Selection and Insertion of Vascular Access Devices in Pediatrics: A Systematic Review

Rebecca S Paterson ^{a b}, PhD; Vineet Chopra ^{e f}, MD MSc; Erin Brown ^{a b}, PhD; Tricia M Kleidon ^{a d}, RN MNursPrac; Marie Cooke ^{a c}, RN PhD; Claire M Rickard ^{a c}, RN PhD; Steven J Bernstein ^{e g}, MD MPH; Amanda J Ullman ^{a c d}, RN PhD

Affiliations: ^a Alliance for Vascular Access Teaching and Research, Menzies Health Institute Queensland, Griffith University, Queensland, Australia; ^b Child Health Research Centre, Faculty of Medicine, The University of Queensland, Queensland, Australia; ^c School of Nursing and Midwifery, Griffith University, Queensland, Australia; ^d Queensland Children's Hospital, Queensland, Australia; ^e Patient Safety Enhancement Program and Center for Clinical Management Research, VA Ann Arbor Health Care System, Ann Arbor, Michigan, USA; ^f The Division of Hospital Medicine, Department of Internal Medicine, University of Michigan Medical School, Ann Arbor, Michigan, USA; ^g The Division of General Medicine, Department of Internal Medicine, University of Michigan Medical School, Ann Arbor, Michigan, USA

Address correspondence to: Amanda Ullman, School of Nursing and Midwifery, Menzies Health Institute Queensland, Griffith University, Kessels Road, Nathan, Queensland, Australia, 4111 [a.ullman@griffith.edu.au], +61 7 3735 6462.

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Abbreviations:

CLABSI	Central line-associated bloodstream infection
CPG	Clinical practice guideline
CVAD	Central venous access device
DVT	Deep vein thrombosis
ECG	Electrocardiogram
ICU	Intensive care unit
IV	Intravenous
PN	Parenteral nutrition
PICC	Peripherally inserted central catheter
PICU	Pediatric intensive care unit
PIVC	Peripheral intravenous catheter
SVT	Superficial vein thrombosis
USG	Ultrasound guided/guidance
VAD	Vascular access device
VTE	Venous thromboembolism

Table of Contents Summary

This systematic review provides the first synthesis of the breadth of evidence available for the selection and insertion of VADs in pediatric patients.

What's Known on this Subject

Individual studies, systematic reviews, and focused clinical practice guidelines that evaluate VADs in various pediatric populations, are available. However, to date, no systematic review examining the appropriateness, and inappropriateness, of VADs, across common pediatric clinical scenarios exists.

What this Study Adds

There is strong evidence to support and facilitate appropriate clinical decision-making in some pediatric indications. However, certain populations, device types and characteristics, and insertion procedures, are poorly evidenced, necessitating the application of clinical judgment for VAD decision-making.

Contributors' Statement Page

Dr Paterson assisted with data extraction and synthesis, drafted the initial manuscript, and reviewed and revised the manuscript.

Dr Brown carried out data collection, article screening, and initial data extraction and synthesis, and reviewed and revised the manuscript

Dr Chopra, Ms Kleidon, Prof Cooke, Prof Rickard, and Dr Bernstein assisted with the conception and design of the study and reviewed and revised the manuscript.

Dr Ullman conceptualized and designed the study, carried out article screening, data extraction and synthesis, and reviewed and revised the manuscript.

All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

ABSTRACT

Objective

To critically review the evidence for the selection and insertion of pediatric vascular access devices (VADs).

Data Sources

Data were sourced from the U.S. National Library of Medicine, Cumulative Index to Nursing and Allied Health, the Cochrane Library databases, Embase, and international clinical trial databases.

Study Selection

Clinical practice guidelines, systematic reviews, cohort designs, randomized control trials, quasi-randomized control trials, before-after trials, or case control studies that reported on complications and/or risk, and reliability of VADs in patients aged 0 to 18 years were included.

Data Extraction

Articles were independently reviewed to extract and summarize details of number of patients and catheters, population, age of participants, VAD type, study method, indication, comparators, and the frequency of VAD failure or complications.

Results

VAD selection and insertion decision-making in general hospitalized and some specialized patient populations were well-evidenced. The use of single-lumen devices, and ultrasound guided techniques was also broadly supported. There was a lack of randomized control trials, and for neonates, cardiac patients, patients with difficult venous access, midline catheters, catheter-to-vein ratio, and near-infrared devices, the lack of evidence necessitated broadening the review scope.

Limitations

This review was limited by the lack of formal assessment of the quality of evidence and the lack of randomized control trials and systematic reviews. Consequently, clinical decision-making in certain pediatric populations is not guided by strong, evidence-based recommendations.

Conclusions

This is the first synthesis of available evidence for the selection and insertion of VADs in pediatric patients, and is important for determining the appropriateness of VADs in pediatric patients.

INTRODUCTION

Vascular access devices (VADs) are a common and essential component of pediatric healthcare.¹ There is a range of peripheral and central venous devices, providing a route to administer critical and supportive therapies such as antibiotics, nutrition, and chemotherapy. Poor choice of VAD can lead to the insertion of an inappropriate device, which reduces treatment efficiency and places the patient at increased risk of harm.²⁻⁵ Clinicians need to make device and insertion decisions that ensure optimum therapy provision, while preventing or reducing VAD-related complications (such as infection, thrombosis and vessel damage), patient distress and treatment delays.⁶

In order to make VAD choices which mitigate patient harm and optimize treatment provision, clinical decision-making needs to reflect current, evidence-based guidance for pediatric patients. Individual studies, systematic reviews, and focused clinical practice guidelines, which evaluate VADs in various pediatric populations, are available. However, to date, no systematic review examining the appropriateness, and inappropriateness, of VADs, across common pediatric clinical scenarios exists. Systematic identification of high-quality evidence is necessary, not just to inform clinical decision-making and improve patient outcomes, but to further identify gaps in evidence which translate to gaps in practice and increases risk of patient harm. This review aimed to systematically and pragmatically evaluate all available evidence and guidance for VADs, to inform the determination of Michigan Appropriateness Criteria for Intravenous Catheters in pediatrics (miniMAGIC)^{7,8} using the RAND Corporation / University of California, Los Angeles (RAND/UCLA) Appropriateness Method.⁹

METHODS

A systematic review was undertaken to synthesize existing evidence on selection and insertion of pediatric VADs, following the RAND/UCLA Appropriateness Methods.⁹ The systematic review protocol was registered and published with PROSPERO (CRD201994286)¹⁰ and is reported in accordance with the PRISMA standards.¹¹

Search Strategy

We conducted searches of the U.S. National Library of Medicine (MEDLINE), Cumulative Index to Nursing and Allied Health (CINAHL), the Cochrane Library databases, Embase, and international clinical trial databases for all studies that report vascular access device use (success and complications) in a pediatric population, from 2008 until 16 May 2018. Search terms were developed in collaboration with an experienced medical librarian. We used exploded MeSH terms (e.g., catheters) and relevant keywords and their variants (e.g., child, pediatrics). Refer to Table 1 for the electronic database search strategy.

Table 1. Summary of search terms used for the electronic database search.

<u>Boolean variable</u>	<u>Search terms</u>
AND	Title/Abstract terms: paediatric* OR pediatric* OR child* OR youth* OR adolescen* OR neonate* OR toddler* OR baby OR babies OR MeSH terms: Child OR Adolescent OR Infant OR "Infant, Newborn"
AND	Title/Abstract terms: vascular access device* OR central venous catheter* OR midline* OR Central venous access device* OR PICC* OR peripherally inserted central catheter* OR peripheral cannula* OR peripheral catheter* OR peripherally inserted OR intravenous access OR MeSH terms: Vascular Access Devices OR Central Venous Catheters OR Infusions, Intraosseous OR Infusions, Intravenous OR Infusions, Subcutaneous
AND	Title/Abstract terms: vessel health OR adverse OR complicat* OR appropriat* OR inappropriat* OR indicat* OR guideline* OR unnecessary OR publication type: guideline OR practice guideline OR MeSH terms: Guidelines as Topic OR Unnecessary Procedures
NOT	Title/Abstract terms: abortion OR blood donor* OR caesar* OR obstet* OR pregnan* OR distraction OR immunization OR immunisation OR venipuncture OR venepuncture OR sucrose OR dose OR case report OR case study OR MeSH terms: Drug dosage calculations OR publication type: case reports
FILTERS	Language: English AND Publication date: from 2008/01/01

Eligibility Criteria

Following the RAND/UCLA Appropriateness Methods, our goal was to provide a critical review of the literature summarizing the scientific evidence available surrounding the appropriateness of pediatric vascular access device selection, insertion and characteristics.⁹ This meant a range of study designs were eligible for inclusion, including existing clinical practice guidelines (CPGs), systematic reviews, randomized control trials (RCTs), quasi-RCTs, before-after trials, cohorts, or case control studies. Additionally, the guidelines and studies must have been published in a peer-reviewed journal, and report on complications and/or risk, and reliability of VADs in patients aged full-term to 18 years in a pediatric hospital. We defined VADs to include intraosseous devices, midline catheters, peripherally

inserted central catheters (PICC), short- and long peripheral intravenous catheters (PIVC), tunneled, tunneled-cuffed and non-tunneled central venous access devices (CVADs), totally implantable venous devices, and umbilical catheters. We excluded studies that were not published in English, and conference abstracts, animal studies, NICU studies, $n = 1$ studies, case-reports, qualitative reports. While eligibility criteria focused on pediatric studies (i.e., full term to 18 years), we determined that including pre-term neonate and adult studies was preferential to no evidence.

Outcome Measures

The primary outcomes were defined *a priori* as: (1) device and insertion characteristics that impact the success of VAD insertion, and (2) device and insertion characteristics associated with VAD failure, due to complications before the completion of therapy, or after successful VAD insertion. Device characteristics included VAD type, device catheter-to-vein ratio, and device lumens. Insertion characteristics included insertion site and location, and the use of vessel visualization technology. Complications included but were not limited to central line associated bloodstream infection (CLABSI), VAD-associated thrombosis, occlusion, catheter dislodgement, catheter-tip migration, catheter breakage or rupture, local infection, and phlebitis.

Screening

Title and abstract screening was performed independently by two review authors (EB and AU), excluding studies that did not meet eligibility criteria where this could be determined by the abstract alone. Full text articles included for screening were reviewed by two review authors (EB and AU), and independently assessed against the inclusion/exclusion criteria. Duplicate publications were excluded. Where individual studies had been evaluated in a systematic review also returned in the search, the primary study was excluded to avoid

repetition and over-representation of individual studies, and the systematic review was referred to. Any discrepancies were resolved between review authors through mutual discussion and, where required, consulted a third, independent review author (MC).

Data Extraction and Synthesis

All full text articles that met inclusion criteria were independently reviewed by three review authors (RP, EB and AU) to extract details of number of patients and catheters, population, age of participants, VAD type, study method, indication, comparators, and the frequency of VAD failure or complications. These details were summarized in a data extraction sheet and were cross-checked for accuracy and agreement. Additional, relevant, references were added by cross-referenced and second-hand searches through reference lists, and relevant guidelines. Hand-searched references were evaluated to ensure that they met inclusion criteria. Following screening, pragmatic inclusion of wider studies was employed. That is, if no studies identified meeting the preferential inclusion/exclusion criteria, we included wider studies (e.g., *a priori* area of deficit included neonates outside of NICU). The extracted data were then combined using narrative (descriptive) synthesis by categories (i.e., outcome, vascular device, indication).

Study Quality and Risk of Bias

The methodological quality, transparency and relevance of all individual included studies were independently assessed by two review authors (EB & AU) using the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guideline¹² and CASP (Critical Appraisal Skills Programme) for Cohort Study checklist.¹³ RCTs and systematic reviews were preferentially included as the gold-standard level of evidence for evaluating VADs. However, where this level of evidence did not exist, a pragmatic approach was taken, so that studies outside of the scope of the review (e.g., laboratory, premature

neonates or adult studies), and CPGs, which may be limited by the number or quality of included studies, were incorporated into the review. In order to provide a synthesis of the available literature for the purpose of the RAND/UCLA Appropriateness Method,⁹ studies were categorized according to their methodology: (A) Clinical practice guidelines, (B) Systematic review or other review, (C) Randomized control trial, (D) Observational study with comparator, and (E) Other (Clinical review, pilot study, laboratory study).

RESULTS

Study Selection

The results of search strategy and study selection are summarized in Figure 1. Electronic database searches identified 7,430 articles, and hand searches of the bibliography of included studies and clinical guidelines identified 30 additional articles for potential inclusion.

Following removal of duplicates and screening for eligibility, a total of 133 studies and CPGs met eligibility criteria and were included in data extraction.

Study Characteristics

The review includes 27 CPGs (20.4%), 11 systematic reviews, 10 RCTs (7.6%), 79 observational studies (59.8%), three pilot studies (2.3%), two clinical reviews (1.5%) and one laboratory study (0.8%). These were sourced from research teams based in Africa (1.6%), Asia (9.3%), Europe (31.0%), the Middle East 2.3%), North America (40.3%), Oceania (11.6%) and South America (3.9%), with the majority from the United States of America ($n = 34$; 37.8%). Subjects within the included studies ranged in age from premature neonates up to 66 years and required treatment for oncologic or hematologic conditions, support during critical care admission, or vascular access for hemodialysis, postsurgical, or general infusion therapy or parenteral nutrition. Due to the heterogeneity across age and conditions in pediatric patients, included articles were divided into specific clinical subspecialties (e.g., hospitalized

pediatric patients, hematology/oncology; see Figure 2). Results from individual studies based on specific hospitalized populations are presented in Table 2 and include key characteristics for each study.

VAD selection in hospitalized pediatric populations

A total of three CPGs and 26 studies were included for all general hospitalized pediatric patients, including one systematic review, one RCT and 23 observational studies. These studies compared all VADs in hospitalized adult ($n = 3$), child ($n = 13$) and infant ($n = 2$) and neonatal ($n = 3$), and surgical ($n = 1$) populations. With the exception of one CPG, no studies reported on midlines in the pediatric population, so adult studies were also included.¹⁴⁻¹⁶

Neonates

Overall, umbilical catheters were associated with high rates of complications, including catheter-related BSI, occlusion, dislodgement, thrombosis, and local infection or phlebitis,^{6, 17-22} and device failure common.⁶ Umbilical catheter malposition and catheter-tip migration during treatment also frequently occurred,^{6, 23} with concerns that malpositioned or dislodged umbilical catheters may lead to severe hemorrhage and even death if not detected or rectified in a timely manner.²⁴ Despite this, the literature reviewed indicated that umbilical catheter placement is common practice in neonates up to the first seven days of life.²⁵ Evidence for umbilical catheter dwell time was scarce and supported placement for tunneled due to increased risk of device failure.^{17, 26} Consequently, guidance from available CPGs were limited, but recommended placement only for as long as clinically necessary or ≤ 14 days, if managed aseptically.²⁷ Beyond 15 days, ambiguity in the literature regarding the patency of the umbilical vascular system, and catheter, for longer durations was evident.^{23, 27} One CPG did support replacing any umbilical catheter with a PICC for central access > 7 days in order to reduce risk of infection.²⁷ Alternative VADs for neonates include PICCs and CVADs,^{6, 27-}

²⁹ however it was recognized that neonates frequently had poor or difficult to access venous assets, ^{30, 31} were more likely to have higher risk of insertion-related complications, ³¹ and were at high risk of blockage across all devices. ⁶

Infants

PICCs are commonly the first VAD choice for infants. ²⁷ Numerous studies found that PICCs in infants were associated with a lower risk of complications, particularly thrombosis, ^{32, 33} leading current CPGs to recommend their use in children < 1 years, and for therapies for longer durations (> 7 days). ^{27, 32, 34} In comparison, PIVCs had significantly higher rates of dysfunction in infants (50%) compared to children > 1 years old, and for longer dwell times, ²⁰ with one CPG only recommending PIVCs for therapies < 6 days. ²⁷ None of the included evidence evaluated the complications associated with midline catheters in infants, however the *National Association of Neonatal Nurses* recommended them as an appropriate alternative for peripherally compatible intravenous (IV) therapy for < 6-10 days in infants. ²⁷

Compared to PICCs, tunneled-cuffed CVADs were associated with higher rates of thrombosis (although thrombosis tended to occur after longer durations *in situ*), with 60% of tunneled-cuffed CVADs developing DVT. ³⁵ Tunneled-cuffed CVADs were also associated with higher rates of insertion failure in infants and young children. ³¹ Risk of infection in CVADs placed in infants was high, especially compared to toddlers, and linked to the use of totally implantable venous devices. ³⁶ As tunneled CVADs and totally implantable venous devices restrict the future use and availability of accessed veins, and insertion was related to a higher risk of complication, studies and CPGs indicated that their use in infants should be limited. ^{27,}

37

Children and adolescents

In general hospitalized children and adolescents, PIVCs and midline catheters were reported as appropriate for short-term, peripherally compatible therapies due to their low risk of catheter-related infections and thrombosis, in comparison to PICCs.^{14-16, 19, 38, 39} However, one study suggested that they are associated with increased risk of occlusion with extended dwell times.¹⁹ PICCs were reported to have high insertion success rates⁴⁰ and low failure rate in children and adolescents,^{6, 36} although one study reported severe complications in 40.1% of failed PICCs, associated with increasing patient age.³³ PICC insertion was commonly associated with short-term complications such as occlusion, CLABSI and thrombosis,^{6, 21} with rates of these events increasing with longer durations of therapy.²¹

In comparison, tunneled-cuffed CVADs had high rates of infection (4.8-19.9%),⁶ and were associated with short-term complications, such as infection, malfunction, leak and malposition^{36, 41} and high rates of occlusion (12.1%).⁶ While totally implantable venous devices had low rates of infection (0.01-0.28/1,000 catheter-days),⁶ they were associated with early complications, such as bleeding, pneumothorax, nerve lesions, catheter misplacement, occlusion and skin damage,^{37, 42} and long-term complications, such as infection, thrombosis, catheter fracture or disconnection, secondary dislocation, and skin breakdown over port septum.^{6, 34, 42} Overall, tunneled-cuffed CVADs and totally implantable venous devices had high, overall insertion success rates^{31, 36, 43} and low failure rates,^{1, 6} and can be used as alternatives to PICCs in patients requiring frequent vascular access.³⁴ Given their high insertion success rate,⁴³ non-tunneled CVADs can be placed following the failed placement of other CVADs.³⁴

VAD Selection in Special Pediatric Populations

Malignant hematological and oncological conditions

For patients undergoing treatment for malignant hematological and oncological conditions, infection and thrombotic complications, as well as disruption to treatment, are important considerations for VAD selection.^{44, 45} A total of 17 studies, including one systematic review and 16 observational studies, and five CPGs were included. Most studies focused on tunneled-cuffed CVADs and totally implantable venous devices in mixed hematology/oncology ($n = 5$), PN ($n = 1$) and leukemia ($n = 3$) populations. Other studies compared PICCs, CVADs and totally implantable venous devices in mixed hematology and oncology populations ($n = 5$).

Overall, tunneled-cuffed CVADs and totally implantable venous devices had low rates of insertion-related complications, device failure and malfunction,^{44, 46-50} and were associated with low rates of thrombosis.^{2, 51, 52} Reporting on rates of infection between devices was mixed. Two studies found that rates of infection were not statistically different between tunneled-cuffed CVADs and totally implantable venous devices.^{48, 53} In contrast, other studies found higher rates of CLABSI in totally implantable venous devices compared to CVADs,⁴⁴ and higher risk of overall infection in totally implantable venous devices compared to tunneled-cuffed CVADs.⁴⁶ Additional studies found that overall infection rates were higher in tunneled-cuffed CVADs compared to totally implantable venous devices^{50, 54-56}. Although occlusion was common in this population,^{44, 47, 51, 57} rates were not different between tunneled-cuffed CVAD and totally implantable venous devices^{47, 58}. Compared to totally implantable venous devices and tunneled-cuffed CVADs, PICCs had higher rates of device-related complications, and rates of overall infection and CLABSI, thrombosis and occlusion^{2, 50, 51, 59}.

International guidelines recommend the use of tunneled-cuffed CVADs for pediatric patients undergoing hematological and oncological treatment requiring frequent and continuous vascular access, particularly for frequent blood sampling, parenteral nutrition and complex intravenous therapies.^{34, 60} Totally implantable venous devices may also be appropriate across

these indications,⁶¹ especially in patients ≥ 10 kg,³⁰ although they were only recommended for intermittent use, due to the increased risk of infection and thrombosis.^{30, 60} One CPG endorsed the use of PICCs for short- to medium-term treatments⁶⁰, although there was insufficient evidence to support their routine use^{62, 63} and chemotherapy treatment via peripheral venous access was not recommended.^{60, 62} No included studies reported on non-tunneled CVADs, however one international guideline supported the placement for intrahospital use or short durations only.⁶⁰

Critically ill patients

Unlike other patient groups, for critically ill infants, children and adolescents, choice of VAD may be prioritized by whether the patient is stable or unstable.^{64, 65} Seven observational studies, one systematic review and one RCT were included for critical care patients and included the ED ($n = 2$), emergency surgery ($n = 1$), moderate-severe burns ($n = 1$), out of hospital critical care ($n = 1$), and PICU ($n = 4$) populations. No studies explored midline devices in the critical care population, although one study compared short and long PIVCs.⁶⁶ Overall, the focus of studies in this population was on infection and thrombosis and not on outcomes such dwell, occlusion, infiltration, extravasation or bleeding complications.

Stable critically ill patients

In stable, critically ill patients requiring short-term, acute therapy, two CPGs supported the use of non-tunneled CVADs for any type of infusion therapy up to 7 to 10 days, despite risk of infection and thrombosis.^{28, 34} Evidence to support the use of PICCs in this population was mixed. Whereas the *Infusion Therapy Standards of Practice* cautioned against the use of PICCs in critically ill patients (adults and pediatrics) due to risk of infection or thrombosis,²⁹ two other clinical guidelines recommended PICCs for both short^{28, 67} and long term²⁸ durations in critically ill patients. This is likely due to the scarcity of high-quality evidence

directly comparing these devices. PIVCs were frequently reported within this population,^{66, 68} and were recommended over intraosseous devices in non-emergent situations.^{64, 65} Compared to PICCs however, PIVCs were commonly associated with obstruction, leakage and dislodgment,⁶⁸ with short-catheter PIVCs in particular linked to higher rates of local infections, dislocation, infiltration, occlusion and thrombosis compared to long-catheter PIVCs.⁶⁶ There were limited studies reporting on non-tunneled CVADs use in critically ill children, however one study reported children >13 years old with a non-tunneled CVAD were at higher risk of DVT, compared to children < 1 year.⁶⁹ Tunneled-cuffed CVADs and totally implantable venous devices were associated with high rates of infection and thrombosis, but were reported as suitable for long-term therapies in this population.^{28, 70-72} No studies or CPG's reported on the suitability of midline devices in this population specifically, although they were more broadly considered appropriate for therapies lasting one to four weeks.⁶⁷

Unstable critically ill patients

In unstable, critically ill patients, speed of access was prioritized. International guidelines recommended venous access via PIVC placement, unless attempts to cannulate take > 60 seconds or ≥ 2 attempts.^{64, 65} Where IV access is difficult, intraosseous devices were consistently reported as a fast alternative for children and adolescents,^{29, 64, 67, 73-75} and umbilical catheter recommended for neonates, in the first week of age.⁶⁵

Congenital cardiac conditions

For patients with congenital cardiac conditions, VAD selection prioritizes vessel preservation in order ensure key vasculature can be used for future life-saving procedures.³⁴ Overall, three CPGs and four observational studies of pediatric and young adult patients were included in the systematic review and encompassed patients with functionally univentricular and biventricular physiology and cardiac surgery subgroups. Comparisons between umbilical

catheters, PICCs, tunneled CVADs and non-tunneled CVADs based on dwell time, occlusion, thrombosis, and infection risk were the primary focus of the included studies.^{22, 76-78}

Generally, short-term peripheral and non-peripheral compatible therapy delivered via umbilical catheters in infants can be used.²⁹ PICCs were recommended for patients with congenital cardiac conditions requiring ≥ 7 days of IV therapy.²⁷ Due to lower complication rates, PICCs inserted in lower extremity vessels were recommended.²⁷ CVAD (tunneled and non-tunneled) use was reported in this population, however placement ≥ 7 days was associated with an increased risk of CLABSI.^{34, 76} None of the included studies or guidelines included evidence to support the use of totally implantable venous devices in this population.

Specific to neonates with functionally univentricular physiology, umbilical catheters had low rates of CLABSI, thrombosis and occlusion when compared to other devices,²² and can be used when preventing significant vessel loss for future procedures is a priority. While PICCs were generally recommended in congenital cardiac populations, clinical guidelines emphasized the need for specialist consultation for patients with cardiac malformations.²⁷

Femoral non-tunneled CVADs were reported as appropriate for therapies < 14 days in single-ventricle populations, with ≥ 14 days durations associated with a higher risk of thrombosis but not occlusion.²² Comparatively, other femoral devices (tunneled, uncuffed) were not related to an increased risk of thrombosis or occlusion for therapies ≥ 14 days.²²

Long-term vascular access dependent

Long-term vascular access dependency encompassed non-malignant hematological, respiratory, gastrointestinal, metabolic and immunological conditions requiring long-term (> 2 months) and very long-term (> 1 year) VAD placement.⁷⁹ In total, four studies and nine CPGs described this diverse patient population across parenteral (PN) and non-parenteral therapies, and continuous or intermittent therapies. Despite the heterogeneity of reported

populations, vessel preservation and complication prevention were the common themes when comparing PICC, short- and long-catheter PIVC, midline, tunneled cuffed CVAD, and totally implantable venous device indications.⁸⁰⁻⁸³

Long-term PN infusates

CLABSI, occlusion and thrombosis were common complications of long-term PN therapy across all VADs.^{80, 81} Peripheral devices (PIVCs and midlines) are unsafe for delivering PN due to risk of venous damage,^{29, 60, 84} however may be indicated for limited time periods in hospitalized patients with restricted dextrose and protein concentrations (<10% and/or 5%, respectively).^{29, 67, 85} A single-centre observational study supported PICCs for long-term PN⁸⁰ and another CPG recommended PICCs for home PN,⁸⁵ however in general, although associated with an increased risk of infection, tunneled CVADs and totally implantable venous devices were preferred when PN was required for long durations.^{34, 60, 79-81, 86}

Long-term non-PN infusates

Evidence for the use of VADs in patients requiring long-term non-PN infusates was similar. Specifically, except for one CPG, all peripheral devices (PIVCs and midlines) were regarded as inappropriate for long-term dependent, non-PN therapies, especially in patients with chronic renal failure.^{29, 34, 67, 83, 84} Tunneled CVADs and totally implantable venous devices were instead preferred for non-PN therapies required for continuous or intermittent, and extended durations, respectively.^{29, 34, 42, 67, 83, 84}

Difficult venous access

For pediatric patients with difficult venous access, insertion success rates and number of attempts are priority considerations for VAD selection. Factors which affect these include patient physiology, pathology, damage caused by VAD and the procedural skill of the

clinician.⁸⁷ Five observational studies were included for patients with difficult venous access in ED ($n = 2$), elective surgery ($n = 1$), PICU ($n = 1$) and hospitalized children ($n = 1$) populations. The majority of studies compared non-tunneled CVADs ($n = 3$) and evaluated the insertion success rates, and complications associated with number of insertion attempts. Two studies evaluated PIVCs with and without ultrasound guided (USG) techniques in pediatric populations.^{88, 89}

In patients with difficult vascular access, USG PIVC insertion was associated with higher overall, and first and second-attempt success rates after failed insertion via landmark method.

⁸⁸ Up to 17.2% of CVADs in an ED setting experienced a complication (arterial puncture, hematoma, pneumothorax and arrhythmia), and ≥ 3 attempts were significantly related to complication development.⁹⁰ In a study comparing insertion success in neonates and non-neonates, non-tunneled CVAD failure was common (63.1-76.3%), and the success rate after >1 attempts was significantly lower with decreasing patient age and associated with greater insertion-related complications.³¹ Similarly, non-tunneled CVAD placement in PICU patients led to high early mechanical complications (17.5%), and was associated with more insertion attempts and insertion at the subclavian or jugular approach.⁹¹

Recommendations regarding device characteristics

Catheter-to-vein ratio

Determining the appropriate catheter-to-vein ratio is a difficult balancing act of optimizing patient and therapy needs while ensuring risk of catheter-related complications such as occlusion is minimized. Although catheter-to-vein ratio was recognized as important for preventing phlebitis, occlusion and thrombosis,³⁴ few studies reported on catheter-to-vein ratios in neonate and pediatric patients. Only one observational study reported on PICCs in

hospitalized children,⁹² with the included studies broadened to incorporate an adult and laboratory study.^{93, 94} A further six CPGs were referred to for guidance.^{27-29, 34, 60, 95}

Clinical guidelines emphasized selecting the smallest practical sized gauge or French (Fr) that met treatment and patient need.^{27-29, 34, 94} Inadequate catheter-to-vein ratio was linked with an increased risk of thrombosis in two studies, especially in infants with congenital heart disease, and smaller catheter size was associated with higher rates of occlusion.^{34, 60} In contrast, larger catheters had a corresponding increase in rates of phlebitis.²⁹ For any VAD (PICC, PIVC, midline, CVAD or totally implantable venous device) a catheter-to-vein ratio of <50% in pediatric patients and <33% in neonates was generally recommended.^{27, 29, 34} Specific to PICCs, in hospitalized children and adults, thrombosis risk increased with a catheter-vein ratio ≥ 0.33 ⁹² and ≥ 0.45 ,⁹³ respectively. Depending on patient vessel size, 22 to 24 gauge peripheral catheters were considered appropriate for both pediatric patients and neonates.^{29, 67} According to the *National Association of Neonatal Nurses' Peripherally Inserted Central Catheters: Guideline for Practice* stated that 1.1 to 3 Fr (20 to 28 gauge) catheters were commonly used catheter sizes for neonates.²⁷ There were no specific recommendations or empirical evidence for size of CVAD (tunneled or non-tunneled), midline catheters or totally implantable venous devices.

Device lumens

Choosing the optimum number of device lumens to deliver planned therapy while reducing the risk of catheter associated complications, particularly infection, occlusion, and thrombosis, is both complex and important.²⁸ Nine studies described lumen number outcomes in hospitalized adults ($n = 2$), children ($n = 2$) and infants ($n = 1$), immune-competent ($n = 1$), and hematology/oncology ($n = 3$) populations. An additional 11 CPG recommendations

were included in the review. All compared single versus double or multi-lumen catheters in CVADs ($n = 3$), tunneled-cuffed CVADs ($n = 2$) and PICCs ($n = 4$).

Universally, CPGs recommended the minimum number of lumens necessary for therapy provision. Due to increased risk of infection, occlusion and thrombosis, multi lumen VADs are only appropriate where indicated (i.e., for hematopoietic stem cell transplantation, critically ill patients, and patients requiring concurrent infusion of non-compatible infusates such as blood and blood product, PN or chemotherapy).^{28, 29, 34, 60, 61, 67, 84, 85, 96, 97} A dedicated lumen for PN was also frequently endorsed,^{28, 60, 85, 96} but two CPGs stated there was insufficient evidence to support this recommendation.^{34, 98} Similarly, a dedicated lumen for blood sampling, through the largest lumen, was recommended by some, but with limited evidence.^{29, 67}

Evidence evaluating multi lumen PICC was mixed. One study found DVT risk increased with ≥ 2 lumens,³⁵ and another study reported a non-significant reduction in CLABSI risk with single-lumen use,⁹⁹ other studies reported that PICC lumen number was not significantly associated with risk of thrombosis^{32, 100} or infection.¹⁰⁰ Overall, most studies found occlusion was the most common complication associated with catheter lumen number, and ≥ 2 lumen PICCs were associated with highest risk of occlusion.^{33, 99, 100} Similarly, studies reported mixed outcomes based on CVAD lumen number. Two studies reported no association between single and double-lumen catheters and rates of infection⁴⁷ and major CVAD-related complications,¹⁰¹ while others reported higher rates of CLABSI,^{54, 57} exit site/tunnel infection,⁵⁷ malfunction or occlusion,⁵⁷ and complications requiring repositioning¹⁰¹ for double-lumen CVADs.

Recommendations for insertion

Insertion locations

Optimal catheter site selection in pediatric patients is more complex than in adults, as pediatric patients typically have fewer accessible veins, due to their smaller size.^{34, 97}

Determining the appropriate insertion site is important for minimizing risk of insertion and preventing post-insertion related complications,^{34, 96, 97, 102, 103} however, only partial evidence for appropriate vessels and insertion locations for VADs was available. A total of 21 studies and 12 CPGs were included describing insertion location outcomes. Overall, most studies ($n = 15$) compared CVADs in cardiac, neurology and general surgical ($n = 5$), PICU ($n = 4$), hospitalized infant ($n = 1$), oncology ($n = 1$), and stem cell collection ($n = 1$) populations. Five studies compared PIVC device location in surgical ($n = 3$), hospitalized children ($n = 1$), and neonate and infant ($n = 1$) populations, and three studies evaluated PICC device location in oncology ($n = 1$), hospitalized children ($n = 1$), and immunocompetent ($n = 1$) populations.

According to the guidelines reviewed, common insertion sites varied by device type. PIVC insertion was frequently recommended in the hand and upper extremities,^{29, 67} with the scalp and foot suggested as alternative insertion sites for infants and toddlers.²⁹ The *Infusion Therapy Standards of Practice* and *Provisional Infusion Therapy Standards of Practice* guidelines recommended avoidance of areas of flexion including the wrist.^{29, 67} Insertion of PICCs via the basilic vein was the preferred insertion site, although the brachial, cephalic, axillary, temporal and posterior auricular veins were acceptable alternatives.^{29, 34, 67, 84, 85} For neonates, the best available vein was recommended without specific guidance as to what constitutes the best vein?²⁹ Infants could also have PICCs inserted at saphenous and popliteal veins.^{29, 34, 67} Similarly, for midline catheter insertion, the basilic, brachial and cephalic veins were suggested for neonates, infants and pediatric patients,^{67, 98} as well as alternative insertion sites such as the scalp and leg.^{29, 67} For PIVCs, the external jugular vein (EJV) was recommended only in emergency settings or if no other vein available.²⁹ Overall, there were

no preferred insertion sites for tunneled and non-tunneled CVADs or totally-implantable vascular devices in neonates, infants and pediatric patients.^{29, 62, 63, 67, 95} No studies evaluated the insertion locations for tunneled and non-tunneled CVADs in children, however in adults, tunneled and non-tunneled CVADs were commonly inserted into the internal and external jugular, subclavian or femoral vein, although the subclavian vein was the recommended insertion site.^{34, 67, 84, 85}

Insertion success is dependent on vessel and insertion-site

PIVCs had higher success rates when inserted in the cephalic vein in the proximal forearm under ultrasound guidance (USG) techniques or the antecubital fossa^{83, 89} and a longer lifespan when inserted into the arm compared to scalp, hand, or leg insertion sites.¹⁰⁴ CVAD insertion via the axillary vein using USG techniques resulted in fewer insertion attempts and significantly shorter time to guide-wire insertion and time to cannulation.¹⁰⁵ Similarly, CVAD insertion in the subclavian vein was associated with shorter median puncture time, less insertion attempts and significantly less guidewire misplacement compared to insertion via the infraclavicular approach.¹⁰⁶ For one study, there was higher overall insertion success for insertion via the subclavian compared to the internal jugular vein when using landmark technique.¹⁰⁷ In a sample of critically ill newborns and children (0 to 14 years), USG brachiocephalic insertion had significantly higher first-attempt success, fewer insertion attempts and shorter procedure time compared to the internal jugular vein.¹⁰⁸ Similarly, in critically ill neonates and infants, image-guided placement of tunneled CVADs via saphenous or femoral veins using a surgical cut-down was associated with high placement success.¹⁰⁹

Complications are associated with vessel and insertion-site

In pediatric patients, PIVCs inserted at the bend of the arm or lower extremities were associated with increased risk of infiltration, erythema, pain, inability to administer

medications, no or poor flow due to gravity and kinked catheter,^{19, 20} while insertion at the foot, ankle or scalp was significantly associated with increased risk of occlusion.^{19, 20} In neonates and infants PICC insertion at foot or ankle sites was significantly associated with an increased risk of phlebitis, thrombosis and dysfunction.^{20, 27, 110} Overall, there was no direct association between PICC insertion at brachial, cephalic, or saphenous insertion sites and thrombosis in pediatric patients,³² however left-sided PICC insertion was generally associated with higher rates of PICC-related complications.¹¹¹ The majority of studies, with two exceptions,^{105, 112} found rates of infection and complication varied significantly based on CVAD insertion sites.^{35, 52, 76, 91, 107, 113-117} Generally, complications were similar between internal jugular and subclavian veins.¹⁰⁷ One study, however, reported higher rates of early mechanical complications in non-tunneled CVADs inserted through the subclavian compared to the jugular or femoral vein.⁹¹

Across CVAD types, insertion via the internal jugular in infants and pediatric patients was associated with increased risk of high arterial puncture,^{91, 107} postoperative chylothorax,¹¹³ thrombosis,^{35, 114, 115} and infection.^{107, 114} Insertion through the subclavian vein was correlated with an increased risk of high arterial puncture (left-sided approaches),^{91, 107} arrhythmias and misplacement (right-side approaches),⁹¹ malposition and occlusion,¹⁰⁷ postoperative chylothorax,¹¹³ and sepsis.⁷⁶ In pediatric oncology patients, subclavian insertion sites had higher rates of thrombosis compared to external jugular and cephalic sites, but there was no difference in rates between right- or left-side insertion sites.⁵² Comparatively, brachiocephalic insertion-sites were associated with significantly lower CLABSI and thrombosis compared to jugular and subclavian approaches.¹¹⁴ Overall, CVAD insertion through the femoral vein was linked to higher risk of thrombosis^{35, 61, 115} but lower complication and infection rates in infants <5 kilograms.¹¹⁷

Vessel visualization

Vessel and catheter tip visualization technologies, including USG, transillumination, near infra-red guidance (NIR), fluoroscopy and electrocardiogram (ECG), are commonly used in pediatric clinical practice.^{28, 95} Despite the variety of available technologies, all vessel visualization technologies aim to minimize complications and increase success rates during cannulation. Overall, 31 studies describing vessel visualization outcomes for PIVC, midline, PICC, CVAD and totally implantable venous devices, and 15 CPGs were included. Among those, 17 studies focused on VADs in critically ill children, neonates and infants ($n = 4$), hospitalized children ($n = 3$), cardiac, neurological and general surgical patients ($n = 3$), mixed cardiac surgical, CHD and PICU ($n = 1$), ED ($n = 1$), and neonate ($n = 1$) populations. Across these heterogeneous populations, the focus was on increasing first-attempt success rates and overall successful insertion and correct catheter-tip positioning.

Across all CPGs, USG insertion by trained clinicians was recommended for all pediatric populations, device types and insertion sites.^{27-29, 34, 60, 63, 67, 84, 85, 95, 98, 103, 118-120} Most of the evidence reviewed indicated USG insertions were associated with high insertion success and first-attempt success rates, lower procedure time, fewer attempts and fewer complications in PIVCs and CVADs.^{101, 105, 109, 121-131} Only two systematic reviews reported no difference in CVAD insertion success rates between USG and landmark techniques.^{132, 133} PIVC insertion was frequently improved by use of vessel visualization devices,^{66, 88, 89} with fewer complications.⁶⁶ Few studies compared visualization techniques for totally implantable venous device placement. One study reported USG percutaneous puncture of totally implantable venous devices had similar success rates, procedure times and complication rates when compared to surgical cut-down methods.¹³⁴ Another study found that insertion of totally implantable venous devices using USG was significantly more effective in reducing complication rates, had shorter procedure times and was more cost-efficient compared to open surgical cut-down techniques.¹³⁵

Recommendations for other visualization techniques in pediatric populations, including NIR (vessel visualization) and ECG (catheter tip confirmation), however was mixed. Use of NIR light devices may be efficacious in selected, high-risk subpopulations,¹³⁶ and may modestly improve first-attempt success rates,¹³⁷⁻¹³⁹ however, the current evidence does not support an overall benefit,¹⁴⁰ or one that is better than non-image guided methods.¹³⁸ Similarly, low levels of evidence prevent the recommendation of ECG assistance for PICC placement,¹⁴¹ however, one study also found higher first-attempt success and correct tip position success using intracavitary ECG PICC insertion compared to landmark techniques¹⁴². Other techniques, such as ECG techniques, for CVAD placement were reported as successful and accurate.^{143, 144} In particular, the ECG technique was significantly more accurate and associated with fewer complications when compared to landmark¹⁴³ and when intracavitary ECG was undertaken using a dedicated ECG monitor.¹⁴⁴ Only one article discussed vessel visualization techniques for umbilical catheters, and recommended plain radiographs for confirming catheter course and location.²³

DISCUSSION

VAD selection and insertion grounded in evidence-based, standardized decision-making can reduce risk of complications, pain, length of hospital stay and costs, and improve overall safety and treatment efficacy¹⁻⁶. Despite many individual studies, systematic reviews and targeted CPGs, there is no evidence-based guide to assist clinical decision-making in common pediatric indications. This systematic review is the first of its kind to evaluate the evidence that informs VAD selection and insertion for common pediatric indications using rigorous methodology and a wide breadth of scope. Overall, the review synthesized the available, high-quality evidence to inform clinical decision-making, while also highlighting practices in need of further enquiry.

This systematic review revealed evidence and guideline-based recommendations for VAD selection and insertion in numerous pediatric populations^{27, 29, 34, 67}. Overall, there was a large quantity of evidence to support VAD selection and insertion decision-making in general hospitalized pediatric patients and specialized populations, such as malignant hematological and oncological, and critically ill pediatric patients. Use of most VADs and their associated complications, especially for PICCs, was well-evidenced within these population groups. Evidence to support the use of single-lumen devices unless otherwise indicated (e.g., for PN) was broadly supported within the literature and in clinical practice guidelines^{28, 29, 33, 34, 54, 57, 60, 67, 84, 85, 96, 97, 99-101}. Similarly, evidence to suggest that VAD insertion assisted by USG techniques reduced complications and improved insertion success was repeatedly reported by high-quality studies and recommended across multiple clinical practice guidelines^{27-29, 34, 60, 63, 67, 84, 85, 95, 98, 101, 103, 105, 118-131}. The strength of the evidence for device selection and insertion in these populations therefore facilitates the implementation of quality clinical decision-making. In comparison, this study highlighted gaps in evidence, especially in the form of randomized control trials, for some pediatric populations, devices and indications. In some pediatric populations, evidence was so sparse that the scope of the review had to be broadened to include adult and laboratory studies. Specific populations, such as neonates, cardiac patients, and patients with difficult venous access relied on a few observational studies, making recommendations on device selection challenging. Similarly, while there was a significant proportion of quality evidence on VADs in patients dependent on long-term PN, there was limited evidence for other long-term VAD dependent populations (e.g., cystic fibrosis). Universally, there was a dearth of evidence evaluating midline catheters for the majority of pediatric indications. The literature for recommendations regarding optimal catheter-to-vein ratio was also limited, therefore this review had to be broadened to include adult and laboratory studies. Finally, while there was abundant evidence to support use of USG

techniques for the majority of device insertions, there was shortage of evidence for the use of other technologies, particularly NIR. As such, further high-quality research evaluating these populations, device types and characteristics, and insertion procedures is warranted.

Although this study undertook a systematic and rigorous review of the available literature, the results should be interpreted with caution and in the context of its limitations. Firstly, we did not undertake formal assessment of the quality of evidence (e.g., using GRADE analysis), however, all individual included studies were independently assessed by two review authors, and their quality indicated by their study methodology, in accordance with the RAND/UCLA methodology.⁹ Additionally, while this study prioritized the review of randomized control trials and systematic reviews as the gold-standard for evaluating VADs, this level of evidence was rarely available. In line with the RAND/UCLA Appropriateness Method, the purpose of this review was to include the best available evidence to provide a synthesis of information to guide panel decision-making.⁹ In order to avoid indications where there was no evidence, we included evidence from lower quality studies (e.g., cross-sectional, surveillance, consecutive cases) and studies outside the initial scope of this review (NICU, adult and laboratory studies). The inclusion of these studies for some indications, means that future clinical decision-making in certain pediatric populations is not guided by strong, evidence-based recommendations. However, most of the evidence that was broadened beyond the original scope of the systematic review was well supported by clinical practice guidelines, suggesting that these findings can be implemented into clinical practice with confidence.

CONCLUSION

This systematic review provides the first synthesis of the breadth of evidence available for the selection and insertion of VADs in pediatric patients, in order to guide clinical decision-making. There was strong evidence to support and facilitate appropriate clinical decision-

making in some pediatric indications. However, certain populations, device types and characteristics, and insertion procedures, were poorly evidenced, necessitating the application of clinical judgment for some indications. Overall, the findings of this review will be vital to inform criteria using the RAND/UCLA Appropriateness Method to determine the appropriateness of VADs in pediatric patients.

Table 2. Summary of Clinical Practice Guidelines and Studies Included in Systematic Review

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
Adams, 2016 ¹⁶	-	Clinical review	Clinical review of midline catheter device indications and complications for use in the Emergency department	-	Midline	Midlines have a low complication rate, long dwell time, and high rate of first-attempt placement	General pediatrics
Aiyagari, 2012 ²²	89	Observational	To compare the clinical outcomes for infants with single ventricle physiology following umbilical catheter and femoral CVAD placement	Patients with single ventricle physiology admitted to NICU (4-13d)	Non-tunneled CVAD, umbilical catheter	Non-tunneled CVADs were associated with higher rates of thrombosis and vein occlusion. No difference between CLABSI, need for transhepatic access, and ultrasound-documented thrombus at the inferior vena caval-right atrial junction. Patients with non-tunneled femoral CVAD for ≥ 14 days had a higher prevalence of thrombosis than those for < 14 days. No difference in the prevalence of iliofemoral vein occlusion.	General pediatrics
Ainsworth, 2015 ⁸¹	549	Systematic review	To evaluate PN delivery via PIVC or CVAD in hospitalized neonates	Included 6 RCTs evaluating PN delivery via PIVC or CVAD in hospitalized neonates	PIVC, non-tunneled CVAD	Non-tunneled CVAD smaller deficit of nutrients, fewer catheters. No difference for invasive infection	Long-term dependent
Alten, 2012 ¹²⁶	115	Observational	To compare USG CVAD insertion to landmark techniques in critically ill neonates	Retrospective review of critically ill neonates ($M = < 14d$) admitted to the PICU requiring CVAD placement using USG or landmark techniques	CVAD	Insertion using USG was associated with higher overall success, first-, and second- attempt success, and lower arterial puncture rates.	Vessel visualization
Anil, 2011 ¹¹²	128	Observational	To evaluate complications associated with CVAD placement in the PICU	Retrospective review of all patients ($Mdn = 21mo$) admitted to the PICU requiring CVAD placement	CVAD	No difference in complications for CVAD insertion at femoral, subclavian or jugular veins	Insertion location
ANZICS, 2012 ¹⁰²	-	CPG	Specific recommendations for insertion central lines for the prevention of CLABSI	-	Non-tunneled CVAD, tunneled CVAD	-	Insertion location

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
Allen, 2008 ⁵⁶		Observational	To determine the risk of infection in pediatric oncology patients requiring long-term vascular access	12 month prospective study of pediatric oncology patients (3mo-20yo) with a totally implantable venous device, or tunneled-cuffed CVAD	Totally implantable venous device, tunneled-cuffed CVAD	Higher rate ratio for CLABSI in tunneled cuffed CVAD	Hematology and oncology
ARC and NZRC, 2010 ⁶⁴	-	CPG	Specific recommendations for access to circulation in infants and children in the context of cardiorespiratory arrest	-	CVAD, intraosseous, PIVC,	-	Critical care
ARC and NZRC, 2010 ⁶⁵	-	CPG	Medication or Fluids for the Resuscitation of the Newborn Infant	-	Intraosseous, PICV, umbilical catheter	Specific recommendations for newborn infants in the context of resuscitation	Critical care
ARC and NZRC, 2010 ²⁵	-	CPG	Specific recommendations for vascular access in pediatric patients in the context of cardiopulmonary arrest	-	CVAD, intraosseous, PICV	-	General pediatrics
Arnts, 2014 ²⁶	203	Observational	To compare the rates of complications between umbilical catheter and PIVCs in newborns	Patients admitted to NICU (24-42 weeks gestation) requiring a PICC or umbilical catheter	PICC, umbilical catheter	No difference in complication rate, or due to gestational age.	General pediatrics
Athale 2012 ⁴⁵	358	Observational	To evaluate the impact of CVAD on 5 year overall and event-free survival in children with cancer	Children with non-CNS cancer (≤19yo) who required a CVAD	CVAD	CVAD dysfunction controlling for thromboembolism is associated with poorer 5 year overall and event-free survival	Hematology and oncology
Avanzini, 2017 ¹⁰¹	194	Observational	To describe a single-center transition from CVAD placement via surgical cut-down to USG insertion techniques	Retrospective review of pediatric patients (7d-18yo) who underwent tunneled CVAD placement using USG or surgical cut-down techniques	Tunneled CVAD	Double-lumen PICCs were associated with increased risk of complications, compared to single-lumen PICCs; Complications reported but not significantly compared between USG and surgical cut-down techniques	Device lumens; Vessel visualization
Barnwal, 2016 ¹⁴³	60	Observational	To compare ECG and landmark insertion techniques CVAD placement	Pediatric patients (0-11yo) undergoing elective cardiovascular surgery were randomly assigned to CVAD insertion via landmark or ECG techniques	CVAD	Fewer complications using USG insertion techniques	Vessel visualization

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
Barrier, 2012 ³³	1280	Observational	To determine risk factors for PICC-related complications in children	Immunocompromised children (<i>M</i> =3.2yo; 0-21yo) requiring a PICC	PICC	Double-lumen catheters, PICCs placed in the femoral vein and children 1-4yo, compared to older children (5-10yo, >10yo), were more at risk of complications	General pediatrics; Device lumens; Insertion location
Baskin, 2019 ⁷⁹	-	CPG	Specific recommendations for central venous catheters in children with chronic illness	-	Midline, PICC, totally implantable venous device, tunneled-cuffed CVAD	-	Long-term dependent
Ben Abdelaziz, 2017 ²¹	215	Observational	To examine the incidence of PIVC-related complications in pediatric patients	Comparison of complications versus no complications in hospitalized children (0.1-18yo) requiring a PIVC	PIVC	Longer duration associated with local complication	General pediatrics
Bezzio, 2009 ⁷⁶	205	Observational	To investigate the rate of and risk factors for infection in children undergoing cardiac surgery requiring CVAD placement	Prospective study of pediatric patients (1d-25yo) undergoing cardiac surgery	CVAD	Infection risk significantly increased with increased duration of device placement; SCV vein more likely to develop CLABSI	Congenital cardiac; Insertion location
Blotte, 2017 ⁸⁰	162	Observational	To compare PICC and CVAD complications in pediatric patients with intestinal failure	Pediatric patients (1d-12yo) with intestinal failure requiring PN	PICC, tunneled-cuffed CVAD	Tunneled cuffed CVAD higher infection rate, PICCs more likely to break. More tunneled cuffed CVADs had central venous thrombosis, more PICCs had basilic vein thrombosis	Long-term dependent
Birhane, 2017 ¹⁰⁴	178	Observational	To assess factors that impacted PIVC lifespan in neonates and infants	Neonates and infants (1d-11mo) requiring PIVC placement	PIVC	Compared to placement at the scalp, hand or leg, PIVCs inserted at the arm had a longer lifespan	Insertion location
Bodenham, 2016 ²⁸	-	CPG	Specific recommendations for the insertion of VADs in all patients	-	CVAD, PIVC	-	Critical care; Catheter-to-vein ratio; Device lumens; Vessel visualization
Boe, 2015 ⁷⁸	92	Observational	To evaluate risk factors and complications associated with the placement of transhepatic CVADs	Retrospective review of congenital cardiac patients (<i>IQR</i> = 2yo-10yo) undergoing	Transhepatic CVAD	Placement ≥21 days associated with increased transhepatic CVAD complications	Critical care

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
				transhepatic CVAD placement			
Borasino, 2014 ¹¹³	392	Observational	To determine if CVAD insertion into veins in the upper body are a risk factor for chylothorax	Retrospective review of pediatric patients (<1yo) undergoing cardiac surgery; comparison between CVAD placement at IJV versus SCV versus femoral vein	CVAD	Insertion at IJV or SCV associated with higher risk of chylothorax	Insertion location
Boretta, 2018 ¹¹¹	107	Observational	To evaluate the management and complications associated with PICCs inserted in pediatric oncology patients	Pediatric oncology patients (0-17yo) requiring PICC placement	PICC	Compared to right-side insertion locations, PICCs inserted on the left-side of the body were associated with more complications	Insertion location
Bouaziz, 2015 ¹²⁰	-	CPG	Specific recommendations for the placement of VADs under USG in all patients	-	CVAD, PIVC	-	Vessel visualization
Bozaan, 2018 ⁹⁹	226	Pilot Study	To evaluate the impact of an intervention designed to increase use of single-lumen PICCs	Pre- and post-intervention of PICC placement in hospitalized adults (60yo)	PICC	Making single-lumen PICCs default option and providing indications for multi-lumen devices increased use of single-lumen PICCs	Device lumens
Bratton, 2014 ⁵⁰	178	Observational	To report complication rates of VADs in children undergoing radiotherapy	Retrospective review of pediatric patients (1-26yo) undergoing radiotherapy who received a VAD	PICC, totally implantable venous device, tunneled-cuffed CVAD	Totally implantable venous devices were associated with lower infection and complication rates, and had greater durability	Hematology and oncology
Byon, 2013 ¹⁰⁶	98	RCT	To evaluate the efficacy of USG SCV catheterization	Pediatric patients (0-2.9yo) undergoing elective congenital cardiac- or neuro-surgery; randomized to supraclavicular or infraclavicular approaches	CVAD	The supraclavicular approach was associated with shorter puncture time, fewer insertion attempts and less misplacement	Insertion location
Camkiran Firat, 2016 ¹⁰⁷	280	RCT	To compare the rate of complications associated with IJV and SCV CVAD insertion	Pediatric patients (16-2.2yo) undergoing cardiac surgery; randomized to IJV or SCV insertion	CVAD	Insertion via the SCV was associated with higher success rates, lower rates of arterial puncture, catheter-tip cultures and CLABSI, and higher rates of malposition. There was no difference in mechanical complications,	Insertion location

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
						ICU and hospital length of stay, and in-hospital mortality	
Campagna, 2018 ¹⁵	1538	Observational	To determine the safety of midline catheters used in general hospitalized adults	Hospitalized adults (<i>Mdn</i> = 83yo) requiring a midline catheter across two Italian hospitals	Midline	10% of midline catheters had a serious adverse event	General pediatrics
Carlson, 2015 ⁷³	3846	Observational	To characterize procedures performed on critically ill children by emergency medical service personnel in out-of-hospital contexts	Retrospective review of pediatric patients (0yo-17yo) requiring out-of-hospital critical care	CVAD, intraosseous	CVADs had higher success rates compared to intraosseous devices	Critical care
Carraro, 2013 ³⁰	-	CPG	Specific recommendations for the use of long-term central venous access in pediatric hematology and oncology patients	-	Totally implantable venous device, tunneled-cuffed CVAD	-	Hematology and oncology
Cesaro, 2016 ⁵⁷	1161	Observational	To report the frequency and associated risk factors for central venous catheter-associated complications in children with hemato-oncological conditions	Pediatric hematology-oncology patients (<i>Mdn</i> = 6.1yo) requiring a tunneled-cuffed CVAD	Tunneled-cuffed CVAD	<6.1yo more mechanical complications, more malfunction/occlusion; Compared to single-lumen devices, double-lumen devices had more mechanical complications, exit-site/tunnel infections and malfunction/occlusion	Hematology and oncology; Device lumens
Chen, 2019 ¹¹⁰	4405	Systematic review	To compare risk associated with PICCs placed in the upper versus the lower extremity in neonates.	Neonates (< 28 do) requiring PICC placement	PICC	Greater risk of non-elective removals and malposition in PICCs placed in the upper vs lower extremity. Lower risk of thrombosis in PICCs placed at the upper extremity. No differences in mechanical complications, PICC-related infection or phlebitis.	Insertion location
Choi, 2017 ¹³⁴	23	Observational	To determine the safety and accuracy of totally implantable venous device placement using USG compared to surgical cut-down	Retrospective review of pediatric (0-16yo) hematology, oncology and PN patients undergoing totally implantable venous device placement	Totally implantable venous device	No difference using USG in insertion time or complication, compared to surgical cut-down	Vessel visualization

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
CLABSI Toolkit ⁹⁷	-	CPG	Specific recommendations for preventing CLABSI in CVADs	-	CVAD	-	Device lumens
Cooling, 2017 ¹¹⁶	75	Observational	To examine the performance and safety of femoral CVADs	Retrospective study of pediatric patients undergoing stem-cell collection (<i>Mdn</i> = 3yo) requiring CVAD placement	CVAD	Compared to thoracic CVADs, femoral CVADs had fewer flow-related adverse events	Insertion location
Crocoli, 2015 ⁶⁰	-	CPG	Central venous access devices in pediatric patients with cancer	-	Midline, PICC, non-tunneled CVAD, totally implantable venous device, tunneled CVAD, tunneled-cuffed CVAD	-	Hematology and oncology; Long-term dependent; Catheter-to-vein ratio; Device lumens; Vessel visualization
Debourdeau, 2009 ⁶¹	-	CPG	Prevention of thrombosis associated with central venous catheters in patients with cancer	-	Totally implantable venous devices, tunneled CVAD	-	Hematology and oncology; Device lumens; Insertion location
De Carvalho Onofre, 2012 ¹²¹	42	RCT	To compare the use of US and palpation insertion success for PICC placement in pediatric patients	Any pediatric patient (1mo-16yo) requiring IV therapy for >7 days; randomized to USG PICC insertion or palpation	PICC	USG PICC insertion was associated with higher first-attempt success rate, better catheter positioning and shorter insertion time	Vessel visualization
de Souza, 2018 ¹²²	80	RCT	To determine if USG PICC placement led to higher insertion success compared to landmark techniques	Critically ill pediatric patients (<i>IQR</i> = 3mo-1.3yo) admitted to the PICU requiring PICC insertion via the IJV; randomized to USG or landmark insertion	PICC	USG PICC insertion associated with higher overall success rate, first- and third-attempt success rate, lower insertion time, and fewer hematomas and arterial punctures, compared to landmark	Vessel visualization
DeWitt, 2015 ¹⁸	180	Observational	To determine procedural success and failure rates in umbilical catheter placement	Patients with congenital heart disease <20 hours old versus >20 hours old requiring a umbilical catheter	Umbilical catheter	Younger: Higher success rate.	General pediatrics

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
Dheer, 2011 ³¹	103	Observational	To compare the rates of immediate insertion-related complications following CVAD placement in pediatric patients	Hospitalized children (<12 yo) requiring a CVAD; comparison of complications between neonate versus infant versus >1-12yo	CVAD	Neonates at higher risk of immediate insertion-related complications, more insertion attempts associated with insertion-related problems	General pediatrics
Doellman, 2015 ³⁴	-	CPG	Specific recommendations regarding central venous catheters that account for the unique needs of pediatric patients	-	Hemodialysis catheter, PICC, non-tunneled CVAD, totally implantable venous device, tunneled CVAD	-	General pediatrics; Hematology and oncology; Critical care; Congenital cardiac; Long-term dependent; Catheter-to-vein ratio; Device lumens; Vessel visualization
Dongara, 2017 ¹⁷	144	RCT	To compare success and complication rates, cost, and insertion time between PICCs and umbilical catheters inserted in the NICU	Patients admitted to NICU (<i>M</i> =34 weeks gestation) requiring a PICC or umbilical catheter	PICC, umbilical catheter	No difference in success rate, time, and short-term complications between PICCs and umbilical catheters	General pediatrics
Elser, 2013 ²⁴	-	Clinical review	Clinical review of umbilical catheter placement	Patients admitted to NICU requiring a umbilical catheter	Umbilical catheter	Umbilical catheter malposition or dislodgement are associated with hemorrhaging and death	General pediatrics
Fallon, 2014 ³⁶	244	Observational	To determine device related complications in infants requiring a VAD	Hospitalized children (0-3yo) requiring a central venous catheter for prolonged therapy	Totally implantable venous device, tunneled CVAD	Infants ($\leq$ 1yo) had higher complication rate, higher operative exchange rate, higher infection rate, shorter duration compared to toddlers ($>$ 1 yo)	General pediatrics
Faustino, 2013 ⁶⁹	101	Observational	To explore the incidence of DVT in PICU patients requiring a central venous catheter	Critically ill children (0-17yo) admitted to PICU; Comparisons made between age (<1yo versus 1-13yo versus 13-17yo)	Non-tunneled CVAD	Compared to infants (<1yo), PICU patients 13yo-17yo had higher odds of DVT	Critical care
Froehlich, 2009 ¹²⁹	93	Observational	To determine if CVAD placement using USG increases insertion success and decreases complications, following single-center transition to USG insertion techniques	Prospective study of critically ill pediatric patients (<i>Mdn</i> – 2.5yo) admitted to the PICU requiring CVAD placement with USG or landmark techniques	CVAD	USG was associated with significantly lower arterial punctures, and fewer number of attempts. No difference in success rate or insertion time between USG and landmark groups	Vessel visualization

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
Frykholm, 2014 ⁸⁴	-	CPG	Specific guidelines for patients requiring central venous catheters regarding vascular approach, USG, and prevention of complications	-	dialysis catheters, non-tunneled CVAD, PICC, totally implantable venous device, tunneled-cuffed CVAD	-	Long-term dependent; Device lumens; Vessel visualization
Gaballah, 2014 ¹⁰⁹	150	Observational	To describe complication rates associated with CVAD placement using USG and fluoroscopic guidance in neonates and infants	Retrospective review of critically ill neonates and infants (Premature-1yo) requiring CVAD placement with USG versus fluoroscopic guidance	CVAD	No difference in complication rates	Insertion location Vessel visualization
Gallagher, 2014 ¹²⁸	168	Observational	To determine whether CVAD placement using USG techniques improved insertion success in pediatric ED patients	Retrospective study of pediatric (3yo-15yo) emergency patients requiring CVAD placement with or without USG	CVAD	Higher insertion success when using USG	Vessel visualization
Gonzalez, 2012 ⁴⁷	172	Observational	To determine if early placement of totally implantable venous devices or tunneled-cuffed CVADs in patients at high risk of thrombosis and infection, led to higher surgical complications	Retrospective review of children with ALL (4d-16yo) at high risk of infection and thrombosis	Totally implantable venous devices, tunneled-cuffed CVADs	No difference for infection rate between totally implantable venous devices and tunneled-cuffed CVADs; No difference in rate of infection in single versus double-lumen devices	Hematology and oncology; Device lumens
Gorski, 2016 ²⁹	-	CPG	Specific practice recommendations for adult and pediatric patients requiring infusion therapy, including device selection, placement and complication prevention	-	Hemodialysis catheters, intraosseous, long PIVC, midline, non-tunneled CVAD, PICC, short PIVC, totally implantable venous device, tunneled CVAD,	-	Critical care; Congenital cardiac; Long-term dependent; Catheter-to-vein ratio; Device lumens; Vessel visualization

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
					umbilical catheter		
Gray, 2012 ³⁵	333	Observational	To identify risk factors for catheter-related DVT in infants younger than 1yo	Hospitalized infants (<i>M</i> = 34 weeks gestation) requiring a VAD	PICC, tunneled-cuffed CVAD	Mean catheter days before DVT diagnosis shorter for PICCs than tunneled cuffed CVADs; Higher rates of DVT in multi-lumen CVADs; Majority of DVT was in femoral veins. Femoral CVADs were associated with greater DVT rates than jugular or SCV CVADs. More DVT in femoral lines than sapheno-femoral tunneled cuffed CVADs.	Long-term dependent; Device lumens; Insertion location
Gurien, 2016 ¹²⁵	1134	Observational	To determine the incidence of complications associated with CVAD placement using USG techniques	Retrospective, multi-center review of pediatric patients (1.5-12yo) who underwent CVAD placement with landmark or USG insertion	CVAD	Higher first attempt success rate using USG. Higher risk of hemothorax using USG	Vessel visualization
Habas 2018 ¹¹⁴	225	Observational	To determine the complications associated with CVAD placement at the BCV insertion site	Retrospective review of pediatric patients (<i>M</i> = 7yo) admitted to PICU requiring CVAD placement; BCV insertion site versus all others (femoral, subclavian, jugular)	CVAD	Compared to other insertion sites, BCV had fewer complications	Insertion location
Hamed, 2013 ⁷⁵	300	Observational	To describe insertion success rate and complication rate following delivery of anesthesia to critically ill infants and toddlers	Critically ill infants and toddlers (21d-1.3yo) requiring emergency surgery	Intraosseous	Intraosseous access appropriate for unobtainable peripheral or central access	Critical care
Hancock-Howard, 2010 ¹³⁵	60	Observational	To determine the cost-effectiveness of totally implantable venous device placement using interventional radiology	Retrospective review of pediatric oncology patients undergoing placement of a totally implantable venous device using interventional radiology (<i>M</i> = 7yo) or surgical cut-down (<i>M</i> = 4yo) techniques	Totally implantable venous device	Insertion time was shorter and resulted in fewer complications using interventional radiology, compared to surgical cut-down	Vessel visualization

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
Handrup, 2010 ⁵⁵	98	Observational	To evaluate the rates of VAD-related complications associated with placement of a totally implantable venous device or tunneled-cuffed CVAD	Retrospective review of children with ALL (<4yo to >9yo) who received a totally implantable venous device or tunneled-cuffed CVAD over an eight-year period	Totally implantable venous devices, tunneled-cuffed CVADs	Higher CLABSI rate and non-elective removal for tunneled-cuffed CVAD	Hematology and oncology
Hanson, 2012 ⁷²	1070	Observational	To investigate the rate of and risk factors for VTE in children with cardiac disease admitted to the PICU	Children with cardiac disease (<i>Mdn</i> = 10mo) admitted to the PICU. Comparisons made between <6mo versus 6mo-1yo versus 1-2yo versus 2-12yo versus 12-18yo versus. >18yo	CVAD	VTE incidence was associated with increasing number of CVAD days. In young children (<6mo) VTE incidence was significantly higher	Critical care
Heinrichs, 2013 ¹⁴⁰	1076	Systematic review	To evaluate assistive technologies, other than USG, in improving PIVC insertion success	Seven randomized control trials of pediatric patients (0-21yo) requiring PIVC insertion using novel interventions	PIVC	Transillumination was associated with higher first-attempt success compared to traditional insertion techniques; first-attempt success using NIR and traditional methods not significantly different. No difference in time or number of attempts between insertion methods. Included studies: <i>Hosokawa 2010; Katsogridakis 2008; Nager 1992; Perry 2011; Chapman 2011; Kim 2012; Maynard 1089</i>	Vessel visualization
Institute for Healthcare Improvement, 2012 ¹⁰³	-	CPG	Specific recommendations for the prevention of CLABSI	-	CVAD	-	Vessel visualization
IVNNZ, 2012 ⁶⁷	-	CPG	Specific practice recommendations for adult and pediatric patients requiring infusion therapy, including device selection, placement and complication prevention	-	Intraosseous, midline, non-tunneled CVAD, PICC, totally implantable venous	-	Critical care; Long-term dependent; Device lumens; Vessel visualization

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
					device, tunneled CVAD, umbilical catheter		
Katsogridakis, 2008 ¹³⁷	240	Observational	To determine if transillumination increases PIVC insertion success in pediatric patients	Pediatric patients (<i>M</i> = 13yo) with difficult venous access admitted to the emergency department requiring non-urgent PIVC placement; randomized to with or without transillumination	PIVC	Insertion using transillumination associated with higher first- and second-attempt success, compared to without transillumination	Vessel visualization
Kim, 2017 ¹⁰⁵	132	RCT	To compare USG to landmark techniques for CVAD insertion in children	Pediatric cardiac -, neuro- or general surgical patients (1mo-6yo) requiring CVAD insertion; randomized to USG insertion to the axillary vein or LM insertion via the SCV	CVAD	USG + Axillary insertion was associated with fewer attempts, shorter insertion time. No difference in complication rates. Results confounded by location/imaging	Insertion location; Vessel visualization
Kulkarni, 2014 ⁴⁸	-	Systematic review	A systematic review of totally implantable venous devices and tunneled-cuffed CVADs in adults and children receiving chemotherapy	5 RCT's and 25 Observational studies of adults and children undergoing chemotherapy	Totally implantable venous devices, tunneled-cuffed CVADs	Tunneled CVAD associated more infections, non-infectious complications, and device removal.	Hematology and oncology
Kulkarni, 2017 ⁴⁹	176	Observational	To describe the complications related to VAD insertion in babies with hemophilia	Babies (0-2yo) with hemophilia requiring either a PICC, totally implantable venous device or tunneled CVAD	PICC, totally implantable venous device, tunneled CVAD	Totally implantable venous devices had the lowest rates of complications	Hematology and oncology
Lam, 2018 ¹⁰⁰	954	Observational	To evaluate the impact of defaulting to single-lumen PICCs	Hospitalized adults (<i>M</i> = 66yo) requiring PICC placement; comparison of single versus double lumens	PICC	Single-lumen PICCs were associated with lower complications	Device lumens
Lamperti, 2012 ⁹⁵	-	CPG	Specific recommendations regarding ultrasound-guided vascular access device placement	-	CVAD, PICC	-	Catheter-to-vein ratio; Vessel visualization
Lau, 2016 ¹³¹	760	Systematic review	To examine the safety and efficacy of CVAD insertion using USG	8 RCTs comparing the use of USG and landmark CVAD	CVAD	USG had higher success rate and fewer number of insertion attempts	Vessel visualization

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
				placement in pediatric patients (<18 years)		compared to landmark techniques Included studies: <i>Alderson 1993;</i> <i>Vergheze 1999;</i> <i>Vergheze 2000;</i> <i>Grebenik 2004;</i> <i>Chuan 2005;</i> <i>Ovezov 2010;</i> <i>Aouad 2010;</i> <i>Bruzoni 2013</i>	
Levy, 2010 ⁴⁰	279	Observational	To determine the rate of and potential risk factors for infectious and non-infectious complication associated with PICCs in pediatric patients	Hospitalized children (10d-21yo) requiring a PICC	PICC	Older age associated with infectious complications	General pediatrics
Lindquester, 2017 ¹¹⁷	33	Observational	To examine the safety and efficacy of tunneled CVAD placement at the internal and external jugular in neonates and infants <5 kg	Multi-center retrospective review of hospitalized infants weighing <5kg (0-1yo) with a tunneled CVAD	Tunneled CVAD	No difference in complications associated with jugular and femoral vein insertion locations	Insertion locations
Loveday, 2014 ⁹⁶	-	CPG	Specific recommendations for the prevention of hospital-acquired infections	-	PICC, totally implantable venous device, tunneled CVAD	-	Long-term dependent; Device lumens
Malbezin, 2013 ⁴³	5435	Observational	To prospectively determine the overall success and complication rate of CVAD insertion over a 22 year period	Hospitalized children (<i>M</i> =5yo) requiring any CVAD	CVAD	Device failure more likely in children <3kg	General pediatrics
Marshall, 2017 ⁷⁷	19	Observational	To compare tranhepatic CVADs to non-tunneled CVADs as an alternative for preserving future central venous access	Retrospective review of infants (1.8-7.8mo) with congenital heart disease who underwent placement of one or more tranhepatic CVADs	Non-tunneled CVAD, tranhepatic CVAD	Transhepatic CVAD longer duration. No difference in thrombi, thrombolytic burden, or catheter sites requiring wound care consultation. Higher frequency of infection in tranhepatic CVAD. No difference in rate of infection-related removal.	Congenital cardiac
Marquez, 2016 ¹¹⁵	175	Observational	To determine risk factors for thrombosis following placement of non-tunneled CVADs in PICU patients	Prospective, multi-center study of pediatric patients (4mo-8.6yo) admitted to the PICU undergoing CVAD placement	Non-tunneled CVAD	Higher rates of DVT in patients with right-side non-tunneled CVAD placement, and insertion at SCV	Insertion location

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
May, 2018 ⁸²	912	Observational	To determine the rates of thrombosis, infection, and insertion site symptoms following placement of PICCs and totally implantable venous devices in patients with cystic fibrosis	Retrospective review of adult and pediatric patents (<i>M</i> = 7.4yo) with cystic fibrosis	PICC, totally implantable venous device	Double-lumen PICCs were associated with greater rates of complications	Long-term dependent; Device lumens
Menéndez, 2016 ⁹²	256	Observational	To evaluate the incidence and risk factors for PICC-related thrombosis in children	Hospitalized children (<i>IQR</i> = 2.4-13yo) requiring PICC placement	PICC	Catheter/vein ratio of >0.33 predicted PICC-related superficial vein thrombosis and DVT	Catheter-to-vein ratio
Mermel, 2009 ⁸⁶	-	CPG	Specific recommendations for the prevention of catheter-related Infection	-	CVAD, midline, PICC, PIVC, totally implantable venous device	-	Long-term dependent
Moon, 2018 ⁵³	629	Observational	To determine risk factors for CLABSI in children hemato-oncological disease requiring long-term VADs	Retrospective review of children with hemato-oncologic disease (<i>Mdn</i> = 6yo; 14d-17.9yo) requiring any long-term CVAD	totally implantable venous device, tunneled-cuffed CVAD	No difference in rate of CLABSI	Hematology and oncology
Mushtaq, 2018 ¹⁴	693	Observational	To determine the safety, specifically: rates of CLABSI, mechanical complications, hospital length of stay, readmission within 90 days of discharge, and mortality of midline catheters compared to CVADs in adults admitted to intensive care	Adults > 18yo admitted to the ICU or medical-surgical ward with either a CVAD or midline catheter	CVAD, midline	CVADs were associated with higher rates of CLABSI, crude mortality, readmission, transfer to ICU. Midline catheters had more mechanical complications	General pediatrics
NANN, 2015 ²⁷	-	CPG	Specific recommendations for vascular access in neonates and infants	-	Midline, PICC, PIVC, totally implantable venous device, tunneled CVAD, umbilical catheter	-	General pediatrics; Congenital cardiac; Catheter-to-vein ratio; Vessel visualization
Noailly Charny, 2018 ²	295	Observational	To compare the risk of thrombosis in PICCs and tunneled-cuffed CVADs	Children (<18yo) diagnosed with leukemia who received a PICC or tunneled-cuffed CVAD	PICC, tunneled-cuffed CVAD	PICCs associated with increased risk of thrombosis	Hematology and oncology

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
Nifong, 2011 ⁹⁴	-	Laboratory study	To determine the effect of catheter size of fluid flow rates	-	PICC	Fluid flow rate decreases with increasing catheter size	Catheter-to-vein ratio
O'Grady, 2011 ⁹⁸	-	CPG	Specific recommendations for the prevention of intravascular catheter-related infections	-	Midline, non-tunneled CVAD, PICC, PIVC, totally implantable venous device, tunneled CVAD	-	Device lumens; Vessel visualization
Ohno, 2016 ³⁷	120	Observational	To determine the rates of complications and CLABSI in babies and small infants (<1yo or <10kg) compared to children (>1 yo or >10kg)	Children (4mo-22yo) requiring a totally implantable venous device	Totally implantable venous device	Age not associated with increased risk of complications	General pediatrics
Oulego-Eroz, 2016 ¹⁰⁸	46	Pilot Study	To determine whether CVAD insertion to the BCV using USG techniques had greater insertion success compared to insertion to the IJV	Prospective study of critically ill children (0.6mo-13yo) requiring urgent CVAD insertion; non-random assignment to BCV+USG or IJV insertion	CVAD	BCV+USG had higher first attempt success rate, fewer insertion attempts and lower insertion time, compared to IJV. No difference in overall success rates	Insertion location; Vessel visualization
Oulego-Eroz, 2018 ¹²³	500	Observational	To determine if CVAD placement outcomes can be improved using USG insertion	Prospective, multi-centre study of all critically ill children (<i>IQR</i> = 2mo-4.9yo) requiring temporary CVAD placement using USG or landmark techniques	CVAD	USG had higher first attempt success rate, and fewer puncture attempts and mechanical complications	Vessel visualization
Pacilli, 2018 ³⁹	18	Observational	To determine the appropriateness of long PIVCs in pediatric patients undergoing surgery	Children undergoing surgery (<i>M</i> = 6.3yo) requiring long PIVC insertion	Long PIVC	No immediate complications. Day 3: removals due to 3 occlusions and one red/pain.	General pediatrics
Palandini, 2018 ⁶⁶	40	Pilot	To compare the success of ultrasound guided long PIVC insertion in children admitted to the emergency department to short PIVCs	Children > 10 yo (<i>M</i> = 13yo) who were admitted to the emergency study; comparison of blind short PIVC versus USG PIVC insertion	Long PIVC, short PIVC	Short PIVCs had a shorter dwell time duration, and more complications compared to long PIVCs; USG had lower risk of failure and complications, but results confounded	Critical care; Vessel visualization
Park, 2016 ¹³⁶	3832	Systematic review	To determine the utility of NIR light devices	11 randomized control trials of any pediatric patient (<21yo)	PIVC	No overall difference in overall success rate between NIR and	Vessel visualization

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
				undergoing PIVC placement using NIR or no assistive device		traditional methods, however NIR had higher success rate for subsets deemed high risk of failure; Included studies: <i>Chapman 2011;</i> <i>Perry 2011;</i> <i>Kaddoum 2012;</i> <i>Kim 2012;</i> <i>Cuper 2013;</i> <i>Graaff 2013;</i> <i>Sun 2013;</i> <i>Szmuk 2013;</i> <i>Woude 2013;</i> <i>Graaff 2014;</i> <i>Curtis 2015</i>	
Pasteur, 2010 ⁴²	-	CPG	Specific recommendations for patients with non-CF bronchiectasis	-	Totally implantable venous devices	-	Long-term dependent
Peterson, 2012 ¹³⁸	1399	Observational	To determine if assistive devices improve PIVC insertion success	Hospitalized children (<i>M</i> = 1yo) requiring PIVC placement; randomized to unassisted versus assisted (transillumination versus NIR guided) insertion	PIVC	PIVC insertion success was higher when no assistive device was used compared to assisted methods	Vessel visualization
Perin, 2015 ¹⁴¹	-	Systematic review	To review evidence related to the assessment of catheter tip positioning in pediatric patients	Included 42 pediatric studies examining outcomes for patients undergoing vascular access device placement using vessel visualization techniques	CVAD, PICC, umbilical catheter	Insufficient high-quality evidence to make specific recommendation for use in pediatric patients	Vessel visualization
Pinon, 2009 ⁵⁴	915	Observational	To determine the incidence and risk factors of central venous catheter-related complications in pediatric hemato-oncological and immunological conditions	Single-center, prospective study of children (0-19yo) with oncological, hematological, or immunological diseases	Totally implantable venous device, tunneled CVAD	Tunneled-cuffed CVADs associated with more CLABSI; ≤3yo associated with more dislodgements, more tunnel infections; CLABSI was more prevalent in double versus single-lumen devices	Hematology and oncology; Device lumens

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
Pittiruti, 2009 ⁸⁵	-	CPG	Specific recommendations for central venous access, devices and complication prevention in patients requiring parenteral nutrition	-	Midline, PICC, PIVC, totally implantable venous device, tunneled CVAD	-	Long-term dependent; Device lumens; Vessel visualization
Polkinghorne, 2013 ¹¹⁸	-	CPG	Specific recommendations for vascular access in patients with chronic renal disease	-	Non-tunneled CVAD, tunneled CVAD	-	Vessel visualization
Qian, 2014 ⁸³	40	Observational	To examine complication rates in pediatric patients with CF following the placement of a long PIVC	Prospective audit of pediatric patients with CF with infective exacerbation	Long PIVC	Complication rates were high, no serious adverse outcomes.	Long-term dependent
Ramer, 2016 ¹³⁹	53	RCT	To evaluate the effectiveness of NIR light technology for PIVC placement in pediatric hematology and oncology patients	Pediatric hematology and oncology patients (1-21yo) requiring PIVC placement; randomized to NIR or landmark insertion techniques	PIVC	NIR was associated with faster insertion time and higher satisfaction	Vessel visualization
Rauth, 2008 ⁷¹	138	Observational	To investigate the rate of infection in infants when the venous catheter is exchanged for a tunneled-cuffed CVAD following ECMO decannulation	PICU patients (<i>M</i> = 13d) requiring CVAD placement following decannulation from ECMO	Tunneled-cuffed CVAD	Increasing duration of ECMO and CVAD placement independently predicted CLABSI	Critical care
Revel-Vilk, 2010* ⁵¹	423	Observational	To determine the rate of catheter-related complications in children undergoing chemotherapy during 12 months of therapy	Single-center, prospective study of pediatric patients (29d-28yo) undergoing chemotherapy	PICC, tunneled-cuffed CVAD	PICCs were associated with a higher risk of DVT; tunneled CVAD had a higher risk of occlusion at 1 year	Hematology and oncology
Rey, 2009 ⁹¹	825	Observational	To identify risk factors for early mechanical complications in CVADs	Pediatric patients (<i>Mdn</i> = 22mo) admitted to the PICU; comparisons between femoral, jugular and SCV CVAD insertion sites	CVAD	SCV and jugular vein, and increasing number of attempts, were associated with significantly more early mechanical complications	Difficult venous access; Insertion site
Rivera-Tocancipa, 2018 ¹²⁴	201	Observational	To describe the incidence of complications associated with USG CVAD insertion in children, compared to anatomical landmark techniques	All hospitalized children (0-18yo) requiring CVAD insertion using USG or LM insertion techniques	CVAD	USG had fewer immediate complications, no arterial punctures and higher rates of insertion success compared to landmark techniques	Vessel visualization

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
Rosado, 2013 ⁷⁰	255	Observational	To examine the rate of CVAD-associated infection in PICU patients	Prospective, single-center review of children (majority <6yo) admitted to the PICU requiring a CVAD	CVAD	CVADs inserted ≥7 days were associated with higher risk of CLABSI	Critical care
Rossetti, 2015 ¹⁴⁴	309	Observational	To investigate the safety and accuracy of intracavitary ECG guided insertion in pediatric patients	Prospective, multi-center study of hospitalized pediatric patients (1mo-18yo) requiring a vascular access device; insertion using nontu vs. intracavitary ECG with dedicated ECG monitor compared	CVAD, PICC	Insertion accuracy higher with dedicated ECG monitor	Vessel visualization
Schiffer, 2013 ⁶³	-	CPG	Specific recommendations for central venous catheters in patients with cancer	-	Non-tunneled CVAD, PICC, tunneled CVAD, totally implantable venous device	-	Hematology and oncology; Vessel visualization
Sharp, 2015 ⁹³	136	Observational	To identify the optimal ratio cut-off to reduce rates of VTE	Prospective study of hospitalized adults (<i>M</i> = 57yo) requiring PICC insertion, comparison between ≤45% versus ≥45% catheter-to-vein ratio	PICC	>45% ratio more likely to develop VTE	Catheter-to vein ratio
Shenep, 2017 ⁴⁴	90	Observational	To determine the interaction between parenteral nutrition and external central venous devices in increasing risk of complications	Rates of complications during PN and non-PN periods in pediatric oncology patients (<i>Mdn</i> 7.3yo) requiring central venous devices	Totally implantable venous device, tunneled CVAD	Risk of CLABSI was higher during PN for children with totally implantable venous devices. Occlusion risk was higher for totally implantable venous devices. Complication rates for totally implantable venous devices were lower during the non-PN period but similar during the PN period.	Loong-term dependent

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
Sibson, 2018 ⁶²	-	CPG	Specific recommendations for preventing thrombosis in pediatric patients with cancer	-	PICC, PIVC, totally implantable venous device, tunneled CVAD	-	Hematology and oncology
Sigaut, 2009 ¹³³	359	Systematic review	To evaluate the advantages of USG CVAD placement cover anatomical landmarks in pediatric patients	Children (2d-8yo) undergoing cardiac surgery requiring CVAD.	CVAD	For USG: No difference in rates of artery puncture, hematoma, hemathorax, pneumothorax, or time to insert. USG had higher success rates for subsets of novice operators, and during intraoperative use. Included studies: <i>Alderson 1993; Chuan 2005; Vergheze 1999; Vergheze 2000; Grabenic 2004</i>	Vessel visualization
Smitherman, 2015 ³²	1135	Observational	To determine risk factors for the development of catheter-associated VTE in general hospitalized pediatric patients	Chart review of hospitalized children (<i>M</i> = 8yo) requiring a VAD	PICC	Increasing age related with an increased risk of thrombosis; Lumen number not associated with thrombosis risk; Insertion site (brachial/cephalic, SCV, jugular, or femoral/saphenous) was not associated with an increased risk of thrombosis	General pediatrics; Device lumens; Insertion location
Takeshita, 2015 ⁸⁹	96	Observational	To examine the factors that affect insertion success for invisible and impalpable peripheral veins in children	Pediatric patients (1.1-2.8yo) with invisible or impalpable veins undergoing elective surgery	PIVC	PIVC with USG had better success rates compared to PIVC without USG; Compared to insertion to the dorsal hand vein, the cephalic vein had a higher success rate and shorter insertion time	Difficult access; Insertion location; Vessel visualization
Takeshita, 2015 ⁸⁹	196	RCT	To examine the factors that affect insertion success for invisible and impalpable peripheral veins in children	Pediatric patients 10-40mo) with invisible or impalpable veins undergoing elective surgery	PIVC	Compared to insertion to the dorsal hand or saphenous vein, the cephalic vein had a higher success rate	Insertion location

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
Tripi, 2016 ²⁰	108	Observational	To determine the frequency of PIVC-related dysfunction in pediatric patients	Compared PIVC dysfunction in hospitalized children (0- >12yo) over device durations of 1-2d versus 2-3d versus >3d	PIVC	Higher rates of PIVC dysfunction associated with PIVCs in place for >3 days or inserted in lower extremities	General pediatrics
Troianos, 2011 ¹¹⁹	-	CPG	Specific recommendations for vascular access device placement using ultrasound guidance in pediatric patients	-	CVAD, PICC, PIVC	-	Vessel visualization
Ullman, 2015 ⁶	31933	Systematic review	To review the incidence of vascular access device failure in pediatric patients	Hospitalized pediatric patients, across 74 studies, requiring any VAD	Hemodialysis catheter, non-tunneled CVAD, PICC, totally implantable venous device, tunneled CVAD, umbilical catheter	Hemodialysis catheters and umbilical catheters highest failure rate; TIVDs lowest failure.	General pediatrics
Ullman, 2017 ¹	1027	Observational	To examine the prevalence, management and associated complications of CVADs in pediatric patients	Hospitalized pediatric patients (<i>IQR</i> = 1-12 yo), requiring any VAD	Hemodialysis catheter, non-tunneled CVAD, PICC, totally implantable venous device, tunneled CVAD, umbilical catheter	PICCs had higher proportions of CVAD-associated complications in the previous 7 days	General pediatrics
Unbeck, 2015 ¹⁹	2032	Observational	To identify risk-factor for PIVC-associated complications in pediatric patients	Comparison of hospitalized neonatal versus pediatric patients (0-18yo) requiring a PIVC	PIVC	Occlusion associated with longer dwell time. Neonatal: PIVC survival time shorter, more infiltration; Insertion at the arm bend or ankle associated with higher rates of infiltration and occlusion	General pediatrics; Insertion location
van Gent, 2017 ⁴⁶	538	Observational	To determine the rates of infection and complications in pediatric hematology, oncology and stem cell transplant patients	Retrospective review of pediatric patients (<i>M</i> = 7.8yo) following	Totally implantable venous device,	Tunneled cuffed CVAD lower risk of infection	Hematology and oncology

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
				surgical placement of any CVAD	tunneled-cuffed CVAD		
Vierboom, 2018 ¹³⁰	232	Observational	To evaluate the safety of tunneled CVAD insertion in children weighing <10kg	Retrospective review of all children (<1mo-4yo) receiving surgical insertion of a tunneled CVAD with USG or via surgical cut-down	Tunneled CVAD	USG insertion was associated with lower mechanical blockages, but there was no difference in intraoperative and post-operative complications, time to insert or device longevity	Vessel visualization
Vinograd, 2018 ⁸⁸	300	Observational	To evaluate PIVC insertion success in patients with difficult venous access using USG techniques	Pediatric patients (<i>Mdn</i> = 14yo) in an emergency department who had a failed PIVC attempt via traditional insertion techniques	PIVC	PIVC using USG techniques led to 68% and 87% first and second attempt success rates after failed traditional method.	Difficult access; Vessel visualization
Voigt, 2012 ⁷⁴	-	Systematic review	To review the evidence for the use of intraosseous devices in emergent contexts	Studies evaluating IOs in patients requiring emergent vascular access or nonhuman randomized prospective studies	Intraosseous	Compared to alternative access, no difference in complications using intraosseous devices	Critical care
Wiegeling, 2014 ⁵²	43	Observational	To determine the incidence of catheter-related thrombosis in pediatric oncology patients	Single-center retrospective review of pediatric oncology patients (<i>M</i> = 9.4yo) requiring central venous access	Totally implantable venous device, tunneled-cuffed CVAD	Totally implantable venous devices showed an earlier peak of thrombosis occurrence, than tunneled cuffed CVAD catheters; Highest incidence of thrombosis occurred in the SCV, followed by external jugular and cephalic sites. No difference in complications between insertion at the left- and right-side	Hematology and oncology; Insertion location
White, 2012 ⁵⁸	322	Observational	To compare the rate of complications and early removal between totally implantable venous devices and tunneled-cuffed CVADs	Retrospective review of children (1mo-19yo) with ALL requiring a totally implantable venous device or a tunneled-cuffed CVAD	Totally implantable venous device, tunneled-cuffed CVAD	Totally implantable venous devices had less complications	Hematology and oncology
Wragg, 2014 ⁴¹	100	Observational	To determine the rate of occlusion associated with tunneled-cuffed CVAD insertion under USG	Children (21d-16yo) requiring elective or	Tunneled-cuffed CVAD	Complete venous occlusion was associated with younger age	General pediatrics; Vessel visualization

Study, year ^{ref}	Participants, <i>n</i>	Design / Method	Focus / overview	Study sample and characteristics	Device	Findings and comments	miniMAGIC indication
				emergency removal of a tunneled-cuffed CVAD			
Wu, 2013 ¹³²	508	Systematic review	To evaluate whether US guided CVAD insertion was more successful compared to anatomical landmark techniques	Meta-analysis of RCTs comparing USG versus landmark CVAD insertion in pediatric patients (<i>Ms</i> = 0.5- <8yo)	CVAD	Few pediatric studies (<i>n</i> = 2), which limited analysis. For USG: no reduction in the risk of cannulation failure, arterial puncture, hematoma, pneumothorax, and hemothorax in children or infants.	Vessel visualization
Xia, 2016 ⁶⁸	48	RCT	To determine the efficacy and rate of complications in pediatric patients with moderate to severe burn injuries.	Pediatric patients (<i>M</i> = 2.2yo) with moderate to severe burn injuries	PICC, PIVC	Higher one-time puncture success rate, longer retention duration and complication for PICCs compared to PIVCs	Critical care
Yacobovich, 2015* ⁵⁹	423	Observational	To determine patient- and catheter-related risk factors for CLABSI in children receiving chemotherapy	Prospective study of pediatric patients (29d-28yo) receiving chemotherapy requiring a VAD	PICC, totally implantable venous device, tunneled-cuffed CVAD	Tunneled cuffed CVADs and PICCs higher risk for CLABSI in group of diseases with lower rate of infection. In diseases with high rate of infection, no difference	Hematology and oncology
Zanolla, 2018 ¹²⁷	51	RCT	To determine whether USG techniques reduce number of puncture attempts, procedure time, and complication rates during CVAD insertion via the IJV in children	Prospective study of any child (11mo-9yo) requiring CVAD insertion via the IJV. Patients were randomized to USG versus landmark insertion groups.	CVAD	USG techniques required fewer attempts, took less time and resulted in fewer complications, compared to landmark techniques	Vessel visualization
Zengin, 2013 ⁹⁰	64	Observational	To determine risk factors for CVAD-related complications in children admitted to ED	Retrospective review of pediatric patients (2-16yo) admitted to the emergency department	Non-tunneled CVAD	>3 attempts was associated with more complications,	Difficult venous access
Zhou, 2017 ¹⁴²	281	Observational	To evaluate the feasibility and safety of intracavitary electrocardiogram technique in guiding PICC placement in neonates	Hospitalized neonates (27-41 weeks) requiring PICC placement, using landmark techniques or intracavitary ECG guidance	PICC	Intracavitary ECG guided PICC placement had higher correct tip position on the first attempt, compared to landmark techniques	Vessel visualization

*Same sample; Strength of Evidence: = High (Clinical Practice Guideline [CPG], Systematic Review); = Moderate (Randomized Control Trial [RCT]); = Low (Observational Study [with comparator], Other [e.g., clinical review or pilot study]); ALL = acute lymphoblastic leukemia; BCV = brachiocephalic vein; CLABSI = central line-associated bloodstream infection; CVAD = central venous access device; d = days; ED = emergency

department; IJV = internal jugular vein; *IQR* = interquartile range; *M* = mean; *Mdn* = median; mo = months old; NICU = neonatal intensive care unit; NIR = near infrared light device; PICC = peripherally inserted central catheter; PICU = pediatric intensive care unit; PIVC = peripheral intravenous catheter; SCV = subclavian vein; USG = ultrasound guidance; VAD = vascular access device; yo = years old

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Figure Legend

Figure 1. PRISMA flow chart of study selection

Figure 2. Quantity of evidence based on patient subgroup