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ARTICLE

Chinese Expert Consensus on the Prevention and Management of Thrombosis Associated with Central Venous Catheters in Children with Congenital Heart Disease

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ABSTRACT: Objective: To develop the Chinese expert consensus on the prevention and management of central venous catheter (CVC)-related thrombosis in children with congenital heart disease (CHD) (hereafter referred to as the Consensus), with the aim of standardizing and improving preventive and therapeutic strategies for CVC-related thrombosis in pediatric patients with CHD. **Methods:** The consensus was formulated in strict accordance with the principles of evidence-based medicine by a multidisciplinary panel of experts. Evidence was appraised and synthesized using the JBI Evidence Grading System. The initial draft was refined through two rounds of Delphi consultations involving 16 experts and one expert panel meeting with 15 participants. Statistical analyses demonstrated a high level of agreement among experts, leading to the establishment of a strong consensus. Subsequently, between September and November 2025, the document underwent further revision through an additional two rounds of Delphi surveys (n = 16) and one expert deliberation meeting (n = 15). Quantitative methods were employed to assess expert participation, authority, and the degree of consensus. **Results:** A two-round Delphi consultation was conducted with 16 experts per round, achieving a 100% effective response rate in both rounds. Fourteen experts provided constructive suggestions in the first round, and two in the second round. The expert authority coefficient (Cr) was 0.93 (familiarity coefficient 0.91, judgment basis coefficient 0.94). In the first round, item-level coefficients of variation (CVs) ranged from 0.05 to 0.21, and Kendall's coefficient of concordance (W) was 0.158 (χ^2 = 68.342, p < 0.001). In the second round, CVs narrowed to 0–0.15 and Kendall's W increased to 0.191 (χ^2 = 72.565, p < 0.001), indicating improved consensus. Subsequently, a panel review meeting with 15 experts (100% participation, Cr = 0.91) yielded CVs of 0–0.12 and Kendall's W of 0.224 (χ^2 = 59.118, p < 0.001), demonstrating good consistency. Through this iterative process, the final consensus was established. **Conclusions:** The development of this consensus was methodologically rigorous, characterized by a highly representative expert panel and a strong level of agreement. It provides clinical nursing professionals with a structured and standardized framework for the prevention and management of CVC-related thrombosis in children with CHD. The consensus holds substantial clinical value in guiding standardized practice, reducing the incidence of thrombosis, and improving patient outcomes.

KEYWORDS: Congenital heart disease; central venous catheter; thrombosis; prevention and management; expert consensus

1 Introduction

Central venous catheter (CVC) plays a pivotal role in perioperative management and long-term nutritional support for pediatric patients with congenital heart disease (CHD), particularly those who are critically ill [1]. However, prolonged CVC placement in this population is associated with a substantial risk of complications. Among these, catheter-related thrombosis (CRT) is relatively common, with an incidence

ranging from 4% to 15% [2], and may be life-threatening. The underlying pathophysiological features of CHD, including structural cardiac abnormalities, altered hemodynamics, and coagulation dysfunction, markedly increase the risk of thrombosis compared with that in the general pediatric population [3,4]. Once CRT develops, it may lead to catheter dysfunction and interruption of therapy, and can precipitate severe thromboembolic events such as pulmonary or cerebral embolism [5]. These complications not only pose an immediate threat to life but also negatively impact long-term prognosis and quality of life [6,7]. Most existing clinical guidelines are broadly designed for hospitalized pediatric populations and lack specificity for children with CHD. In contrast, the present consensus is the first to specifically address this high-risk group, characterized by frequent CVC utilization and a correspondingly elevated risk of thrombosis.

At present, standardized, multidisciplinary clinical practice guidelines for the prevention and management of CRT in pediatric patients with CHD remain lacking. This gap presents significant challenges for healthcare providers in terms of risk stratification, preventive strategies, and clinical management, underscoring the urgent need for unified and evidence-based practice standards [8,9]. To address this unmet need and improve patient outcomes, the *Chinese Expert Consensus on the Prevention and Management of CVC-Related Thrombosis in Children* with CHD was developed. This consensus was formulated by a panel of experts from multiple disciplines, including pediatric cardiology, cardiac surgery, critical care medicine, clinical nursing, and evidence-based medicine. A rigorous methodological framework was employed, incorporating systematic literature review, critical appraisal of existing evidence, and integration of extensive clinical experience from leading domestic medical centers. Through multiple rounds of expert consultation, discussion, and revision, a set of clear, practical, and evidence-informed recommendations was established.

This consensus is intended to provide healthcare professionals with a comprehensive and structured framework for CRT management in children with CHD. It encompasses key domains such as risk assessment, preventive measures, monitoring and early identification, therapeutic interventions, and patient and family education. By promoting standardized and multidisciplinary clinical practice, the consensus aims to enhance care quality, reduce the incidence and burden of CRT, and ultimately improve clinical outcomes for pediatric patients with CHD both in China and globally.

2 Methodology for Consensus Development

This consensus was developed in strict accordance with the principles of evidence-based medicine, incorporating multiple rigorous methodological approaches to ensure both scientific validity and clinical applicability [10,11]. First, the Joanna Briggs Institute (JBI) Evidence-Based Healthcare methodology was applied to conduct a comprehensive and systematic search, appraisal, and synthesis of relevant domestic and international literature, thereby generating a set of preliminary recommendations. The two-round Delphi process was as follows: the first round primarily involved the screening and revision of initial items; the second round, based on anonymous feedback, facilitated the progressive convergence of expert opinions. Finally, an expert panel meeting was convened to deliberate on areas of disagreement and to finalize the consensus statements. By integrating the best available evidence with expert consensus and real-world clinical experience, this methodological approach ensures that the resulting recommendations are both authoritative and practically applicable in clinical settings.

2.1 Search Strategy and Information Sources

In accordance with the 6S evidence model [10,11], a comprehensive search was conducted using a combination of computerized and manual searches across databases including BMJ Best Practice, UpToDate,

JBI, PubMed, CNKI, Wanfang, and VIP. Search terms included central venous catheter, central venous catheterization, thrombosis, catheter-associated thrombosis and thrombus formation. The search period spanned from the inception of the databases to July 2025. Inclusion criteria: (1) study participants aged ≤18 years old; (2) Chinese or English language literature. (3) Included study types were systematic reviews/meta-analyses, randomized controlled trials, cohort studies, case-control studies, clinical guidelines, and expert consensuses. Exclusion criteria: (1) full-text documents unavailable; (2) studies not addressing the target issue; (3) studies of poor quality. Following duplication checks and preliminary screening, 50 studies were ultimately included [12], with the literature search process illustrated in Fig. 1.

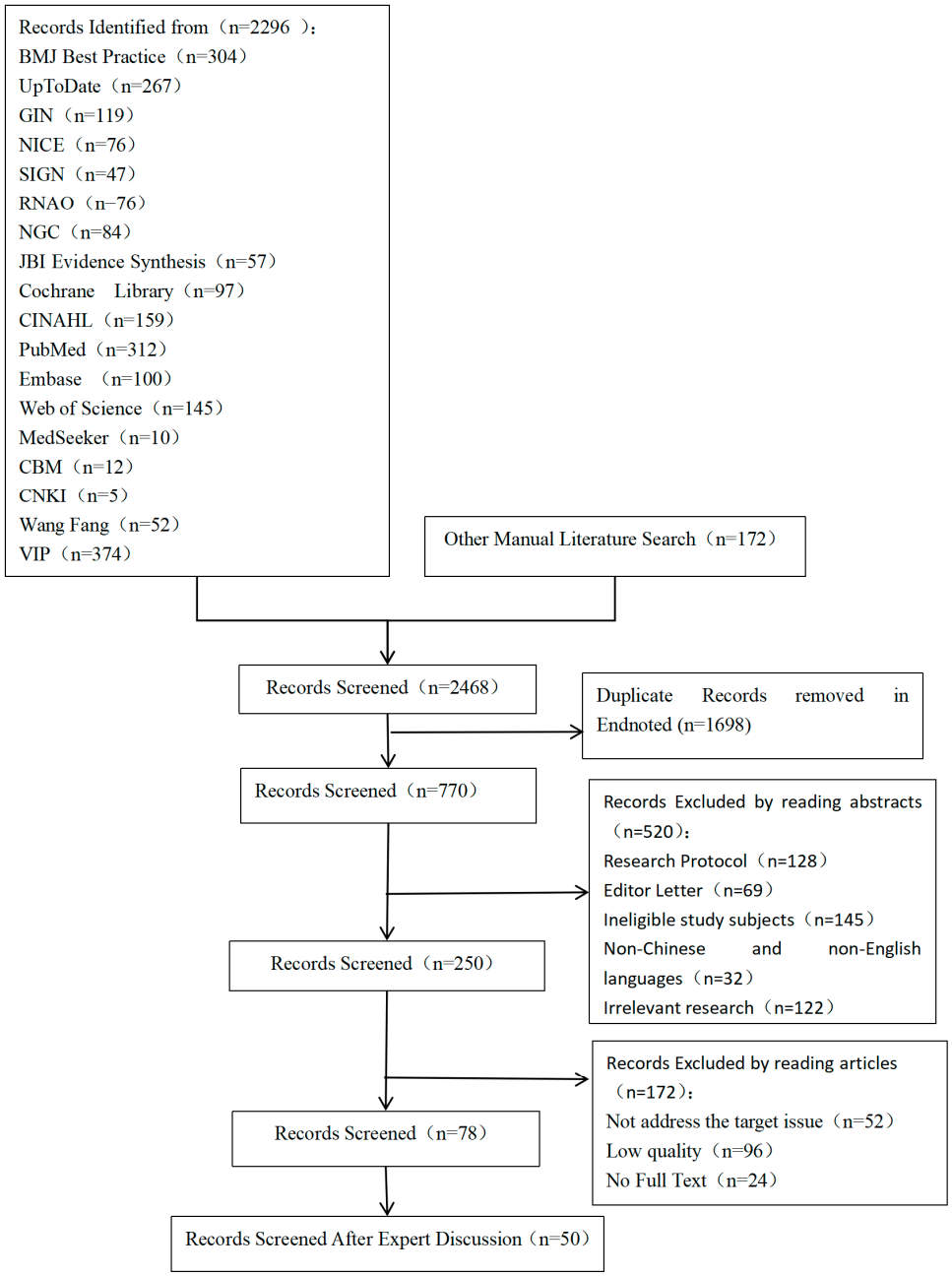

Figure 1: Flow diagram of literature search and study selection.

2.2 Data Extraction and Quality Assessment

For clinical decision-making, the quality of evidence was rigorously assessed by tracing the original sources and applying appropriate appraisal tools. Clinical practice guidelines were evaluated using the Appraisal of Guidelines for Research and Evaluation II (AGREE II) instrument [11]. Evidence summaries were appraised using the Critical Appraisal for Summaries of Evidence (CASE) method [13], while systematic reviews and expert consensus statements were assessed using the JBI Evidence-Based Healthcare Center authenticity appraisal tool for systematic reviews (2016 edition) [10]. All included studies were independently evaluated by two experts in evidence-based nursing methodology, with cross-verification to ensure consistency. In cases of disagreement, research secretaries participated in discussions to achieve consensus.

Based on the types of original studies underpinning the evidence, the JBI Evidence Pre-classification and Evidence Recommendation Levels System (2014 edition) was applied to categorize evidence into five levels (Grades 1–5), ranked from highest to lowest. The strength of recommendations was classified as Grade A (strong recommendation) or Grade B (weak recommendation) according to four criteria: feasibility, appropriateness, clinical significance, and effectiveness [14].

2.3 Personnel Composition and Introduction

A total of 46 experts from 30 leading pediatric cardiac surgery centers across China participated in the development of this consensus. These centers were distributed across multiple regions, including Beijing, Shanghai, Jiangsu, Zhejiang, Guangdong, Jilin, Liaoning, Henan, Shandong, Fujian, Sichuan, Shenzhen, Anhui, Hubei, and Hunan. The expert panel comprised specialists in pediatric cardiology, cardiovascular surgery, intensive care, and clinical nursing. Selection criteria, encompassing surgical volume, geographic representation, and multidisciplinary expertise, were designed to ensure both the authority and representativeness of the panel. On average, participants had more than 20 years of professional experience, and 67.4% held senior professional titles.

The 46 experts were organized into three functional groups: a 15-member core drafting group responsible for project planning, evidence synthesis, and manuscript preparation; a 16-member expert consultation group that participated in two rounds of Delphi surveys; and a 15-member review group tasked with final appraisal and approval of the consensus document.

2.4 Statistical Analysis

Statistical analysis was performed using SPSS version 20.0. Expert positivity was evaluated by the response rate and the rate of opinion provision. The authority coefficient (Cr) was calculated as Cr = (Ca + Cs)/2, with a value $\geq$0.7 indicating acceptable authority. Consensus among experts was assessed using Kendall's coefficient of concordance (W) and the coefficient of variation (CV). A p-value < 0.05 was considered statistically significant.

2.5 Expert Consultation Results

In this study, two rounds of expert consultation were conducted using the Delphi method, with evaluations based on a 5-point Likert scale. Sixteen questionnaires were distributed in each round, all of which were returned and deemed valid, resulting in a 100% effective response rate per round. During the two rounds, 14 and 2 experts, respectively, provided constructive suggestions for revision. The experts' familiarity coefficient (Cs) was 0.91, the judgment basis coefficient (Ca) was 0.94, and the overall Cr was 0.93, indicating a high level of expert reliability. In the first round, the CV for each item ranged from 0.05 to

0.21, and Kendall's coefficient of concordance (W) was 0.158 (χ^2 = 68.342, p < 0.001). In the second round, the CV range further narrowed to 0–0.15, while Kendall's W increased to 0.191 (χ^2 = 72.565, p < 0.001), reflecting an improvement in the level of agreement among experts.

2.6 Panel Review Results

In November 2025, an expert review panel meeting was convened in a hybrid format, with 15 invited experts participating both online and in person. To enhance efficiency and facilitate in-depth discussion, the revised Consensus draft was circulated to all experts two days prior to the meeting. During the session, the experts engaged in comprehensive deliberation on the content and provided constructive recommendations. Following the meeting, the drafting team systematically collated, revised, and incorporated the feedback to further refine the Consensus. Expert participation reached 100%, with a Cr of 0.91. The CV for deliberation outcomes ranged from 0 to 0.12, while Kendall's coefficient of concordance was 0.224 (χ^2 = 59.118, p < 0.001). These iterative processes ultimately led to the formation of the final Consensus draft.

3 Consensus Recommendations

The results demonstrate a progressive improvement in the convergence and consistency of expert opinions across two rounds of Delphi consultation and the subsequent expert deliberation meeting. Ultimately, a high level of consensus was achieved across all components of the consensus, underscoring the methodological rigor, reliability, and credibility of both the research process and its outcomes. Detailed results are presented below.

3.1 Risk Factors

3.1.1 Patient-Related Risk Factors

These risk factors can be categorized into three main domains: age and developmental stage, cardiac disease characteristics and surgical complexity, and baseline health status. Specifically, the risk of thrombosis is higher in infants and adolescents (Level 2 evidence, Grade B recommendation) [15–17]. Patients with single-ventricle physiology, as well as those requiring intraoperative implantation of artificial conduits or prosthetic valves are at high risk (Level 2, Grade B) [18,19]. In addition, a higher surgical risk classification is associated with an increased risk of venous thromboembolism (VTE) (Level 3, Grade C) [20]. Furthermore, patients with a history of thrombosis, concomitant autoimmune diseases, or recent hospitalization (within 30 days) are also at significantly increased risk of thrombotic events (Level 3, Grade C) [21].

3.1.2 Catheter-Related Risk Factors

These factors cover four dimensions: catheter material and design, insertion techniques, management during indwelling, and infection-related issues. Polyethylene or polyvinyl chloride catheters have higher complication rates compared to polyurethane or silicone catheters (Level 3, Grade C) [22]. Early research indicated significant benefits of heparin-coated catheters in pediatric populations; however, current evidence does not support this advantage (Level 1, Grade B). Factors potentially causing this discrepancy include hypercoagulability in neonates, catheter-vessel size mismatches, complications following complex cardiac surgeries, and vascular injuries [23]. Multilumen catheters are associated with higher VTE risk compared to single-lumen catheters (Level 4, Grade C). A catheter diameter exceeding the vessel's internal diameter increases thrombosis risk (Level 2, Grade A) [24]. Lower extremity venous catheterization poses a higher thrombosis risk than upper extremity placement (Level 2, Grade B). Thrombosis risk is elevated when catheterization frequency exceeds two times (Level 4, Grade C) [25], and a catheterization duration of 72 h

or longer also increases risk (Level 3, Grade B) [26]. A catheter tip positioned at the junction of the superior vena cava apex and the right atrium, or tip displacement, heightens CRT risk (Level 4, Grade C) [27]. Central line-associated bloodstream infections (CLABSI) further impact outcomes, with a reciprocal relationship existing between CRT and CLABSI. Fibrin sheaths formed around catheters facilitate microbial colonization and CLABSI, while inflammation caused by CLABSI promotes thrombosis [28].

3.1.3 Treatment and Surgical Factors

These factors can be grouped into three main categories: recent invasive procedures, postoperative mobility status, and specific medications or infusions. Recent cardiac surgery (within two weeks), deep hypothermic circulatory arrest, postoperative extracorporeal membrane oxygenation (ECMO) support, and cardiac catheterization procedures are all associated with an increased risk of deep vein thrombosis (DVT) (Level 2 evidence, Grade B) [29]. In addition, the administration of hypertonic or high-concentration solutions, such as glucose and calcium during prolonged parenteral nutrition, is associated with an elevated risk of thrombosis. A Braden Q mobility dimension score of ≤ 2 also indicates significantly reduced mobility and increased risk (Level 3, Grade C) [30]. Postoperative use of fresh frozen plasma further contributes to thrombotic risk (Level 3, Grade C) [31]. Concerning vasoactive drugs, existing studies have reported inconsistent findings. While some evidence suggests an increased risk of thrombosis, other studies have found no significant association. Therefore, further large-scale prospective studies are required to clarify this relationship [28,32].

4 Preventive Measures

Prevention is the cornerstone of CRT management. This consensus proposes a multi-tiered preventive strategy, in which primary prevention serves as the foundation, catheter-related management constitutes the core component, and pharmacological as well as mechanical interventions are considered adjunctive measures.

4.1 High-Risk Symptom Assessment

Healthcare providers should maintain a high level of vigilance to ensure early detection of CRT and its associated complications. Prompt diagnostic evaluation is warranted when patients present with clinical manifestations such as pain, erythema, swelling, or discoloration at the catheter insertion site; facial or cranial edema; features suggestive of superior vena cava syndrome; chest pain or dyspnea indicative of pulmonary embolism (PE); or persistent difficulty in aspirating from or infusing fluids through the CVC (Level 3 evidence, Grade C) [28].

4.2 Catheter Management

4.2.1 Catheterization Process Management

Before catheterization, a comprehensive assessment of the patient's clinical condition should be performed (Level 4, Grade B). The catheter insertion depth should be carefully calculated based on the selected access site and external anatomical measurements (Level 2, Grade B) [28]. Central venous catheterization should be performed by experienced pediatric anesthesiologists or pediatric critical care specialists (Level 1, Grade B) [23]. Preferred insertion sites include the internal jugular, subclavian, or cephalic veins, while use of the femoral vein should be minimized whenever possible (Level 1, Grade B; Level 4, Grade B). In pediatric cardiac surgical patients, right internal jugular vein access is recommended as the first-choice approach for central venous catheterization (Level 3, Grade B) [33,34].

When conventional access sites are unavailable or inadequate, ultrasound-guided supraclavicular venous puncture or subcutaneous tunneled femoral vein catheterization may be considered, particularly in preterm or term neonates (Level 1, Grade A) [33].

Catheter size selection should adhere to a maximum catheter-to-vessel outer diameter ratio of 0.33 [35]. The smallest appropriate catheter should be selected according to patient weight, with recommended sizes of 4F/5 cm for patients ≤5 kg and 5F/5 cm or 5F/8 cm for patients >5 kg (Level 1, Grade B) [23]. In high-risk pediatric populations, the use of antibiotic-impregnated catheters (e.g., rifampicin or dimethyltetracycline-coated catheters) is recommended (Level 2, Grade B) [32].

During catheterization, the patient should be placed in a Trendelenburg position (head-down, feet-up) when accessing the neck or chest, provided it is clinically tolerated (Level 1, Grade B). Catheter placement should be performed using the Seldinger or modified Seldinger technique (Level 1, Grade B) [36,37]. Ultrasound-guided vascular puncture is strongly recommended (Level 2, Grade B) [34]. For internal jugular vein catheterization, real-time ultrasound guidance is mandatory for vessel identification and venous puncture (Level 1, Grade B) [38]. Real-time ultrasound guidance may also be utilized for subclavian or femoral vein access when feasible (Level 1, Grade B) [39]. Strict aseptic technique must be maintained throughout the procedure (Level 4, Grade B), together with maximal barrier precautions (Level 2, Grade B). Prior to catheterization, skin disinfection should be performed using a chlorhexidine–alcohol solution with a minimum concentration of 0.5%. The antiseptic field should extend at least 15 cm beyond the intended dressing area (Level 2, Grade B), and catheter insertion should proceed only after the disinfectant has completely dried (Level 4, Grade B) [39]. Puncture attempts should be minimized, and no more than two catheterization attempts should be performed in the same vessel (Level 1, Grade B) [23]. Appropriate patient positioning should be ensured to optimize venous filling. Following catheter placement, intravascular positioning should be confirmed using pressure measurements or waveform analysis prior to initial use. Reliance solely on blood return or pulsatile flow is not recommended for confirming catheter or microcatheter placement (Level 1, Grade B). Bedside ultrasound or chest radiography should be used to verify catheter tip location (Level 2, Grade B) [39]. Finally, the entire catheterization process should be documented using a standardized procedural checklist (Level 2, Grade B) [39].

4.2.2 Catheter Maintenance Management

Daily monitoring of the puncture site for signs of infection is essential (Level 1, Grade A). This includes assessment of dressing integrity, inspection for erythema or swelling, and evaluation of catheter patency (Level 2, Grade B) [31]. Strict adherence to bundled infection-prevention strategies is critical, including hand hygiene, pulsatile positive-pressure flushing, and thorough disinfection of needle-free connectors (Level 2, Grade B). Dressings should be changed every seven days after catheter placement, or immediately if they become moist, curled, dislodged, contaminated, or if fluid accumulation is observed beneath the dressing (Level 2, Grade B). External tubing and three-way connectors should be replaced every 72 h, or immediately when catheter-related infection is suspected (Level 2, Grade B) [39].

Due to CHD and its treatment, routine CVC maintenance should include flushing at least every 12–24 h (Level 2, Grade A) and catheter locking at least every 24 h (Level 1, Grade A). However, in patients receiving continuous infusion of vasoactive drugs through the catheter lumen, particularly at high doses, routine interruption for flushing may result in hemodynamic instability. Therefore, individualized maintenance protocols should be established based on patient-specific clinical conditions. In patients with hypercoagulable states, shorter flushing intervals and increased flushing frequency are recommended (Level 5, Grade B). The catheter should be flushed immediately after administration of hypertonic solutions,

vasoactive agents, traditional Chinese medicine injections, chemotherapeutic agents, or antibiotics (Level 5, Grade B). A syringe with a minimum volume of 10 mL or a prefilled catheter flush device should be used for pulsatile flushing (Level 5, Grade B). All lumens of double- or multi-lumen catheters must be flushed (Level 5, Grade B), and the flushing volume should be at least twice the combined internal volume of the catheter and its accessories (Level 5, Grade B). When non-prefilled syringes are used, 0.5–1.0 mL of solution should be retained to prevent blood reflux (Level 1, Grade A) [40].

For catheter locking, either heparin solution—for newborns, use a concentration of 1 U/mL or preservative-free 0.9% sodium chloride solution should be used with a positive-pressure technique (Level 1, Grade A). In hypercoagulable patients, initial flushing with normal saline followed by locking with heparinized saline is recommended (Level 5, Grade B). In cases of severe hypercoagulability, higher heparin concentrations may be considered under close monitoring of coagulation parameters (Level 5, Grade B). Lock solutions should be withdrawn prior to subsequent catheter use (Level 5, Grade A), and the lock volume should be approximately 1.2 times the total internal volume of the catheter and its accessories (Level 5, Grade B). Prompt identification of catheter-related bloodstream infection (CRBSI) is essential (Level 5, Grade B). In high-risk patients with long-term CVC use and recurrent CRBSI, prophylactic antibiotic–heparin lock therapy may be considered [40]. Alcohol lock therapy may also reduce the incidence of CLABSI, thereby indirectly lowering the risk of thrombosis.

4.2.3 Catheter Removal Management

Prompt removal of the catheter is recommended when it is no longer clinically necessary (Level 1, Grade A). If catheter-related infection is suspected, a new catheter should be inserted at a different puncture site rather than performing *in situ* guidewire exchange (Level 1, Grade A). In cases of confirmed CRT, catheter retention with anticoagulation and close monitoring may be considered only when the catheter remains functional, uninfected, and clinically indispensable. Otherwise, removal is indicated (Level 4, Grade B) [31]. For confirmed CVC-related thrombosis, catheter removal is recommended after 3–5 days of standardized anticoagulation therapy. Patients should be closely monitored for complications such as PE or VTE during and after catheter removal, and appropriate imaging studies should be performed as clinically indicated (Level 4, Grade B) [41].

During catheter removal, the patient should be placed in a supine position. Immediate manual pressure should be applied to the puncture site, followed by an occlusive dressing to reduce the risk of air embolism (Level 5, Grade B). In asymptomatic patients, ultrasound screening is recommended within 48 h after catheter removal to detect occult thrombosis (Level 1, Grade B). Removal technique may be adjusted according to age: (1) neonates and infants, observe respiratory pattern and remove during expiration; (2) toddlers, use distraction techniques such as blowing pinwheels or whistles to facilitate smoother removal; (3) older cooperative children, teach breathing exercises and perform removal during breath-holding (Level 5, Grade B). After removal, the integrity of the catheter should be carefully inspected (Level 5, Grade B) [42]. All relevant laboratory data, including coagulation parameters, complete blood counts, and coagulation function tests, should be documented in nursing records and handover reports (Level 2, Grade B). The condition of the puncture site, catheter length, and other procedural details should be clearly recorded. When catheter cultures are performed, the source of the specimen must be explicitly specified (Level 1, Grade A) [39,43].

4.3 Primary Prevention

The core principle of primary prevention is the maintenance of optimal blood flow [44]. Key nursing interventions include minimizing unnecessary bed rest, promoting early mobilization, supporting routine

daily activities, facilitating appropriate limb exercises, and ensuring adequate hydration [45,46] (Level 2, Grade A). For bedridden patients, targeted instruction and supervision should be provided to perform ankle pump exercises and other suitable in-bed physical activities [47] (Level 2, Grade B).

4.4 Pharmacological Prevention

Pharmacological prophylaxis requires a careful risk–benefit assessment and is not routinely recommended. This consensus strongly advises against the routine use of anticoagulants for primary prevention in pediatric patients (Level 1, Grade B) [23,37]. Anticoagulant therapy should be considered only in children identified as extremely high risk after multidisciplinary evaluation, with careful consideration of bleeding risk (Level 1, Grade A) [1]. All regimens should be individualized [48]. For children requiring medium- to long-term postoperative prophylaxis, initial anticoagulation may involve unfractionated heparin (UFH) or low-molecular-weight heparin (LMWH), followed by transition to oral anticoagulants more suitable for pediatric CHD populations, such as warfarin, apixaban, or rivaroxaban (Level 1, Grade B/A) [2]. In children with CHD-associated pulmonary hypertension, anticoagulation intensity should be carefully adjusted to reduce the risk of severe bleeding complications, including hemoptysis (Level 3, Grade A) [49,50]. During treatment, close monitoring for bleeding manifestations, such as cutaneous or mucosal hemorrhage and puncture site bleeding, is essential, along with regular assessment of laboratory parameters including platelet function, international normalized ratio (INR), and D-dimer levels (Level 1, Grade A) [45]. Current evidence-based guidance for anticoagulation and thrombolysis in pediatric CRT remains limited. Existing recommendations generally favor conventional anticoagulants, including UFH, LMWH, and vitamin K antagonists (VKAs) [51]. Aspirin is the most commonly used prophylactic agent, followed by LMWH [1]. Thrombolytic therapy should be reserved for clearly defined indications. FDA-approved oral anticoagulants primarily include direct factor Xa inhibitors and direct thrombin inhibitors [15,20].

4.5 Mechanical Prevention

Mechanical prophylaxis serves as an adjunctive strategy and commonly includes graduated compression stockings (GCS), intermittent pneumatic compression (IPC) devices, and vacuum foot pumps (VFPs) [20]. Clinicians should carefully assess the individual condition of children with CHD before selecting any mechanical intervention. For patients weighing more than 40 kg who are at risk of catheter-related venous thrombosis (C-RVT), compression stockings or appropriately sized IPC devices may be considered as adjunctive preventive measures (Level 3, Grade B) [52]. Prior to application, clinicians must carefully screen for contraindications to ensure patient safety (Level 2, Grade A) [53].

Early studies suggested limitations in the effectiveness of electrical stimulation devices; although newer-generation devices demonstrate improved tolerability, their efficacy still requires confirmation through well-designed, adequately powered randomized controlled trials [20]. In clinical practice, combining mechanical and pharmacological prophylaxis may offer enhanced preventive efficacy by targeting different stages of thrombus formation through complementary mechanisms.

5 Supportive Examinations

5.1 Imaging Studies

Color Doppler ultrasonography is the primary imaging modality for monitoring thrombus formation. Examination should begin proximally and proceed along the venous pathway originating from the catheter insertion site. Diagnostic features suggestive of thrombosis include venous lumen dilation with poorly echogenic (hypoechoic) intraluminal material, failure of venous compressibility under applied pressure,

intraluminal filling defects, or complete absence of detectable blood flow, all of which indicate thrombus formation requiring clinical intervention (Level 4, Grade B). In anatomically challenging regions, such as the subclavian or intrathoracic veins, further confirmation using magnetic resonance imaging (MRI) or contrast-enhanced computed tomography (CT) is recommended to ensure diagnostic accuracy (Level 2, Grade A). Routine imaging surveillance is advised within 7 days following catheter placement, with subsequent periodic evaluations continuing until catheter removal (Level 4, Grade B) [54]. Patients presenting with elevated risk factors for CRT should undergo earlier and more frequent imaging assessments.

5.2 Laboratory Markers

D-dimer levels are considered a supportive diagnostic marker when CRT is suspected (Level 2, Grade A) [55]. In addition, elevated C-reactive protein (CRP) levels (>118.01 mg/L) have been associated with an increased risk of thrombosis and may serve as an adjunctive risk indicator [56].

6 Management and Intervention

Currently, definitive clinical evidence supporting the treatment of asymptomatic thrombi in pediatric patients with CHD receiving CVCs remains limited. Asymptomatic superficial venous thrombi often resolve spontaneously without intervention. Some studies suggest that asymptomatic upper-limb DVT may contribute to chronic venous occlusion and potentially complicate future catheter placement. However, most asymptomatic thrombi detected by ultrasound in routine clinical practice are small in size, carry a low risk of progression in the absence of anticoagulation, and do not demonstrate meaningful differences in clinical outcomes between treated and untreated groups [22].

6.1 Thrombolytic Therapy

Recombinant tissue plasminogen activator (alteplase) may be used for isolated catheter occlusions to lyse intraluminal thrombi and re-establish catheter patency (Level 1, Grade A). However, given the substantial risk of bleeding complications, its use should be restricted to life- or limb-threatening arterial or venous thromboses, particularly in the perioperative management of pediatric patients with CHD. For confirmed CRT, a urokinase lock may be applied to maintain or restore catheter function. Nevertheless, routine prophylactic use of thrombolytic lock solutions is not recommended (Level 5, Grade B) [57].

6.2 Anticoagulation Therapy

In the absence of contraindications, anticoagulation with UFH, LMWH, VKAs, or DOACs is recommended for both symptomatic and asymptomatic CRT. Initial therapy should commence with UFH or LMWH for a minimum of five days, followed by transition to oral anticoagulants for maintenance treatment (Level 4, Grade B). Laboratory monitoring should be conducted in accordance with pediatric antithrombotic guidelines and supplemented by serial imaging to evaluate thrombus regression (Level 4, Grade B). Anticoagulation therapy should be maintained for at least six weeks, with duration extended based on imaging-confirmed thrombus resolution and clinical reassessment (Level 4, Grade B). Routine primary anticoagulant prophylaxis is not recommended for all pediatric patients with CVCs. However, secondary prophylaxis may be considered in patients with established CRT who require prolonged catheterization or who present additional thrombotic risk factors (Level 4, Grade B).

6.3 Monitoring and Education

Accurate and comprehensive documentation of catheter-related data, including patient demographics, underlying diagnosis, catheter type and specifications, dates of insertion and removal, associated complications, and indications for removal, is essential for safe clinical practice and quality assurance (Level 2, Grade B). Healthcare professionals should receive standardized training in catheter insertion and maintenance to ensure adherence to evidence-based protocols. In addition, children and their families should be provided with age-appropriate education covering routine catheter care, early recognition of potential complications, recommended levels of physical activity, medication adherence precautions, and clear indications for when to seek medical attention (Level 2, Grade B). Healthcare institutions should also systematically track catheter-related infection rates, expressed per 1000 catheter-days, and perform ongoing evaluation of these data to guide quality improvement initiatives (Level 2, Grade B) [39].

6.4 Vena Cava Filters

Vena cava filters are indicated in pediatric patients with acute proximal lower-extremity DVT who have absolute contraindications to anticoagulation, primarily to reduce the risk of fatal PE. Routine use in upper-extremity DVT is not recommended. Anticoagulation should be resumed promptly once contraindications have resolved following filter placement [20,24]. In preterm infants undergoing catheterization, venous filters may help reduce the risk of thrombosis (Level 1, Grade B). Prophylactic filter placement may also be considered in selected high-risk patients, including those with contraindications to anticoagulation, those with recurrent or progressive thrombosis despite adequate anticoagulant therapy, or those presenting with acute PE (Level 1, Grade B) [32].

6.5 Thrombectomy and Catheter-Based Thrombolysis

Early thrombus removal strategies are recommended in children with acute (≤14 days of symptom onset), symptomatic, and extensive iliofemoral venous thrombosis to reduce the risk of long-term post-thrombotic syndrome (PTS). Percutaneous mechanical thrombectomy may be considered when the child weighs ≥10 kg, the vessel diameter is sufficient to allow catheter access (typically ≥3–4 mm), and no significant anatomical abnormalities are present. In patients with increased bleeding risk, such as those with a platelet count $<100 \times 10^9$/L, fibrinogen <150 mg/dL, or a recent history of surgery or trauma, pure mechanical thrombectomy is preferred over catheter-directed thrombolysis (CDT). In infants and neonates younger than 2 years, careful individualized assessment is required to determine the necessity and feasibility of invasive intervention, given the limitations of vascular access and procedural risks [20].

7 Discussion

Unlike existing general guidelines, this consensus is the first to systematically focus on children with CHD, a population characterized by extensive use of CVCs and a substantially increased risk of thrombosis. Based on the expertise of domestic specialists from centers responsible for approximately 80% of national CHD surgical volume, the consensus establishes a comprehensive, end-to-end management framework that integrates CHD-specific risk factors, including univentricular circulation, prosthetic conduits or valves, deep hypothermic circulatory arrest, and ECMO support. The document explicitly advises against routine pharmacological prophylaxis (Level 1, Grade B) and emphasizes a stratified, stepwise prevention strategy that prioritizes foundational preventive measures and meticulous catheter management, with pharmacological and mechanical interventions reserved for selected cases. It also provides detailed, practice-oriented recommendations, such as catheter size selection based on body weight, age-appropriate respiratory

coordination during catheter removal, and structured approaches to the screening and management of asymptomatic thrombosis. These specifications address the limited applicability of general guidelines to the CHD population and the persistent clinical challenge of balancing anticoagulation efficacy against bleeding risk in these patients. Furthermore, grounded in Chinese clinical practice and acknowledging the limited availability of high-quality pediatric evidence, this consensus was developed through a multidisciplinary Delphi process to generate pragmatic recommendations with clearly defined evidence levels (1–5) and grades of recommendation (A/B/C). By covering the full continuum of care, from pre-insertion risk assessment, insertion techniques, and catheter maintenance to removal and post-treatment surveillance, it provides a practical, CHD-specific reference for frontline settings such as cardiac intensive care units, cardiovascular surgery departments, and pediatric intensive care units. Ultimately, it reduces the uncertainty associated with extrapolating adult or general pediatric guidelines to CHD patients and offers a structured, clinically applicable framework with strong relevance and adaptability.

Limitations and future directions. Although this consensus is grounded in the best available evidence, its conclusions are constrained by the limited availability of high-quality clinical studies in pediatric patients with CHD. Several recommendations are supported by low-level evidence (Level 3–5) or are extrapolated from adult data and expert clinical experience, and therefore require confirmation through prospective, multicenter, randomized controlled trials. In addition, systematic research on the epidemiological baseline characteristics, risk prediction models, and individualized anticoagulation strategies for Chinese children with CHD remains insufficient. The safety and efficacy of mechanical prophylactic approaches and DOACs in low-body-weight pediatric populations also warrant further investigation. Therefore, the relatively low W values truly reflect the current knowledge uncertainty and clinical decision-making complexity in this field, rather than a methodological failure. Future research should prioritize the establishment of a standardized, CHD-specific CVC thrombosis registry through regional medical center networks, the development and validation of risk stratification tools tailored to the Chinese pediatric population, and the implementation of well-designed interventional studies. Efforts should also be directed toward the development of pediatric-specific anticoagulant agents and improved biocompatible catheter materials, with the ultimate goal of advancing higher-level, evidence-based management strategies in this high-risk population.

8 Conclusions

Based on a systematic literature review and a multidisciplinary expert consensus developed through a two-round Delphi process followed by a panel review, this consensus is the first to systematically focus on children with CHD—a population with an extremely high frequency of CVC use and a markedly elevated risk of thrombosis. It establishes a comprehensive management framework covering risk factor identification, multi-level prevention, diagnostic workup, therapeutic intervention, and long-term follow-up. The consensus explicitly recommends against routine pharmacological primary prophylaxis, emphasizes individualized risk assessment and meticulous catheter management, and provides detailed actionable recommendations. These features effectively address the limited applicability of general guidelines to CHD children and the clinical dilemma of balancing anticoagulation against bleeding risk in this population.

Grounded in Chinese clinical practice and based on the expertise of specialists from centers accounting for 80% of national CHD surgeries, this consensus employs transparently reported levels of evidence and grades of recommendation. It serves as a ready-to-use, CHD-specific guide for frontline settings, offering high practical value and potential for broad implementation.

Nevertheless, limited by the scarcity of high-quality pediatric studies, some recommendations rely on low-level evidence or adult data. Future multicenter randomized controlled trials, CHD-specific thrombosis registries, risk stratification tools for Chinese children, and safer anticoagulant strategies are needed to advance evidence-based management for this high-risk population. This consensus will be regularly updated as new evidence emerges.

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