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ORIGINAL ARTICLE

Prevention of occlusion of cEnTral lInes for children with cancer: An implementation study

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Aim: Central venous access devices (CVADs) are vital medical devices to support the treatment of paediatric cancer; however, device occlusion is common, which disrupts treatment. This study aimed to improve the identification and management of CVAD occlusions in children with cancer, as well as to identify the demographic, clinical and device characteristics associated with increased risk for CVAD occlusion.

Methods: A pre–post-implementation study was conducted at a metropolitan paediatric oncology facility in Australia, using the Theoretical Domains Framework. Patients with a CVAD for anti-cancer therapy were prospectively followed for occlusive events pre- and post- the implementation of clinical resources to support the identification and management of CVAD occlusive events. CVAD occlusion and management data were collected and compared pre- and post-implementation. Risk factors for CVAD occlusion were described by mixed-effects Poisson regression and incident rate ratios (IRR).

Results: A total of 133 CVADs were inserted into 131 patients for a total of 6784 catheter days. The incidence of CVAD-related occlusion pre-implementation was 59.7 (95% confidence interval (CI) 51.4–69.0, per 1000 catheter days); compared to 31.6 (95% CI 26.4–37.6); $P < 0.01$) post-implementation of clinical resources. In multivariate models, other than post-implementation phases (IRR 0.51 (95% CI 0.32–0.81)), only neutropaenia significantly increased the risk of CVAD occlusion (IRR 2.14 (95% CI 1.15–3.97)).

Conclusion: CVAD occlusions in paediatric oncology are common. The development and implementation of CVAD occlusion resources to guide the identification and management of occlusive episodes led to a significant decrease in occlusive events.

Key words: catheterization, peripheral; central venous catheter; implementation science; neoplasm; oncology nursing; venous thrombosis.

What is already known on this topic

1 Occlusions of central venous access devices (CVADs) are common, costly to treat and cause a significant disruption to essential treatment.
2 Clinical practice guidelines are available to support clinical decision-making, to prevent and treat CVAD occlusion
3 Daily assessment of device patency is a core component of CVAD care and maintenance.

What this paper adds

1 Occlusion of CVADs in paediatric oncology is more common than previously described.
2 Implementation of standardised assessment and management resources for CVAD occlusion can significantly reduce their frequency.

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Central venous access devices (CVADs) are essential for the short- and long-term care provision of ~50 000 Australian children annually.[1–3] Almost all children with cancer require the insertion of a CVAD to enable the safe administration of anticancer drugs, supportive therapies, and for blood sampling. Despite their ubiquity and necessity, one in three CVADs used during treatment for paediatric cancer is associated with a severe complication and subsequent device failure; disrupting essential treatment.[4]

An Australian point prevalence audit brought to attention the burden of CVAD occlusion in paediatric health care, with 6% of CVADs ($n = 15$) becoming blocked in the previous 7 days.[1] CVAD occlusion (or blockage) varies in presentation, severity and sequelae.[5] Aspirate occlusion (i.e. an inability to aspirate blood) and injection occlusion (i.e. an inability to infuse) occur secondary to mechanical (e.g. needleless connector malfunction, catheter tip malposition), infusate (e.g. medication precipitation) or thrombotic causes (e.g. catheter tip or intraluminal thrombus).[4,5] Catheter occlusion often leads to breakage, if excessive flushing force is applied.[4] Complete CVAD failure can result, causing delays to necessary treatment and the need for device replacement, often under general anaesthetic.

Strategies exist to avoid preventable occlusion and breakage, and thereby reduce risk of catheter failure and treatment disruption. These include catheter tip positioning on device insertion, pulsatile flushing before and after medication administration and blood sampling, awareness when infusing viscous or multiple incompatible medications, and the use of flushing and lock solutions.[6] Treatment options in the management of occlusions, vary from inexpensive and minimally invasive (e.g. child positioning, change of needleless connectors, pulsatile flushing), to expensive and invasive (e.g. administration of thrombolytic agents, CVAD replacement). Early treatment of partial CVAD occlusion (e.g. aspiration occlusion only) can prevent complete CVAD occlusion and associated sequelae.[5] International clinical practice guidelines, including the Infusion Nurses Society,[6] are available to support clinical decision-making, to prevent and treat CVAD occlusion, however these have not been tailored to specific health services or populations. Unsurprisingly, a point prevalence audit indicated that the international clinical practice guidelines are inconsistently applied in Australian, paediatric clinical practice.[1]

Decisions by clinicians surrounding the identification and management of CVAD occlusion in paediatric cancer care are complex. Successful and sustained implementation of evidence-based practice in this setting requires behaviour change across disciplines. The Theoretical Domains Framework[7] and Behaviour Change Wheel[8] provide frameworks to both develop and implement health service interventions. They can be used to identify which components need to change for the target behaviours to occur, and provide guidance on the strategies that can be used to modify the behaviour.[8]

Via the "Prevention of Occlusion of cEnTral lInes for Children with cancer (POETIC)" implementation study, we aimed to improve the identification and management of CVAD occlusions in paediatric oncology, and thereby reduce CVAD occlusion frequency, severity and sequelae. We also sought to identify demographic, clinical and device risk factors associated with increased risk for CVAD occlusion, to target future innovations and improvement activities.

Methods

Study design

Between 2017 and 2018, a pre–post-implementation study was undertaken across Oncology departments (inpatient and outpatient) at the Queensland Children's Hospital. The Queensland Children's Hospital is the tertiary referral hospital for paediatrics in Queensland, Australia.

All stages of the implementation study were informed by the Theoretical Domains Framework[7] and Behaviour Change Wheel.[8] This included the methodological design, stakeholder engagement, intervention development and implementation strategies. Within pre-implementation phase (9 October 2017 to 9 January 2018; 3 months), CVAD clinical practice and occlusion incidence data were collected. The POETIC interventions were developed and implemented in partnership with key interdisciplinary stakeholders. Post-implementation (28 May 2018 to 27 August 2018; 3 months) involved replication of the CVAD clinical practice and occlusion incidence data collection.

Approval to undertake the project was provided by the Children's Health Queensland Human Research Ethics Committees (HREC/17/QCH/154 and 2017/581). The study has been reported in accordance with the Standards for Reporting Implementation Studies (StaRI) recommendations.[9]

Development of POETIC interventions and implementation

Stakeholder engagement

An interdisciplinary group of key stakeholders were involved throughout the project phases. They were identified prior to project commencement, including representation from oncology clinical areas, other relevant clinical specialties and researchers. The group involved nurse educators, managers, pharmacists, oncologists, vascular access specialists and implementation scientists.

The key stakeholder group met prior to study commencement, and guided pre-implementation data collection. After the pre-implementation period, the key stakeholder group then co-developed the POETIC interventions and implementation strategies. During a 1-day facilitated workshop (led by AJU, RE and TK), the stakeholder group reflected on the pre-implementation data, in comparison to international, and local, clinical practice guidelines.[6]

The group identified two core clinical practice resource gaps, relevant to the project: (i) Lack of routine and consistent CVAD patency assessment and documentation; and (ii) Inconsistent and uncoordinated interventions and escalation for occlusion management. After identifying these gaps, the group developed two resources, based on previous research and recommendations. These were: (i) CVAD patency daily assessment documentation, based on the catheter injection and aspiration (CINAS) classification[5]; and (ii) A CVAD Patency Flowchart, based on the Infusion Nurses Society guidelines.[6] After preliminary design during the facilitated workshop, the final design was reviewed by the key

stakeholder group for content and face validity using standard methods.[10] The final version (summarised below), was approved by the key stakeholder group, and relevant local health service committees.

CINAS CVAD daily assessment documentation

The key stakeholder group proposed that precise, common language was necessary to ensure consistency and accuracy of CVAD occlusion identification and care planning. Within pre-implementation data, catheter malfunctions were documented using diverse, inconsistent terms (e.g. sluggish vs. partially blocked), potentially causing misunderstanding. The CINAS classification system was developed by Goossens, De Waele[5] to describe catheter function, including an ability to discriminate between occlusion types (i.e. aspirate ability vs. injection ability). It involves ranking of aspirate (AS) and injection (IN) abilities as easy (i.e. non-hindered injection or blood aspiration; score = 1), difficult (i.e. tight injection or a diminished or unsteady flow while aspirating blood; score = 2), impossible (i.e. the inability to inject or aspirate blood; score = 3) or unknown (i.e. not assessed; score = U). While the CINAS system also incorporates a complex 16 combination coding system (e.g. IN1AS1), the summative results are displayed in a traffic light format (red = impossible; orange = difficult; easy = green; blue = unknown). The CINAS classification system was originally developed for totally implantable venous devices (TIVDs), and has high accuracy in the clinical environment (clinician vs. experts; 98.7%; 95% confidence interval (CI) 95.3–99.8).[5]

The key stakeholder group recommended the incorporation of the CINAS system within the patient's medical records, while also incorporating a visual pattern of daily assessment for each CVAD lumen. This visual display was based on the Children's Early Warning Tool resources, that were both familiar to the local clinicians, and demonstrated escalation in occlusion severity over time.[11] The bedside document (see Fig. 1) also provides room for centralised documentation of occlusion treatment procedures.

CVAD patency management flowchart

The key stakeholder group recommended providing a consistent, evidence-based process for escalation of CVAD occlusion management. Within the pre-implementation phase, the stakeholder group identified several inappropriate and inconsistent occlusion management procedures being used, including an acceptance of partially-occluded (i.e. difficult injection or aspiration) devices. Additionally, the group recognised cases where clinicians had continued with

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DO NOT WRITE IN THIS BINDING MARGIN

Children's Health Queensland Hospital and Health Service

Queensland Government

CINAS
(Catheter INjection ASpiration)
CVAD Daily Assessment
PLEASE USE A SEPARATE FORM FOR EACH DEVICE

IN3 / AS3	Impossible aspirate / injection See *Patency Flowchart* over page
IN2 / AS2	Difficult aspirate / injection See *Patency Flowchart* over page
IN1 / AS1	Easy aspirate and injection
U	Unknown / not assessed

(Affix patient identification label here)

URN:
Family Name:
Given Names:
Address:
Date of Birth: Sex: ☐ M ☐ F ☐ I

Injection (**IN**) Aspiration (**AS**) Unknown (**U**)	Lumen 1	Lumen 2	Lumen 3	Lumen 1	Lumen 2	Lumen 3	Lumen 1	Lumen 2	Lumen 3	Lumen 1	Lumen 2	Lumen 3	Lumen 1	Lumen 2	Lumen 3	Lumen 1	Lumen 2	Lumen 3	Lumen 1	Lumen 2	Lumen 3	Lumen 1	Lumen 2	Lumen 3	Lumen 1	Lumen 2	Lumen 3	Lumen 1	Lumen 2	Lumen 3
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Fig. 1 Catheter injection and aspiration (CINAS) central venous access device (CVAD) daily assessment documentation.

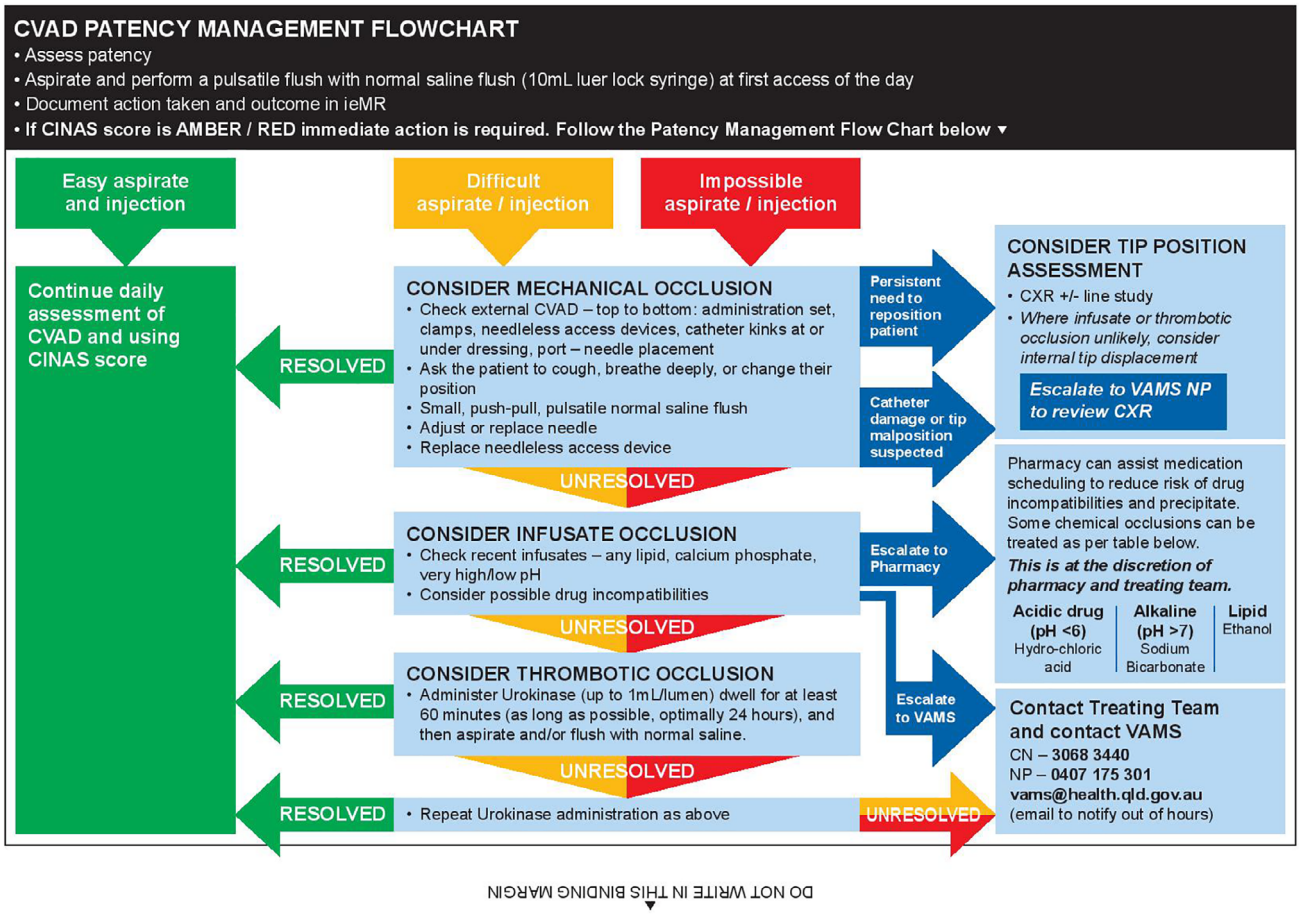

Fig. 2 Central venous access device (CVAD) patency management flowchart.

short-term patency restoration procedures (e.g. patient repositioning) for extended times, when escalation to investigatory assessment was warranted but rarely and inconsistently followed through.

There are three primary causes of CVAD occlusion: mechanical, infusate and thrombosis.[12] Each CVAD occlusion cause needs targeted treatment, with individual treatments varying in invasiveness and risk.[6] Using the Infusion Nurses Society guidelines, the key stakeholder group summarised the management pathway for the identification and treatment of CVAD occlusions, after CINAS assessment[6] (see Fig. 2). The CVAD Patency Management Flowchart incorporates reminders of CINAS assessment procedures, and then provides treatment recommendations, beginning with the least invasive treatment option. It also provides a clear escalation pathway to local experts (i.e. the treating team and Vascular Assessment and Management Service) for recurrent issues.

Implementation strategies

The Theoretical Domains Framework[7] and Behaviour Change Wheel[8] provided the framework for the implementation of the POETIC intervention. Educational strategies aimed to build upon clinicians pre-existing foundational knowledge and understanding of the overarching goal of uninterrupted treatment provision. These included the use of real, pre-implementation case studies as examples for potential improvement. Education regarding the interventions was delivered by education and project clinicians (PC, RE, VG) to physicians and nurses, before and throughout the post-implementation phase, via large discipline-based in-services, one-on-one bedside teaching sessions, and posters displayed in staff areas. Practically, the CINAS CVAD daily assessment documentation was incorporated into everyday clinical practice in the patient bedside charts, and physically linked to the CVAD Patency Management Flowchart.

Data collection

Data were collected prospectively over the two audit periods; pre- and post-implementation.

Population

All children with CVADs receiving treatment in the Oncology Department, at De-identified participated. CVADs included peripherally inserted central catheters (PICCs), tunnelled cuffed CVAD, and TIVDs.

Table 1 Demographic, clinical and device characteristics of the participants (*n* = 131) and central venous access devices (CVADs) (*n* = 133)

Patient characteristic	Pre (*n* = 56)	Post (*n* = 75)	Total (*n* = 131)
Age (years)†			
Median (IQR)	10.5 (4–14)	6 (2–12)	7 (3–13)
Age (>2 years), *n* (%)	47 (84)	62 (83)	109 (83)
Age (≤2 years), *n* (%)	7 (13)	11 (15)	18 (14)
Weight (kg)			
Median (IQR)	35.5 (14–53)	20 (14–48)	23.5 (14–49)
Sex‡			
Male, *n* (%)	30 (54)	65 (61)	76 (58)
Reason for admission, *n* (%)			
Booked admission	37 (66)	42 (56)	79 (61)
Medical (emergent)	18 (32)	26 (35)	44 (34)
Surgical (emergent)	3 (5)	3 (4)	6 (5)
Surgical (elective)	0 (0)	4 (5)	4 (3)
Diagnosis, *n* (%)			
Acute lymphoblastic leukaemia	19 (34)	23 (31)	42 (32)
Brain and CNS	3 (5)	18 (24)	21 (16)
Acute myeloid leukaemia	4 (7)	8 (11)	12 (9)
Neuroblastoma	6 (11)	5 (7)	11(8)
Bone tumours	4 (7)	7 (9)	11 (8)
Rhabdomyosarcoma	7 (13)	3 (4)	10 (8)
Non-Hodgkin lymphoma	4 (7)	2 (3)	6 (5)
Other	9 (16)	10 (13)	19 (14)
Co-morbidities, *n* (%)			
Nil	48 (86)	58 (77)	106 (81)
1	6 (11)	15 (20)	21 (16)
≥2	2 (4)	2 (3)	4 (3)
Neutropenic§, *n* (%)			
Yes	5 (9)	7 (9)	12 (9)
No	43 (77)	62 (83)	105 (80)
Unknown	8 (14)	6 (8)	14 (11)
Location on first assessment¶, *n* (%)			
Inpatient	22 (39)	49 (65)	71 (54)
Outpatient	34 (61)	25 (33)	59 (45)
CVAD characteristic	**Pre (*n* = 56)**	**Post (*n* = 77)**	**Total (*n* = 133)**
Device number, *n* (%)			
Initial CVAD	37 (66)	50 (65)	87 (65)
Subsequent CVAD	19 (34)	27 (35)	46 (35)
CVAD type, *n* (%)			
Tunnelled cuffed CVAD	23 (41)	42 (55)	65 (49)
TIVD	17 (30)	21 (27)	38 (29)
PICC	16 (29)	13 (17)	29 (22)
Non-tunnelled CVAD	0 (0)	1 (1)	1 (15)
Gauge, *n* (%)			
3 Fr	5 (9)	4 (5)	9 (7)
4 Fr	9 (16)	6 (8)	15 (11)
5 Fr	2 (4)	4 (5)	6 (5)
6.5 Fr	3 (5)	18 (23)	21 (16)
7 Fr	17 (30)	32 (42)	49 (37)
TIVD	14 (25)	2 (3)	16 (12)
Other	5 (9)	10 (14)	15 (11)
Unknown	1 (2)	1 (1)	2 (2)
Lumen number, *n* (%)			
Single	32 (57)	29 (38)	61 (46)
Double	22 (39)	45 (58)	67 (50)
Triple	2 (4)	3 (4)	5 (4)

CVAD characteristic	Pre (*n* = 56)	Post (*n* = 77)	Total (*n* = 133)
Side‡, *n* (%)			
Left	14 (25)	13 (17)	27 (20)
Right	40 (71)	64 (83)	104 (78)

†Missing data 4.

‡Missing data 2.

§Absolute neutrophil count less than 1000/uL.

¶Missing data 1.

CNS, central nervous system; Fr, French; IQR, interquartile range; PICC, peripherally inserted central catheter; TIVD, totally implanted venous device.

Outcomes

Key practices and outcomes included:

1 Occlusive events: As per the CINAS classification system,[5] and assessed by clinicians.
2 CVAD outcome: Reason for device removal, including removal due to catheter complication such as occlusion, fracture and thrombosis.[4]
3 Treatment delays associated with CVAD occlusion: Time from CVAD occlusion, to when prescribed treatment (i.e. blood sampling, medication administration), is able to be resumed.
4 CVAD occlusion management: All interventions by clinicians to treat CVAD occlusion, including but not limited to flushing, patient positioning and use of thrombolytic agents.

Participant demographics (e.g. age), clinical (e.g. admission location, primary diagnosis, co-morbidities) and device (e.g. CVAD type and characteristics) were also collected.

Process

Oncology admission lists were screened by project nurses three times per week to identify patients admitted to the Oncology Services Department with a CVAD *in situ*. Data were collected by the project nurses, who had skills in paediatrics, oncology and vascular access nursing. Data were collected directly from patient records, with additional points of clarification via discussions with children, families and clinicians. These data were then entered into a secure web-based REDCap database (Research Electronic Data CAPture, Vanderbuild).

Data analysis

The demographic and clinical characteristics of the participants are descriptively reported, using categorical and continuous descriptors appropriate to their distribution. Comparisons pre- and post-implementation were analysed using χ^2 and *t*-test or Mann Whitney two-sample statistic test depending upon data type and distribution. Mixed effects Poisson regression was used to determine the association between occlusion events and pre- and post-group, reported as incident rate ratio (IRR). The multivariable model was adjusted for age, weight, gender, diagnosis, leukocytes, patient location at day 1, device number, CVAD type, lumen numbers and presence of blood product infusion, which were the risk factors presented in previous literature.[3,13] The group and subject ID (repeated measures) were used for random effects in this model to adjust for the effects of clustering within

Table 2 Central venous access device (CVAD) occlusions and function (*n* = 133)

	Pre (*n* = 56)	Post (*n* = 77)	Total (*n* = 133)	*P* value
Any CVAD occlusion, *n* (%)	37 (66)	37 (48)	74 (56)	0.04†
Occlusion rate per 1000 catheter days (95% CI)	59.7 (51.4–69.0)	31.6 (26.4–37.6)	43.6 (38.9–48.8)	—
Occlusion events per participant, median (IQR)	1.5 (0–4)	1 (0–2)	1 (0–3)	0.01‡
Reason for CVAD removal§, *n* (%)				
In situ at study end	47 (84)	62 (80)	109 (82)	—
Treatment completion	7 (13)	3 (4)	10 (8)	—
Insertion of another device	0	4 (5)	4 (3)	—
Suspected infection	0	5 (6)	5 (4)	—
Aspirative occlusion	2 (4)	1 (1)	3 (2)	—
Extravasation	1 (2)	0	1 (1)	—
Other	0	2 (3)	2 (1)	—

†Chi square.

‡Mann–Whitney two sample statistic.

§Multiple responses.

CI, confidence interval; CVAD, central venous access device; IQR, interquartile range.

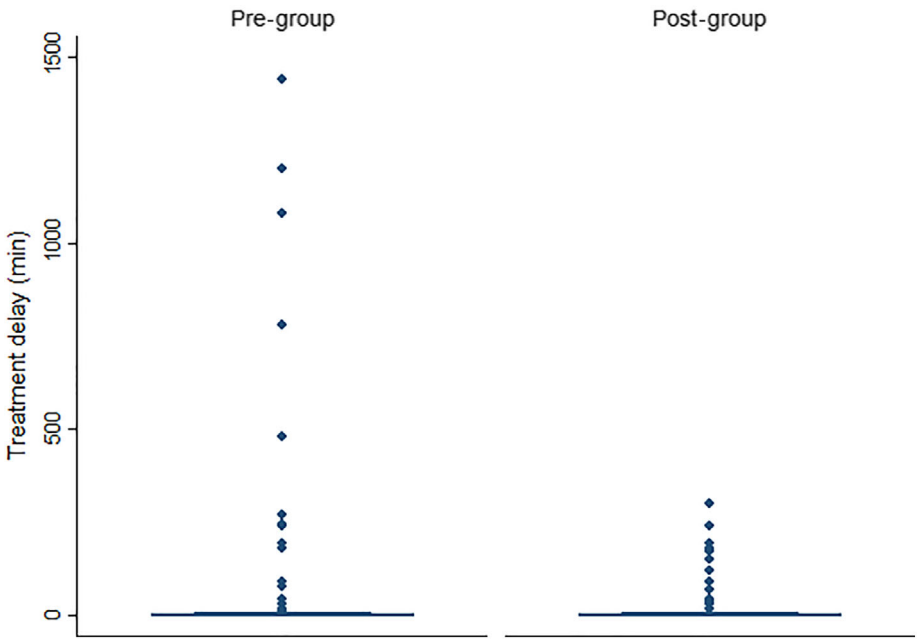

Fig. 3 Delays associated with central venous access device occlusion events, pre- and post-implementation.

groups and same subject when assessing the association between the outcome of interest and independent factors. The variables were analysed in univariate model and then multivariable model. Final model was selected by assessing the Akaike's and Bayesian Information Criterion. The analysis was undertaken using Stata (version 13; StataCorp, College Station, TX, USA).

Results

Participant and CVAD characteristics

Between 9 October 2017 and 27 August 2018, 131 patients with 133 CVADs received care through the Oncology Services Department of the Queensland Children's Hospital: 56 patients pre-implementation, 75 patients post-implementation; with 2351 catheter days studied. Demographic, clinical and device characteristics of the participants and CVADs are described in Table 1. The majority of clinical characteristics were similar between the pre- and post-implementation periods. The most common diagnosis was acute lymphoblastic leukaemia ($n = 42$; 32%) and brain or central nervous system cancers ($n = 21$; 16%), with neutropaenia (absolute leucocyte value <1000/uL) confirmed in 9% of the cohort ($n = 12$). Tunnelled, cuffed CVADs ($n = 65$; 49%) and TIVDs ($n = 38$; 29%) were the most common CVADs used. The main difference between the cohort were median age (pre: 10.5 years (IQR 4–14); post: 6 years (IQR 2–12)); however, there were equal distribution of children less than 2 years (pre: $n = 47$; 84%; post $n = 62$; 83%). More children in the pre-implementation period had their first assessment in an out-patients department ($n = 34$; 61%) than in the post-implementation period ($n = 25$; 33%). There were also less PICCs, and more tunnelled, cuffed CVADs in the post-implementation period (pre: tunnelled, cuffed CVAD $n = 23$; 41%; PICCs $n = 16$; 29% vs. post: tunnelled, cuffed CVAD $n = 42$; 55%; PICCs $n = 13$; 17%).

CVAD occlusion and function

Overall, there were 296 occlusion events in 133 CVADs, over 6784 catheter days (43.6 per 1000 catheter days). As displayed in Table 2, there was a significant reduction in the percentage of CVADs that had an occlusion event (either aspiration or injection occlusion), after the implementation of the POETIC resources (pre: $n = 37$; 66% vs. post: $n = 37$; 48%. Chi^2 4.27; $P = 0.04$). There was an associated reduction in CVAD occlusion rate (per 1000 catheter days; pre: 59.7 (95% CI 51.4–69.0) vs. post 31.6 (95% CI 38.9–48.8); IRR 0.51 (95% CI 0.41–0.64); $P < 0.01$), and median occlusion events per participant (pre: 1.5 (IQR 0–4) vs. post: 1.5 (IQR 0–2); $P = 0.01$). The majority of CVADs remained *in situ* at the study end ($n = 109$; 82%).

The most common occlusion events in both study phases were related to aspiration, with 271 aspiration occlusion episodes documented in total. Described via CINAS, this included 212 difficult aspirations (pre: $n = 135$ (14% assessments) vs. post: $n = 77$ (6% assessments)) and 67 impossible aspirations (pre: $n = 26$ (3% assessments) vs. post: $n = 41$ (3% assessments)).

Injection occlusions were less common, with 109 injection occlusion episodes documented in total. Described via CINAS, this included 89 difficult injections (pre: $n = 54$ (5% assessments) vs. post: $n = 33$ (2% assessments)), and 30 impossible injections (pre: $n = 10$ (1% assessments) vs. post: $n = 20$ (1% assessments). Changes in either impossible aspirations or injections between the pre- and post-implementation phases were not statistically significant.

Figure 3 demonstrates the different treatment delays associated with occlusion events, with a comparison pre- and post-implementation phases. Median treatment delay associated with occlusion events were unchanged between the study periods: 1.5 min (IQR 0–5; range 0–1440) in the pre-phase, 2 min in the post-phase (IQR 0–5; range 0–300; $P = 0.59$).

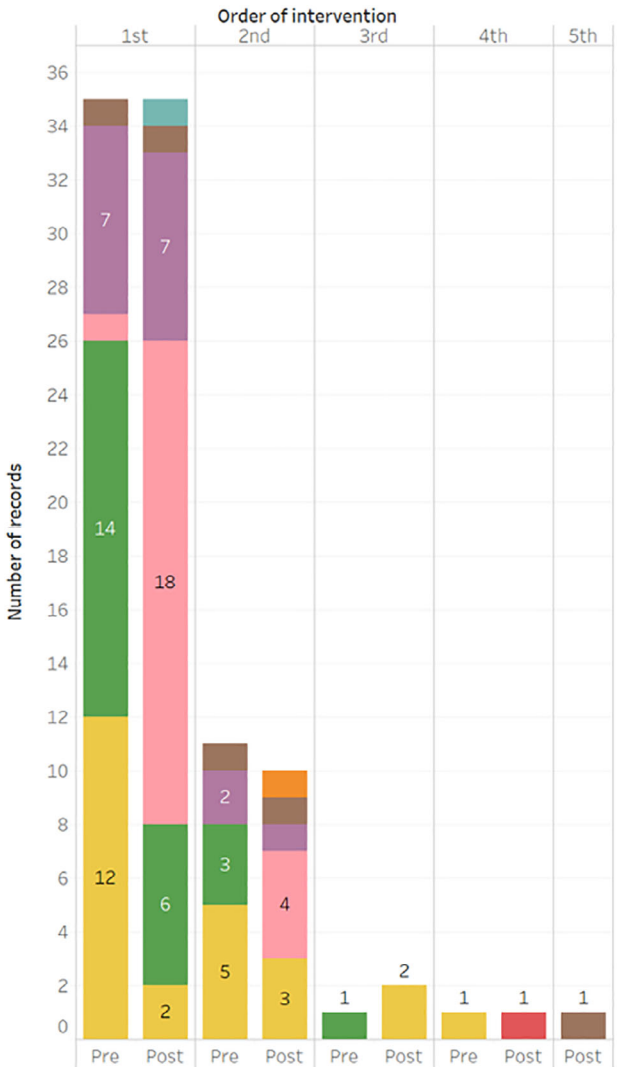

Fig. 4 Central venous access device occlusion interventions strategies used, pre- and post- implementation. Intervention: (■), imaging for correct placement; (■), medical referral; (■), needleless connector change; (■), urokinase administration; (■), patient repositioning; (■), pulsatile saline flush; (■), normal saline flush; (■), other.

Occlusion management

Displayed in Figure 4 is a summary of the occlusion management strategies, and the order they were used by clinicians (1st–5th), the first time the participant experienced a CVAD occlusion during the study period. During the pre-implementation phase, many occlusion management strategies used first by clinicians fit the 'other' category (n = 12; 34%), indicating the strategies were not in accordance with local or international guidelines. Additionally, there was limited use of pulsatile saline flushing (n = 1; 3%) and no changes of needleless connectors, medical referral or imaging for correct placement. Following the implementation of the CVAD Patency Management Flowchart and other POETIC resources, 'other' strategies reduced (n = 2; 6%), pulsatile flushing increased (n = 18; 51%), as did referral and imaging requests (n = 1; 3% each).

Risk factors for CVAD occlusion

As displayed in Table 3, the post-implementation group had 49% fewer occlusion events (IRR 0.51 (95% CI 0.32–0.81)) than those who were in the pre-implementation group after adjusting for age, weight, gender, diagnosis, neutropaenia, patient location at day 1, device number, CVAD type, lumen numbers and presence of blood product infusion for when all other predictors held constant. Neutropaenia, as described by neutrophil count, was the only variable significantly associated with higher occlusion events.

Discussion

This study demonstrates the implementation of a co-developed and effective intervention to reduce CVAD occlusions in paediatric cancer care. The overarching implementation science approach was fundamental to the study success, facilitated by the Theoretical Domains Framework[7] and Behaviour Change Wheel.[8] Practically, the study involved the development of the POETIC interventions using an invested and collaborative key stakeholder group. Through the implementation of a clear, common language (via the CINAS CVAD daily assessment documentation) and management pathway (via the CVAD Patency Management Flowchart) clinicians were able to provide proactive, consistent and effective strategies to mitigate and treat occlusion. This approach has resulted in a significant reduction in the incidence of CVAD occlusions, and an increase in the use of consistent CVAD occlusion management strategies.

CVAD occlusion is a significant problem, in paediatric cancer care and beyond. This study identified 56% of CVADs had an occlusive event during treatment, and the sequelae for children with cancer can be substantial. Internationally, clinical researchers have examined the impact of CVAD disruption due to complications during treatment, on 3- and 5-year survival, within paediatric cancer care. Within a Canadian study, difficulty with CVAD aspiration and medication administration during treatment was associated with a significantly reduced 5-year overall survival in children receiving treatment for non-central nervous system cancer (hazards ratio (HR) 1.87; 95% CI 1.02–3.42; P = 0.043).[14] An earlier, smaller US study involving children with brain tumours, demonstrated similar findings, with CVAD occlusion associated with a significantly reduced overall survival rate ($P < 0.001$).[15] Our project did not result in a significant reduction of severe occlusion episodes. Innovation and practice improvement are necessary.

This study identified only one patient-related risk factor for CVAD occlusion, neutropaenia. The reason for the increased risk for CVAD occlusion for patients with neutropaenia is unclear, and may be due to the association between neutropaenia and clinical (e.g. severity of illness) or practice (e.g. frequency of CVAD access) variables. However, our results build on previous international observational studies. An Italian prospective observational study (418 CVADs; 386 children) demonstrated children with haematological malignancies or non-malignant diseases are at increased risk of CVAD complications, compared to children

Table 3 Risk factors for central venous access device (CVAD) occlusion: Unadjusted and adjusted multilevel mixed effects Poisson regression analyses (n = 126)

		Univariable (unadjusted)			Multivariable (adjusted)		
Variables	*n*	IRR	95% CI	*P*	IRR	95% CI	*P*
Group							
Pre	56	Reference			Reference		
Post	77	0.54	0.35–0.81	<0.01	0.51	0.32–0.81	<0.01
Age, year	133	0.99	0.96–1.04	0.92	0.94	0.86–1.02	0.12
Weight, kg	133	1.01	0.99–1.01	0.45	1.01	0.99–1.03	0.27
Gender male (reference: female)	78	1.34	0.87–2.05	0.18	1.57	0.99–2.48	0.05
Solid tumour (reference: other diagnosis)	43	1.33	0.85–2.09	0.21	1.55	0.95–2.55	0.08
Neutropaenia (reference: no)	13	2.33	1.25–4.36	<0.01	2.14	1.15–3.97	0.02
Assessed in outpatient at day 1 (reference: Inpatient)	60	1.09	0.69–1.72	0.73	1.33	0.81–2.20	0.26
Subsequent CVAD (reference: initial CVAD)	46	0.92	0.59–1.44	0.72	0.90	0.57–1.43	0.67
CVAD type							
Tunnelled cuffed CVAD	65	Ref:					
TIVD	38	0.74	0.43–1.29	0.29	1.78	0.61–5.16	0.29
PICC and non-tunnelled CVAD	30	1.08	0.63–1.87	0.78	1.99	0.90–4.40	0.09
Multiple lumens (reference: single)	72	1.41	0.89–2.24	0.15	2.30	0.93–5.67	0.07
Blood products (ever received) (reference: no)	74	1.41	0.89–2.23	0.15	1.19	0.72–1.98	0.50

Observation days was set as exposure. The group and subject ID (repeated measures) were set for random effects.

CI: confidence interval; IRR, incident rate ratio; PICC, peripherally inserted central catheter; TIVD, totally implanted venous device.

with solid tumours (relative risk (RR) 3.0; 95% CI 1.8–4.8; $P < 0.01$), as well as age less than 6 years at CVAD insertion (RR 2.5; 95% CI 1.5–4.1; $P < 0.01$).[13] Comparatively, a retrospective Israeli study (262 children) identified increased risk of occlusion with tunnelled, cuffed CVADs and TIVDs (HR 3.8; 95% CI 1.6–9.2 and HR 51.2; 95% CI 4.6–564.3, respectively) in comparison to other CVADs. They also identified increased risk of occlusion with TIVD tip placement in superior vena cava (SVC), compared to the right atrium (RA) or RA-SVC junction (HR 2.7; 95% CI 1.23–5.93).[16] Together, these results have clinical significance. Device-related risk factors can be used to inform device selection decisions and insertion practices (e.g. tip position). Patient-related risk factors (e.g. age, diagnosis, neutropaenia) can be used to focus further clinical innovation to prevent and manage CVAD occlusions, such as thrombogenic catheter materials and lock solutions.

Our study has limitations. Due to the observational nature of the study, ascertainment of study outcomes was based upon patient records, parent reports and nursing reports and it is possible that occlusive events were not captured. Not all potential patient and clinical risk factors for CVAD occlusion were examined within this dataset, and future studies should examine characteristics such as catheter tip positioning. We are also unsure of the sustainability of the improvements, after the data collection period; however, we suspect that the high level of key stakeholder engagement in the early phases of identifying barriers to CVAD guideline compliance, as well as in co-development of the implementation strategy and resources will be an important factor. The study was undertaken in a single, metropolitan, tertiary paediatric facility within cancer care, limiting generalisability to other hospitals, settings and diagnostic groups. The POETIC resources were developed by specialists in this context; however, we believe these resources can be adapted for other clinical contexts including general paediatrics, regional and rural paediatric facilities, and adults.

Conclusion

This study reports the successful development and implementation of CVAD occlusion identification and management resources in a large, paediatric oncology service. Development of the POETIC resources with key stakeholders and end-users contributed to the useability, and successful implementation of resources in the oncology unit. The study was underpinned by relevant theoretical frameworks, which helped strengthen the methods from conceptualisation through to completion.

This study demonstrated the implementation of a co-developed clinical resource can have a significant positive effect on clinical practice (appropriate occlusion management strategies) and associated patient outcomes (decreased CVAD occlusion incidence). The association between CVAD occlusion with treatment delays, means that the improvements demonstrated in this study may have significant clinical consequence. Further studies to innovate and improve practice in this area are warranted, especially in the reduction of severe CVAD occlusions. Future studies should focus on improving the quality of evidence to prevent and manage CVAD occlusion in paediatric cancer care and beyond.

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