 (0.27–1.72)	0.79 (0.31–2.00)
Other	1.69 (1.00–2.85)	1.39 (0.81–2.39)
Insertion: Blind puncture (Reference: US)	1.10 (0.51–2.39)	††
Diagnosis (Reference: Respiratory)†		
Infection	1.88 (0.93–3.81)	1.66 (0.79–3.48)
Haematology	1.73 (0.83–3.61)	1.71 (0.80–3.62)
Gastroenterology	2.24 (1.09–4.58)	2.27 (1.05–4.90)¶
Oncology	2.37 (0.98–5.73)	2.11 (0.85–5.20)
Other	2.94 (1.53–5.62)	1.88 (0.89–4.01)
Number of lumens: Two (Reference: One)	0.81 (0.46–1.42)	††
Tip placement: Other (Reference: Cavo-atrial junction)	1.50 (0.98–2.31)†	1.69 (1.06–2.69)¶
Indication (Reference: No)		
Antibiotics	0.68 (0.45–1.03)†	§
Difficult access	2.15 (1.26–3.69)†	1.92 (1.02–3.73)¶
Infusion	2.04 (1.06–3.92)†	§
Total parenteral nutrition	1.41 (0.92–2.19)†	§
Other‡‡	1.06 (0.68–1.66)	§

†LR test statistically significant at $P < 0.20$. ‡Ineligible for multivariable analysis due to correlation with another covariate. §Dropped from multivariable model at Wald test $P \geq 0.05$. ¶Statistically significant at Wald test $P < 0.05$; ref = reference category. ††Ineligible for multivariable analysis at LR test $P \geq 0.20$. ‡‡Includes apheresis, blood products, chemotherapy, dialysis, inotropes and other. CI, confidence interval; LR, likelihood ratio; US, ultrasound.

landmark and surgical cut-down techniques.[9,29] First attempt success (OR 2.09; 95% CI 1.26–3.46; $P \leq 0.001$), reduced procedural complications (OR 0.47; 95% CI 0.24–0.91; $P = 0.025$)[30] and zero incidence of arterial puncture during CVAD insertion[31] have been reported when using USG, in comparison to blind puncture. Specific patient groups, such as centrally inserted CVADs with an oncology, respiratory and gastroenterology diagnosis, were associated with at least twofold greater odds of requiring multiple insertion attempts. Reasons for the relatively low rate of USG are not clear. This was an observational study, and the majority of inserters were already on the plateau of their learning curve with their preferred technique. This clinician learning curve can be considerable and variable, as these clinicians are often highly skilled in their previous insertion technique, and significant time and practice is necessary for USG mastery.[32,33] It may be that these experienced clinicians are unwilling to learn a new technique, on the basis it may expose patients to more risk during the learning curve.[33]

CVAD failure is often preventable, as evident by improved CVAD insertion[34] and management[35] practices that have resulted in a reduction in the proportion of failed devices.[9,35,36] We observed several modifiable risk factors for CVAD failure, including catheter tip placement and vessel accessed. Like previous studies, we found a significant increase in catheter failure when the catheter tip was positioned outside the CAJ. A study of 2574 PICCs found all non-central PICC tip locations including midline (incidence rate ratios 4.59; 95% CI 3.69–5.69), midclavicular (2.15; 1.54–2.98) and other (3.26; 1.72–6.15), compared with central tip location, were associated with an increased risk of complications.[37] In children, careful attention to catheter tip position is vital to ensure the CVAD remains functional and minimise the number of catheter replacements required during their lifetime.

When the cephalic vein was accessed to insert a PICC, device failure increased significantly compared to placement via the basilic vein. The preferential use of the cephalic vein is likely due to its superficial location on the lateral side of the upper arm, providing an easy target when ultrasound technology was not used.[38] However, we observed with a small increase in the uptake and mastery of USG venepuncture, a conservative increase in preferential puncture of the basilic vein.

Numerous non-modifiable risk factors were observed, which significantly impacted CVAD failure, including age, weight and diagnosis. These findings align with existing studies which demonstrate increased CVAD complications in certain diagnostic groups such as oncology and haematology, catheter types (PICCs) and subsequent catheters.[1] Other non-modifiable risk factors such as tunnelled cuffed CVADs, compared to TIVPD, increase the risk of catheter failure. Insertion of TIVPD is not recommended or practical for children who require continuous infusions such as parenteral nutrition or multiple infusions.[39] This demonstrates the gap in current strategies for the complex vascular access needs of paediatric chronic disease sufferers. Although reducing vessel trauma by improving first attempt insertion success is an important focus of current vascular access studies,[30] further interdisciplinary, co-ordinated approaches to CVAD insertion and care are needed to implement and evaluate additional initiatives for patients with lifelong vascular access needs to maximise CVAD longevity and vessel patency.

Implications for clinical practice

These findings have important implications for clinicians. As previously described, CVAD failure is high and this has significant implications for the child, their family and the health service. Interventions that might reduce the risk of device failure include: use of ultrasound to insert catheters, ensuring catheter tip is located at CAJ at insertion, use of 70% chlorhexidine and alcohol skin antisepsis and taurolidine citrate catheter lock solution for patients at risk of recurrent CABSI. Additionally, this study substantiates positive results of Corkum *et al*.[26] and Zanwar *et al*.[40] that advocate attempted catheter salvage in select patients rather than immediate removal, as well as the use of catheter lock solution in high-risk patients.[12] Additionally, although successful initiation of practice change was slow, over time small improvement in patient outcomes were observed and it is hoped that these

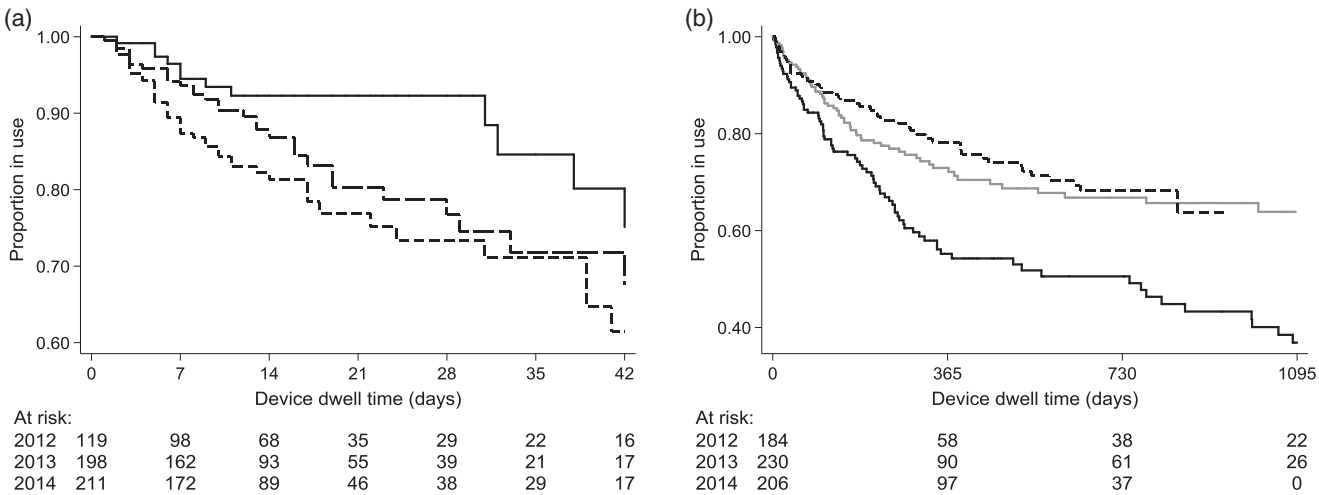

Fig. 1 (a) Kaplan–Meier curve of peripherally inserted central catheter failure. (——), 2012; (– – –), 2013; (-----), 2014. (b) Kaplan–Meier curve of centrally inserted device failure. (——), 2012; (——), 2013; (-----), 2014.

practice changes will continue, and so too will the trajectory of improved patient outcomes. Furthermore, it is hoped that investment in USG training and education for clinicians will improve clinically necessary skills. Large efficacy trials to confirm and further validate evidence-based practice are necessary.

Strengths and limitations

This study has some limitations. The data came from a single tertiary paediatric facility; thus, findings may not be generalisable. CVADs inserted in intensive care or the emergency department were not included, and all catheters were inserted in the operating suite. Catheter tip placement was confirmed using mobile fluoroscopy at procedure, which might impact the accuracy of catheter tip location. However, this study has many strengths including its pragmatic design and data integrity. Vascular access is often compartmentalised into inserters, and practitioners who maintain them, making practice change difficult. Vascular access experts collected the data, verifying the consistent use of standardised definitions and the assessment of device outcomes (e.g. CLABSI, thrombosis) by experts.

Conclusions

These findings add to the knowledge of risk factors for catheter failure among paediatric patients. While CVAD insertion practice is improving, and rates of CVAD failure are gradually declining, device failure remains problematic and unacceptably high. A paradigm shift towards adoption of evidence-based insertion and management practices to preserve the vessels of these vulnerable patients is essential, to ensure children enter adulthood with an intact vasculature. To further improve patient outcomes, CVAD insertion, management, data collection and data sharing must continue to evolve to maintain pace with new evidence.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Table S1. Definitions of central venous access device complications.
Table S2. Associations between centrally inserted device failure and patient/device insertion characteristics (Cox regression).