

Implementation of a Venipuncture Difficulty–Graded Nursing Consultation Model and Intravenous Therapy Outcomes in Children Aged 0–3 Years: A Retrospective Before-and-After Cohort Study

Ziyi Chen¹

Guangdong Women and Children Hospital

Minyi Situ¹

Guangdong Women and Children Hospital

Song Wu¹

SongWu1234561@outlook.com

Guangdong Women and Children Hospital

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Abstract

Background: Peripheral intravenous access is frequently difficult in children aged 0–3 years because of small, poorly visualized vessels and limited cooperation. Conventional consultations generally allocate personnel according to experience without systematically considering vascular status or procedural complexity. This study evaluated a consultation model that matched venipuncture difficulty with personnel competency.

Methods: A single-center retrospective before-and-after cohort study was conducted using clinical and nursing records from 2024. Children receiving conventional consultation between January and June were included in the control group, while those managed with the difficulty-graded model between July and December comprised the intervention group. In the intervention group, venipuncture difficulty was assessed using seven domains: puncture site, palpability, visible diameter, visible length, filling, elasticity, and color. The highest domain rating determined the overall difficulty grade, which guided the allocation of appropriately qualified personnel. The primary analysis included 490 peripheral intravenous catheter consultations (control, n=243; intervention, n=247). Outcomes included first-attempt success, waiting time, parental satisfaction, consultation-related complaints, and intravenous therapy–related stress among pediatric nurses.

Results: Baseline characteristics were comparable between groups (all $P>0.05$). First-attempt success was higher after implementation (99.2% vs. 95.9%; $RR=1.034$, 95% CI 1.006–1.064; $P=0.018$). Firth penalized logistic regression adjusted for age, sex, diagnosis, and baseline difficulty confirmed higher odds of first-attempt success in the intervention group ($aOR=4.726$, 95% CI 1.135–19.683; $P=0.033$). Mean waiting time decreased from 14.93 ± 2.48 to 2.36 ± 1.11 min (mean difference= -12.57 min, 95% CI -12.91 to -12.23 ; $P<0.001$). Parental satisfaction increased from 87.8% (231/263) to 98.6% (286/290; $P<0.001$). Complaints decreased from four to zero, although the difference was not statistically significant ($P=0.051$). Nurse-reported stress declined from 66.7% (269/403) to 37.3% (150/402; $P<0.001$).

Conclusions: Matching personnel competency to venipuncture difficulty was associated with improved first-attempt success, shorter waiting times, greater parental satisfaction, and reduced nurse stress. Larger multicenter studies are required to confirm these findings.

Introduction

Peripheral intravenous catheters (PIVCs) are among the most commonly used vascular access devices in pediatric diagnosis and treatment and are widely used to support clinical therapy. Previous studies have shown that approximately 50%–70% of hospitalized children require PIVC placement; however, first-attempt insertion success in children remains suboptimal. Repeated puncture attempts may increase pain, anxiety, and resistance to treatment and may prolong the time required to establish intravenous access [1]. This problem is particularly prominent in younger children. In a prospective cohort study conducted in a pediatric emergency department, Dunstan et al. [2] found that 39% of children had

difficult intravenous access (DIVA), and age ≤ 3 years, a limited number of available veins, insufficient operator experience in venipuncture, and child agitation were associated with DIVA. Therefore, children aged 0–3 years are at high risk of puncture failure and represent a population requiring focused identification and intervention in vascular access management.

Early identification of difficult intravenous access is an important prerequisite for reducing ineffective puncture attempts. In recent years, the DIVA score and modified tools have increasingly been used to assess the risk of peripheral venipuncture difficulty in children. Studies have demonstrated that modified DIVA tools have good clinical value for identifying difficult intravenous access in children across different healthcare settings [3]. A contemporaneous multicenter study in Spain completed cross-cultural adaptation and validation of the DIVA score and showed that a three-variable model could identify high-risk children based on age, vein visibility, and vein palpability [4]. However, the clinical value of risk assessment lies not only in identifying high-risk children but, more importantly, in promptly adjusting the puncture strategy according to the level of risk. If personnel continue to be assigned randomly or empirically after risk stratification, the results of risk identification may not be fully translated into actual benefits in intravenous therapy. Current studies aimed at improving outcomes in children with difficult intravenous access have mainly focused on puncture-assistance technologies. Hosseini et al. [5] reported that ultrasound, near-infrared imaging, and transillumination have all been used to improve the first-attempt PIVC success rate in pediatric patients with DIVA, with ultrasound ranking highest overall; however, the certainty of the evidence remains limited by study heterogeneity and risk of bias. In addition, Yildirim et al. [6] found in 2026 that the use of a vein visualization device in children aged 0–6 years increased first-attempt success and reduced procedure-related pain, although improvements in catheter complications, insertion time, and dwell time were inconsistent. These findings suggest that relying solely on technical devices may be insufficient to address all aspects of difficult intravenous access management in children; operator experience, staffing, and the consultation process may also affect puncture outcomes. From a clinical management perspective, effective matching between venipuncture difficulty and personnel competency may be an important component of improving intravenous therapy outcomes in young children. Previous qualitative research has shown that repeated venipuncture imposes a sustained psychological burden on children and their parents, and timely referral to experienced professionals is considered an important measure for reducing repeated procedures in children with a history of difficult intravenous access [7]. Nevertheless, recent studies have focused more on validating DIVA prediction tools and on auxiliary technologies such as ultrasound and near-infrared imaging. Studies of consultation models that stratify children according to venipuncture difficulty and further match children of different difficulty levels with personnel of corresponding competency levels remain relatively limited, particularly evaluations of clinical effectiveness in children aged 0–3 years. Therefore, this single-center retrospective cohort study compared venipuncture outcomes in children aged 0–3 years managed using the conventional consultation model versus a consultation model based on venipuncture difficulty grading and evaluated intravenous therapy-related stress among pediatric nurses, with the aim of providing evidence for stratified management of difficult intravenous access in young children.

1 Materials and Methods

1.1 General Information A single-center retrospective before-and-after controlled cohort study was conducted. Data on difficult intravenous therapy consultations among children aged 0–3 years at a tertiary children's hospital were retrospectively collected from January to December 2024. Groups were defined according to the implementation period of the standardized consultation model based on venipuncture difficulty grading. Children who received the conventional intravenous therapy consultation model from January to June 2024 were assigned to the control group, whereas children who received the standardized consultation model based on venipuncture difficulty grading from July to December 2024 were assigned to the intervention group. During the study period, 553 eligible children undergoing difficult intravenous therapy consultation were included, comprising 263 in the control group and 290 in the intervention group. These consultations included 28 PICC insertions, 35 PICC/PORT/CVC maintenance consultations, and 490 peripheral intravenous catheter consultations. Children undergoing peripheral intravenous catheter consultation constituted the main analysis population for the first-attempt success rate after consultation and consultation waiting time, including 243 in the control group and 247 in the intervention group. All 553 children undergoing consultation were included in analyses of parental consultation satisfaction and consultation-related complaints.

The study flowchart is shown in Fig. 1. Inclusion criteria were as follows: (1) age 0–3 years; (2) a need to establish or maintain intravenous access for treatment; (3) difficult intravenous therapy identified by the responsible nurse, followed by a consultation request; and (4) complete records of the consultation request, vascular assessment, puncture procedure, and outcomes. According to the original consultation process, children with difficult peripheral venipuncture mainly included those with ≥ 2 failed conventional puncture attempts in the ward or those judged clinically to have a high degree of puncture difficulty requiring further consultation. Exclusion criteria were as follows: (1) missing clinical or nursing data preventing determination of the primary outcome; (2) an effective intravenous access had already been established before consultation and no puncture or catheter maintenance was actually performed; (3) consultation was not completed because of changes in clinical condition, transfer, discharge against medical advice, or other reasons; (4) severe circulatory instability or other conditions requiring immediate emergency vascular access and therefore unsuitable for management according to the routine consultation process; and (5) missing key vascular assessment data preventing determination of the venipuncture difficulty grade. In the main analysis population undergoing peripheral intravenous catheter consultation, there were no statistically significant differences in general characteristics between the two groups (all $P > 0.05$), indicating comparability (Table 1). This study was conducted in accordance with the principles of the Declaration of Helsinki and was reviewed and approved by the hospital ethics committee. Because this was a retrospective analysis of previously collected clinical and nursing data and did not alter children's diagnosis, treatment, or nursing care, the requirement for informed consent was determined by the ethics committee according to the actual approval decision. Study data were de-identified before analysis.

Table 1
Comparison of General Characteristics Between the Two Groups

Item	Control group (n = 243)	Intervention group (n = 247)	χ^2/t value	P value
Age (years, mean $\pm$ SD) $\bar{x}$	0.93 $\pm$ 0.75	1.06 $\pm$ 0.75	1.917	0.056
Sex, n (%)			0.020	0.889
Male	151 (62.1)	155 (62.8)		
Female	92 (37.9)	92 (37.2)		
Disease diagnosis, n (%)			1.695	0.975
Bronchopneumonia	159 (65.4)	175 (70.9)		
Acute upper respiratory tract infection	20 (8.2)	17 (6.9)		
Bronchiolitis	18 (7.4)	16 (6.5)		
Acute gastroenteritis	14 (5.8)	12 (4.9)		
Urinary tract infection	10 (4.1)	8 (3.2)		
Febrile seizure	8 (3.3)	7 (2.8)		
Hand, foot, and mouth disease	6 (2.5)	5 (2.0)		
Other	8 (3.3)	7 (2.8)		
Baseline venipuncture difficulty grade, n (%)			0.094	0.954
Grade I	45 (18.5)	48 (19.4)		
Grade II	78 (32.1)	80 (32.4)		
Grade III	120 (49.4)	119 (48.2)		

1.2 Methods

1.2.1 Control Group

The control group received the hospital's original conventional consultation model for difficult intravenous therapy. When poor vascular conditions and puncture difficulty were identified during routine peripheral venipuncture, and ≥ 2 puncture attempts had failed in the ward, or when the responsible nurse judged that repeated attempts by ward staff might further increase puncture difficulty and the risk of nurse–patient communication problems, a difficult intravenous therapy consultation was initiated. (1) Submission of a consultation request. The responsible nurse in the requesting ward completed an

intravenous therapy consultation request form based on the child's current intravenous therapy needs, recording basic patient information, ward, intravenous therapy requirements, reason for consultation, and previous puncture history. After completing the request, the nurse contacted the leader of the intravenous therapy team by telephone and reported the current difficulty in establishing intravenous access and the need for consultation. (2) Assignment of consultation personnel. After receiving the request, the intravenous therapy team leader assigned a consultation nurse according to the day's staffing schedule and actual personnel availability. Consultation personnel were mainly allocated according to staff availability on that day. (3) Pre-consultation vascular assessment. After receiving the task, the consultation nurse inspected and palpated the child's peripheral veins based on prior clinical venipuncture experience and selected a target vein according to the child's age, previous puncture history, and current vein visibility. (4) Peripheral venipuncture. After verifying the child's identity and intravenous therapy needs, the consultation nurse selected an appropriate puncture site and vein based on clinical experience and inserted a peripheral intravenous catheter. After successful insertion, subsequent management was completed according to the hospital's existing peripheral intravenous therapy standards, and the consultation and puncture outcomes were documented in the consultation record. If the first consultation nurse failed to establish intravenous access, another nurse with greater venipuncture experience was coordinated according to the actual situation to continue management. (5) Consultation documentation. After completion of the consultation, the relevant nurse documented the consultation request, consultation start time, puncture details, and final management outcome. During the study, investigators retrospectively extracted data on first-attempt outcomes and consultation waiting time from historical consultation records. Although the consultation model based on venipuncture difficulty grading had not yet been implemented during the control period, the original intravenous therapy consultation records routinely documented vascular characteristics of the intended puncture vein, including puncture site, vessel palpability, visible diameter, visible length, degree of filling, elasticity, and local appearance. Investigators who had received standardized training retrospectively assigned difficulty grades to these historical records according to the predefined grading criteria to obtain the baseline venipuncture difficulty grade for the control group.

1.2.2 Intervention Group The intervention group received a consultation model based on venipuncture difficulty grading in addition to the original difficult intravenous therapy consultation process (Fig. 2). (1) Establishment of a difficult intravenous therapy consultation team. The nursing management department organized a difficult intravenous therapy consultation team. The team consisted of intravenous therapy specialist nurses and senior venipuncture nurses, with 34 members in total. Of these, 21 intravenous therapy specialist nurses and senior venipuncture nurses formed the peripheral catheter subgroup responsible for difficult peripheral intravenous therapy consultations. Nurses participating in peripheral venipuncture underwent annual comprehensive assessment based on five indicators from the previous year: total number of peripheral venipunctures performed, first-attempt success rate, nurse–patient communication ability, number of complaints related to venipuncture, and years of experience performing venipuncture. They were classified as junior, intermediate, or senior venipuncture nurses. Senior venipuncture nurses were the principal personnel responsible for difficult

intravenous therapy consultations. (2) Standardized training before implementation. One month before formal implementation of the consultation model, the difficult intravenous therapy consultation team provided standardized training to team members and intravenous therapy liaisons in each clinical department. Training covered the use of the peripheral vessel grading assessment form, criteria for judging each venipuncture difficulty grade, indications for difficult-access consultation, consultation procedures, personnel competency grading, and matching principles. Each clinical department involved in intravenous therapy designated one or two intravenous therapy liaisons, mainly head nurses or senior nursing staff. After team members and liaisons completed standardized training and passed the assessment, the liaisons were responsible for training and assessing nursing staff in their own departments to reduce inconsistencies in vascular assessment standards between departments and nurses. (3) Submission of a consultation request. After the child's ward determined that the criteria for difficult intravenous therapy consultation were met, the responsible nurse completed a dedicated intravenous therapy consultation request form. In addition to basic patient information, the form recorded the final consultation outcome and included the peripheral vessel grading assessment. (4) Assessment of peripheral venipuncture difficulty. Before consultation personnel were formally assigned, a trained nurse systematically assessed the peripheral vein intended for vascular access. Seven items were evaluated: puncture site, vessel palpability, visible diameter, visible length, degree of filling, elasticity, and color/local appearance. Each item was assigned a difficulty grade according to the actual vascular condition, with detailed criteria shown in Table 2. After all seven items were assessed, the highest difficulty grade among the seven indicators was designated as the final difficulty grade for that puncture according to the risk-priority principle. (5) Matching venipuncture personnel according to vascular difficulty. After the responsible nurse completed the vascular assessment, the final venipuncture difficulty grade was entered on the consultation request, and the person in charge of intravenous therapy consultation matched a venipuncture nurse with the appropriate competency level according to the difficulty grade. The correspondence between personnel competency and venipuncture difficulty is shown in Table 3. In routine puncture practice, junior venipuncture nurses managed Grade I vessels, intermediate venipuncture nurses could manage Grade I–II vessels, and senior venipuncture nurses could manage Grade I–IV vessels. Lower-level personnel were not permitted to manage difficult vessels beyond their competency level. Children meeting the criteria for difficult intravenous consultation ultimately received consultation from senior venipuncture nurses qualified to manage difficult access. Venipuncture difficulty grading was used to identify puncture risk and escalate consultation in advance rather than waiting for repeated puncture failures before coordinating personnel. (6) Establishment of a centralized consultation site and information-based assignment. The infusion room was designated as the centralized site for difficult peripheral intravenous catheter consultations and was equipped with fixed consultation stations and dedicated puncture lights. Consultations were performed by senior venipuncture nurses with extensive peripheral venipuncture experience and strong communication skills. After the child arrived at the infusion room, the nurse entered patient information and peripheral venipuncture difficulty into a personal digital assistant (PDA) according to the consultation request form. The system assigned a venipuncture nurse to the corresponding consultation station based on the entered information, and the child waited for and received care in the designated consultation area. (7)

Performance of the venipuncture consultation. After matching, the senior venipuncture nurse first verified the child's basic information, current intravenous therapy needs, number of previous puncture attempts, and venipuncture difficulty grade and reassessed the target vein. After confirming the assessment, an appropriate site was selected according to the child's actual vascular condition and a peripheral intravenous catheter was inserted. Sequential repeated attempts by multiple nurses of different competency levels were avoided. When the child's vascular condition was complex or a single senior venipuncture nurse encountered difficulty, other senior venipuncture nurses jointly evaluated the case and determined subsequent management. (8) Documentation of consultation outcomes. After the consultation, details of the puncture procedure were completely documented, including consultation request time, actual consultation start time, number of puncture attempts, and whether the first puncture attempt was successful.

Table 2
Peripheral Venipuncture Difficulty Grading

Assessment item	Grade I	Grade II	Grade III	Grade IV
Puncture site	Head, hand, upper limb, dorsum of foot	Head, hand, upper limb, dorsum of foot, lower limb	Head, hand, upper limb, dorsum of foot, lower limb, neck, elbow, forearm	Meets Grade III criteria and requires consultation by ≥ 2 senior venipuncture nurses or ≥ 2 puncture attempts by a senior venipuncture nurse
Vessel palpability	Clearly palpable	Faintly palpable vein	Not palpable	Same as the comprehensive Grade IV criteria
Visible diameter	≥ 1 mm	< 1 mm	No clearly visible vessel	Same as the comprehensive Grade IV criteria
Visible length	≥ 1 cm	< 1 cm	No clearly visible vessel	Same as the comprehensive Grade IV criteria
Degree of filling	Slightly protrudes above the skin surface after compression	Vein visibly collapses after compression and is faintly visible under pressure	Vein collapses and is faintly visible or not visible under pressure	Same as the comprehensive Grade IV criteria
Elasticity	Soft and elastic	Slightly elastic	No obvious elasticity	Same as the comprehensive Grade IV criteria
Color/local appearance	Bluish	Bluish	Multiple previous puncture marks or slightly red/purplish-red appearance	Same as the comprehensive Grade IV criteria

Table 3
Matching Rules Between Venipuncture Difficulty and Personnel Competency

Venipuncture nurse level	Venipuncture difficulty that may be managed	Scope of practice	Eligibility for difficult-access consultation
Junior venipuncture nurse	Grade I	Routine and low-difficulty peripheral venipuncture	No
Intermediate venipuncture nurse	Grades I–II	Routine and moderate-difficulty peripheral venipuncture	No
Senior venipuncture nurse	Grades I–IV	High-difficulty peripheral venipuncture and management of difficult intravenous access	Yes

1.3 Outcome Measures

1.3.1 Primary Outcome First-attempt success rate of peripheral intravenous catheter insertion. The outcome of the first peripheral intravenous catheter insertion attempt after difficult intravenous therapy consultation was recorded. Using aseptic technique, the catheter was inserted into a superficial peripheral vein for the first time. A first-attempt success was defined as blood return, no obvious local swelling, and smooth infusion after insertion; otherwise, the first attempt was considered unsuccessful. First-attempt success rate = number of children with successful first-attempt insertion / total number of children undergoing peripheral intravenous catheter consultation × 100%.

1.3.2 Secondary Outcomes

(1) Consultation waiting time. This was defined as the interval from the formal submission of a difficult intravenous therapy consultation request by the child's family or the first-contact/responsible nurse to completion of personnel assignment by the consultation team and the formal start of peripheral venipuncture, expressed in minutes. The consultation request time was obtained from the intravenous therapy consultation request record or information-system timestamp, and the formal puncture time was obtained from the consultation procedure record. Consultation waiting time = formal puncture start time – formal consultation request time. (2) Parental consultation satisfaction. Satisfaction was evaluated using the hospital's existing parental satisfaction survey data. The analysis focused on evaluations related to nursing services. A 5-point Likert scale was used, categorized as “very dissatisfied,” “dissatisfied,” “basically satisfied,” “satisfied,” and “very satisfied,” scored from 1 to 5, respectively. According to the hospital's predefined criteria, “satisfied” and “very satisfied” were defined as consultation satisfaction, and the consultation satisfaction rate was calculated as the number of parents meeting the satisfaction criterion / total number of parents who completed the satisfaction assessment × 100%. (3) Consultation-related complaints. Formal complaints directly related to difficult intravenous therapy consultation during the study period were identified through the hospital nursing quality

management system, complaint registration records, and difficult intravenous therapy consultation records. These included complaints arising from venipuncture, consultation waiting, personnel assignment, or the consultation service process that were formally registered and confirmed by the relevant hospital management department. Multiple feedback events arising from the same consultation episode in the same child were counted as one complaint. Consultation-related complaint rate = number of children with consultation-related complaints / total number of children receiving difficult intravenous therapy consultation during the same period $\times 100\%$. (4) Intravenous therapy-related stress among pediatric nurses. This outcome was evaluated using the hospital's existing survey data on intravenous therapy-related stress among pediatric nurses. The questionnaire included three dimensions— intravenous therapy-related stress, workplace violence experience, and intention to leave—with seven items in total. Response options were “yes,” “no,” and “refuse to answer,” and the questionnaire had a Cronbach's α coefficient of 0.882. This study extracted the “intravenous therapy-related stress” item for analysis. A response of “yes” was defined as the presence of intravenous therapy-related stress, “no” as the absence of such stress, and “refuse to answer” as missing data. The prevalence of intravenous therapy-related stress = number of nurses reporting such stress / number of valid responses to that item during the corresponding period $\times 100\%$.

1.4 Statistical Analysis $\bar{x} \pm s$ Statistical analyses were performed using SPSS 26.0 and R 4.4.1. Data meeting the normality assumption according to the Shapiro–Wilk test were expressed as mean $\pm$ standard deviation. Independent cross-sectional questionnaire surveys were conducted before and after implementation of the model. Because the surveys were anonymous and individual nurses could not be matched one-to-one across the two periods, between-group comparisons were performed using the independent-samples t test. Non-normally distributed data were expressed as M (P25, P75) and compared using the Mann–Whitney U test. Categorical variables were expressed as n (%) and compared using the χ^2 test or Fisher's exact test. With the first-attempt success rate as the primary outcome, RR and 95% CI were calculated. Firth penalized logistic regression was further used to analyze the independent association between the consultation model and first-attempt success, adjusting for age, sex, disease diagnosis, and baseline vascular characteristics, and aORs with 95% CIs were reported. Comparisons of consultation waiting time also included the mean difference and 95% CI. All tests were two-sided, and $P < 0.05$ was considered statistically significant.

2 Results

2.1 First-Attempt Success Rate

In the intervention group, first-attempt insertion was successful in 245 children, corresponding to a first-attempt success rate of 99.2% (245/247), compared with 233 children and a success rate of 95.9% (233/243) in the control group. The difference in first-attempt success rate between the two groups was statistically significant ($\chi^2=5.602$, $P = 0.018$). Compared with the control group, the RR for first-attempt success in the intervention group was 1.034 (95% CI: 1.006–1.064), with an absolute increase in

success rate of 3.31 percentage points (95% CI: 0.57–6.04 percentage points), as shown in Table 4 and Fig. 3.

2.2 Consultation Waiting Time, Parental Consultation Satisfaction, Consultation-Related Complaints, and Intravenous Therapy-Related Stress Among Nurses

The consultation waiting time was shorter in the intervention group than in the control group, with a between-group mean difference of – 12.57 min (95% CI: –12.91 to – 12.23 min, $P < 0.001$). Among 553 difficult intravenous therapy consultation episodes, 231 parents in the control period were satisfied with the consultation, corresponding to a satisfaction rate of 87.8% (231/263), whereas 286 were satisfied in the intervention period, corresponding to a satisfaction rate of 98.6% (286/290). Parental satisfaction was higher in the intervention period than in the control period ($\chi^2=26.373$, $P < 0.001$), with an RR of 1.123 (95% CI: 1.071–1.177). Four consultation-related complaints occurred in the control group, accounting for 1.5% (4/263), whereas no consultation-related complaints occurred in the intervention period (0/290). Because the number of complaint events was small, Fisher's exact test was used, and the difference between the two periods did not reach statistical significance ($P = 0.051$). A total of 403 and 402 valid nurse questionnaires were obtained before and after implementation, respectively. Before implementation, 269 nurses reported intravenous therapy-related stress (66.7%), compared with 150 nurses (37.3%) after implementation. The prevalence of intravenous therapy-related stress among nurses was lower after implementation than before implementation ($\chi^2=69.869$, $P < 0.001$), with an RR of 0.559 (95% CI: 0.484–0.646). See Table 4 and Fig. 3.

Table 4
Comparison of Primary and Secondary Outcomes Between the Two Groups

Outcome	Control/before implementation	Intervention/after implementation	Statistic	P value	Effect size (95% CI)
First-attempt success, n (%)	233/243 (95.9)	245/247 (99.2)	$\chi^2=5.602$	0.018	RR = 1.034 (1.006–1.064)
Consultation waiting time (min, mean $\pm$ SD) $x \pm s$	14.93 $\pm$ 2.48	2.36 $\pm$ 1.11	$t = 72.609$	< 0.001	MD = –12.57 (–12.91 to –12.23)
Parental consultation satisfaction, n (%)	231/263 (87.8)	286/290 (98.6)	$\chi^2=26.373$	< 0.001	RR = 1.123 (1.071–1.177)
Consultation-related complaints, n (%)	4/263 (1.5)	0/290 (0)	Fisher	0.051	–
Nurses with intravenous therapy-related stress, n (%)	269/403 (66.7)	150/402 (37.3)	$\chi^2=69.869$	< 0.001	RR = 0.559 (0.484–0.646)
Note: RR, relative risk; MD, mean difference; CI, confidence interval. Consultation-related complaints were compared using a two-sided Fisher's exact test.					

2.3 Multivariable Analysis of Consultation Model and First-Attempt Success

Given the small number of first-attempt failures, Firth penalized logistic regression was used to reduce the influence of complete or near-complete separation and small-sample bias on regression estimates. First-attempt success was used as the dependent variable, consultation model as the main independent variable, and age, sex, disease diagnosis, and pre-consultation venipuncture difficulty were included as covariates. After adjustment for these factors, the consultation model based on venipuncture difficulty grading remained independently and positively associated with first-attempt success (aOR = 4.726, 95% CI: 1.135–19.683, $P = 0.033$). Age (aOR = 0.914, 95% CI: 0.548–1.523, $P = 0.731$), sex (aOR = 1.178, 95% CI: 0.453–3.064, $P = 0.737$), and disease type (aOR = 0.832, 95% CI: 0.308–2.247, $P = 0.716$) were not independently associated with first-attempt success. For each one-grade increase in venipuncture difficulty, the odds of first-attempt success showed a decreasing trend (aOR = 0.623, 95% CI: 0.359–1.080), although the association did not reach statistical significance ($P = 0.092$). See Table 5 and Fig. 4.

Table 5
Firth Penalized Logistic Regression Analysis of First-Attempt Success

Variable	β	SE	aOR	95% CI	P value
Consultation model: intervention vs control	1.553	0.728	4.726	1.135–19.683	0.033
Age (per 1-year increase)	−0.090	0.261	0.914	0.548–1.523	0.731
Sex: male vs female	0.164	0.488	1.178	0.453–3.064	0.737
Respiratory disease vs other diseases	−0.184	0.507	0.832	0.308–2.247	0.716
Venipuncture difficulty (per 1-grade increase)	−0.473	0.280	0.623	0.359–1.080	0.092
Note: aOR, adjusted odds ratio; CI, confidence interval; SE, standard error. The control group, female sex, and non-respiratory diseases were used as the reference categories.					

2.4 Sensitivity Analysis

To evaluate the robustness of the primary analysis, regression models with different levels of adjustment were further constructed. In the unadjusted model, the OR for first-attempt success after consultation in the intervention group versus the control group was 5.258 (95% CI: 1.140–24.250, $P = 0.033$). After adjustment for age and sex, the association between consultation model and first-attempt success after consultation remained stable (aOR = 5.011, 95% CI: 1.168–21.502, $P = 0.030$). After further adjustment for disease diagnosis and the reclassified baseline venipuncture difficulty, the odds of first-attempt success after consultation remained higher in the intervention group (aOR = 4.781, 95% CI: 1.148–19.908, $P = 0.032$). See Table 6.

Table 6
Sensitivity Analysis of the Association Between Consultation Model and First-Attempt Success Across Differently Adjusted Models

Model	Adjustment factors	OR/aOR	95% CI	P value
Model 1	Unadjusted	5.258	1.140–24.250	0.033
Model 2	Age, sex	5.011	1.168–21.502	0.030
Model 3	Age, sex, disease diagnosis, venipuncture difficulty	4.781	1.148–19.908	0.032
Note: Model 1 was unadjusted; Model 2 was adjusted for age and sex; Model 3 was further adjusted for disease diagnosis and baseline venipuncture difficulty. Baseline venipuncture difficulty was reclassified as Grades I, II, and III and coded as 1, 2, and 3, respectively. OR, odds ratio; aOR, adjusted odds ratio; CI, confidence interval.				

3 Discussion

Children aged 0–3 years are at high risk of difficulty in establishing peripheral intravenous access. Because of their small vessel diameter, relatively abundant subcutaneous fat, poor vein visibility and palpability, crying, and limb movement, young children are particularly prone to first-attempt puncture failure and repeated puncture attempts during peripheral intravenous catheterization. Repeated procedures can increase pain, local tissue injury, and treatment delays, may worsen negative experiences for children and their parents, and can increase procedural stress among healthcare professionals. In recent years, the management of difficult intravenous access in children has gradually shifted from reliance solely on operator experience toward pre-puncture risk identification, pathway-based management, and technological escalation. Systematic reviews have shown that appropriate puncture strategies for children with difficult intravenous access can improve first-attempt success [8]. Incorporating DIVA risk assessment into a standardized pediatric peripheral intravenous access pathway can improve first-attempt outcomes [9]. For children already identified as having difficult intravenous access, early implementation of targeted escalation strategies can further improve the efficiency of establishing intravenous access [10]. However, previous studies have focused mainly on specific technologies such as ultrasound guidance and vein visualization, whereas evidence remains relatively limited regarding stratified matching of children's venipuncture difficulty with nurses' procedural competency and rapid consultation scheduling through information-based systems.

On this basis, the present study established a precision consultation model based on venipuncture difficulty grading. Compared with conventional consultation, the first-attempt success rate increased from 95.9% to 99.2% after implementation, while consultation waiting time decreased from (14.93 ± 2.48) min to (2.36 ± 1.11) min. Parental satisfaction also increased and intravenous therapy-related stress among nurses decreased. After adjustment for relevant confounders, the consultation model remained independently associated with first-attempt success. These findings suggest that moving risk identification forward and integrating difficulty assessment, competency-based personnel matching, and consultation resource allocation into a standardized process may be an important approach to improving the quality of difficult intravenous access management in young children. The higher first-attempt success rate observed after implementation of the precision consultation model may be related to the fact that successful pediatric peripheral intravenous catheterization depends not only on age and vascular conditions but also on operator experience, training level, and competency in managing difficult intravenous access. Bhargava et al. [11] reported that standardized ultrasound-guided PIV training for pediatric critical care staff improved first-attempt success, indicating that systematic training and competency development can substantially improve the quality of complex vascular access procedures. Tian et al. [12] found that, compared with the conventional method, nurse-performed ultrasound-guided peripheral intravenous catheter placement had a higher first-attempt success rate and reduced insertion time and number of puncture attempts. Meanwhile, Lam et al. [13] found substantial variation among clinicians in the recognition of pediatric DIVA, timing of escalation, and selection of adjunctive technologies; the absence of standardized escalation criteria may result in unnecessary repeated attempts in some children. The distinctive feature of the present study was not merely to improve the technical skills of all nurses, but to determine procedural risk in advance according to venipuncture

difficulty and then allocate nurses according to competency level, allowing high-difficulty cases to be managed earlier by nurses with appropriate qualifications and experience. This changed the conventional pattern from escalation after puncture failure to pre-puncture risk prediction and proactive escalation. This mechanism can reduce repeated attempts on difficult vessels by personnel with lower competency levels and may prevent the unnecessary occupation of senior venipuncture nursing resources by all children. Therefore, the improvement in first-attempt success may be attributable more to the decision chain of risk grading, competency matching, and timely escalation than to any single procedural component. Consultation waiting time was one of the outcomes showing the greatest improvement in this study, suggesting that the value of the venipuncture difficulty-based consultation model lies not only in puncture technique itself but also in restructuring the consultation process. Under the conventional model, after a responsible nurse identifies a difficult case, a request must be completed, the person in charge contacted, and an appropriate venipuncture nurse located according to current staffing. This process may involve repeated communication, reassessment, and waiting for personnel. A pediatric intravenous procedure quality-improvement project by Dolma et al. [14] showed that process mapping, clear role definition, standardized check tools, and continuous quality improvement can significantly improve the overall quality of intravenous procedures. Nti et al. [15] reported that a structured, staged training system for difficult intravenous access personnel in a pediatric emergency department was feasible and could establish a stable reserve of specialized procedural competency. In the present study, vascular difficulty grade, basic patient information, and nurse competency information were incorporated into a unified scheduling process. Information was transmitted and personnel were matched through a PDA, and a relatively fixed consultation area was established, allowing appropriate personnel to be rapidly identified after a consultation request. This reduced non-procedural time spent on telephone communication, locating personnel, repeated difficulty assessment, and waiting for experienced nurses to arrive.

The present study showed increased parental consultation satisfaction and reduced intravenous therapy-related stress among nurses, suggesting that the precision consultation model may improve both family experience and nursing staff experience. A qualitative study by Taşdelen et al. [16] showed that pediatric nurses may experience anxiety, frustration, and negative perceptions of their own procedural ability after failure of the first intravenous catheter insertion, whereas successful first-attempt insertion and support from experienced personnel can contribute to a more positive professional experience. Therefore, when high-difficulty cases can be transferred promptly according to explicit criteria to senior venipuncture nurses with the appropriate competency, lower-level nurses do not need to continuously undertake procedures beyond their capability, which may reduce technical and responsibility-related stress caused by repeated failures. For children and their parents, the intravenous therapy experience is likewise not determined by a single puncture outcome. Lorenc et al. [17] reported that after implementation of systematic comfort management and team-based quality improvement in more than 20,000 pediatric PIV insertions and blood-collection procedures, the proportion of children achieving adequate comfort increased from 68% to 90%, suggesting that organizational process optimization and team culture also influence children's needle-related experience. In a randomized

controlled trial, Koç et al. [18] found that although use of a musical toy improved some aspects of children's fear and emotional response, it did not significantly improve parental satisfaction, indicating that parental satisfaction is likely a composite outcome influenced by waiting time, number of puncture attempts, communication quality, professional trust, and treatment expectations. Accordingly, the higher parental satisfaction observed in this study may be related to improved first-attempt success, markedly shortened waiting time, and more rapid involvement of specialized personnel. It should be emphasized that although consultation-related complaints decreased from 4 cases to 0, Fisher's exact test showed that the difference was not statistically significant. Because complaints were also rare events, the findings can only be interpreted as a downward trend in the number of complaints after implementation and cannot establish that the model significantly reduces complaint risk.

Current studies aimed at improving difficult intravenous access in children have largely focused on specific puncture technologies. Gürcan et al. [19] reported that optimizing catheter insertion techniques in pediatric hematology and oncology patients could improve first-attempt insertion success. Álvarez-Morales et al. [20] found that ultrasound-guided peripheral intravenous catheterization performed by appropriately trained emergency nurses could improve success rates, supporting the value of advanced adjunctive technologies in DIVA management. However, technological escalation alone cannot resolve all problems in difficult intravenous access management. Kleidon et al. [21] showed that first-attempt PIVC success in children is influenced by multiple factors, including patient characteristics, operator expertise, and adjunctive technology, and that vascular access specialists and ultrasound guidance are both associated with higher first-attempt insertion success. The pediatric DAV-expert consensus algorithm proposed by Pittiruti et al. [22] emphasizes that vascular access decisions should integrate patient characteristics, treatment needs, and vascular conditions. Compared with interventions that mainly depend on devices or procedural techniques, the present model primarily addresses organizational management questions: how to identify difficulty, who should perform the procedure, when escalation should occur, and how appropriate personnel can be deployed rapidly. Its dependence on specialized equipment is therefore relatively low. Accordingly, this model may serve as a foundational framework for difficult intravenous access management. On this basis, ultrasound, near-infrared imaging, and other adjunctive technologies could be further introduced according to the actual needs of children with Grade III–IV difficulty, forming a stepwise management pathway combining “personnel escalation + technology escalation.” The focus on children aged 0–3 years also provides specific clinical relevance. Infants and young children are among the populations in whom establishing intravenous access is most difficult because of anatomical characteristics and limited cooperation. A systematic review by Casal-Guisande et al. [23] showed that ultrasound guidance for peripheral vascular access in infants was associated with higher first-attempt success and fewer puncture attempts, although implementation requires specialized training and appropriate resources. Clarke et al. [24] reported that age < 12 months was an important predictor of insertion abandonment, with significantly increased risk in both children aged < 3 months and those aged 3–12 months. Establishment of specialized vascular access services is another current direction of development. Benvenuti et al. [25] reported that after a dedicated Vascular Access Unit was established in a large hospital, professional training,

multidisciplinary collaboration, and process redesign enabled a large number of vascular access procedures to be completed during the first year, with high first-attempt insertion success, low complication rates, and improved patient satisfaction. Therefore, the difficulty grading and competency-matching mechanism in the present study has room for further development. In the future, more refined escalation criteria could be formulated according to age, DIVA risk, previous puncture failures, and vascular conditions, and senior venipuncture nurses, vascular access teams, ultrasound, and other adjunctive technologies could be integrated into a unified management pathway to improve the accessibility and efficiency of specialized vascular access services for young children.

This study has several limitations. First, a single-center retrospective before-and-after controlled design was used, with the control and intervention groups drawn from different time periods. Therefore, confounding due to the natural accumulation of nursing experience, concurrent changes in management measures, and other temporal trends could not be completely excluded. The findings are therefore more appropriately interpreted as associations between the consultation model and clinical outcomes rather than as evidence of strict causal effects. Second, first-attempt success rates were high in both groups and the number of failure events was small. Although Firth penalized logistic regression was used to reduce bias caused by small samples and near-complete separation, the stability of the effect estimates may still be limited. Third, parental satisfaction and nurses' intravenous therapy-related stress were subjective outcomes that may have been influenced by survey methods, social desirability, and changes in participant composition. If the nurses surveyed before and after implementation were not completely matched individuals, differences in stress cannot be interpreted as strict within-person longitudinal changes. Fourth, the number of consultation-related complaints was small, limiting statistical power for this outcome. Fifth, this study mainly focused on first-attempt success and consultation-process outcomes and did not evaluate longer-term outcomes such as catheter dwell time, infiltration or extravasation, unplanned removal, treatment delay, and resource utilization. Future prospective multicenter studies should stratify participants in advance by age, venipuncture difficulty grade, and history of previous failed attempts, and should further evaluate catheter-related outcomes, cost-effectiveness, and patient-reported outcomes to validate the external validity and sustained implementation value of this model.

4 Conclusion

In summary, the consultation model based on venipuncture difficulty grading was associated with a higher first-attempt success rate and shorter consultation waiting time in children aged 0–3 years, together with higher parental satisfaction and lower intravenous therapy-related stress among nurses. Its potential value may lie in integrating difficult intravenous access risk identification, personnel competency matching, and consultation resource scheduling into an executable standardized management pathway; however, its effectiveness requires further validation in higher-quality prospective studies.

Declarations

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Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request. The data are not publicly available because they contain potentially identifiable clinical information involving pediatric patients.

Ethics Approval

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Guangdong Women and Children Hospital. Owing to the retrospective nature of the study and the use of de-identified clinical and nursing data, the requirement for written informed consent from the participants' legal guardians was waived by the Ethics Committee.

Competing Interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contribution

Z.C. contributed to the study conception and design, methodology, data curation, formal analysis, interpretation of the results, and preparation of the original manuscript. M.S. contributed to data collection, investigation, validation, visualization, and critical revision of the manuscript. S.W. contributed to study conception, supervision, project administration, interpretation of the results, and critical review and editing of the manuscript. All authors read and approved the final manuscript and agreed to be accountable for all aspects of the work.

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Figures

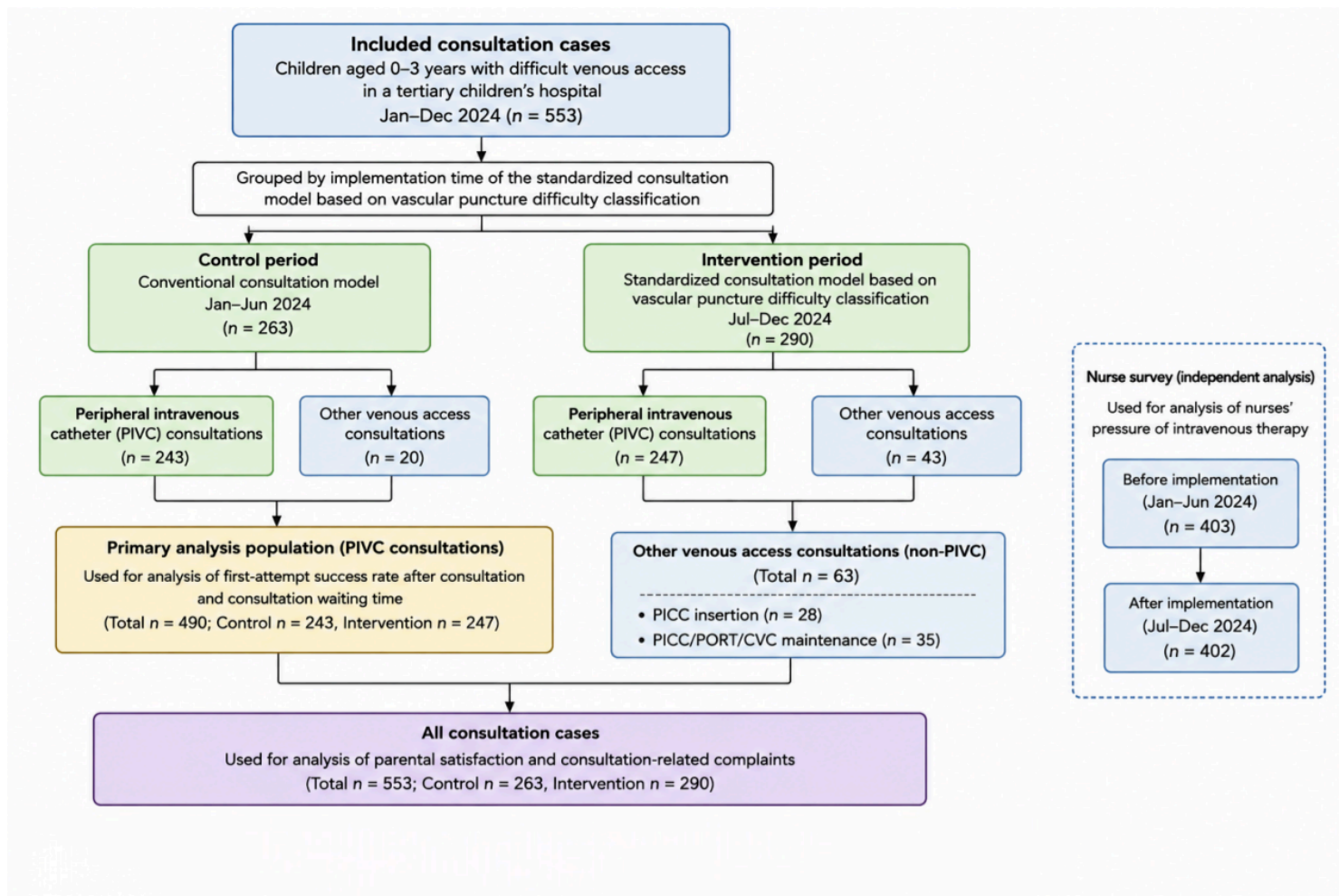


Figure 1

Study Flowchart

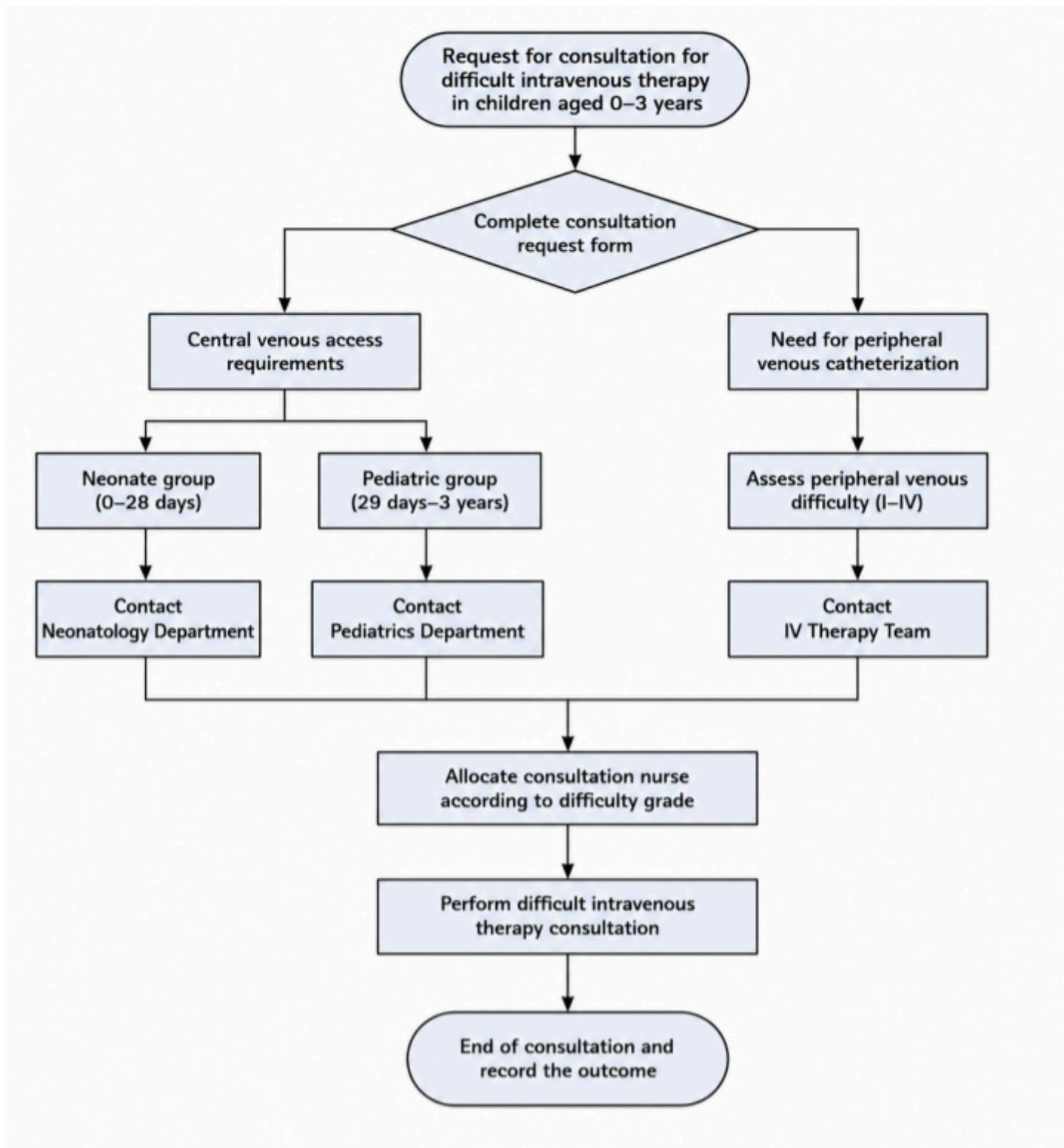


Figure 2

Consultation Model Based on Venipuncture Difficulty Grading

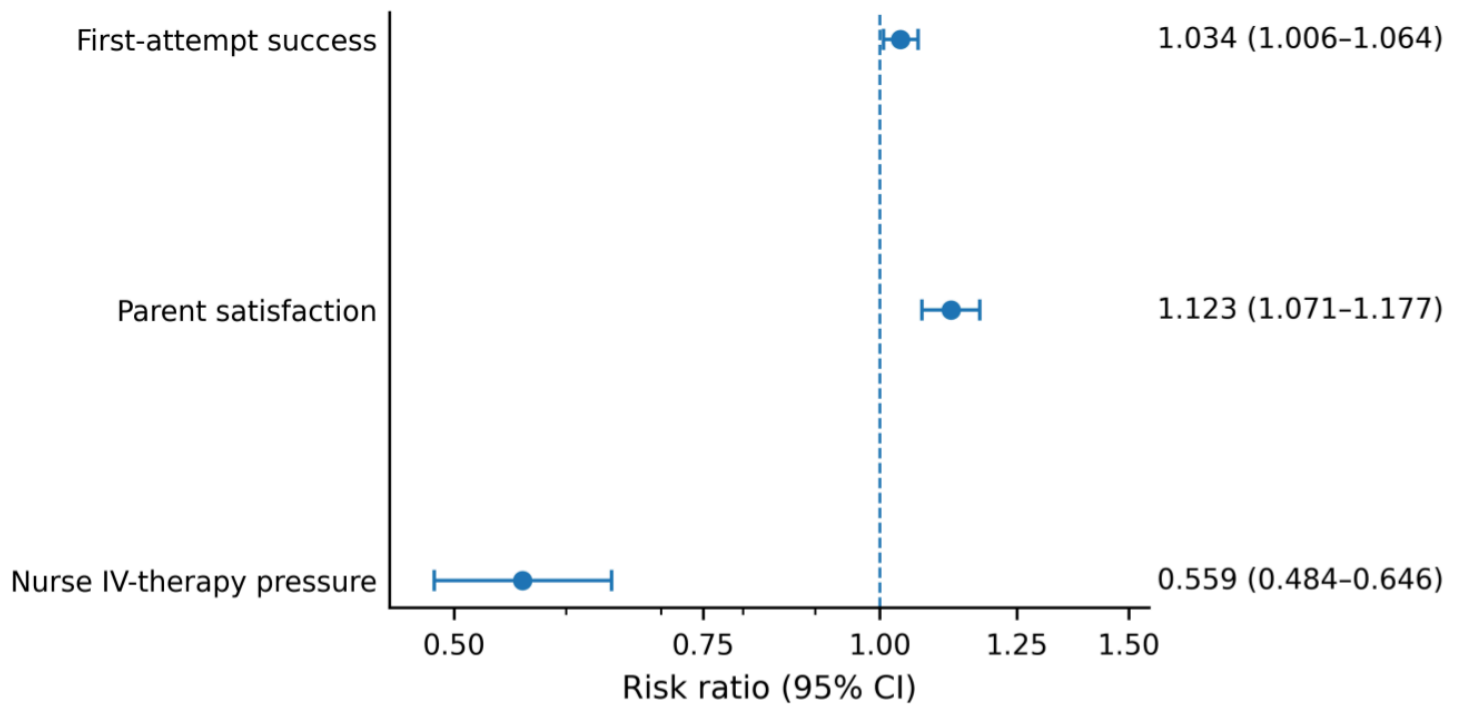


Figure 3

Forest Plot of Effect Sizes for Categorical Outcomes

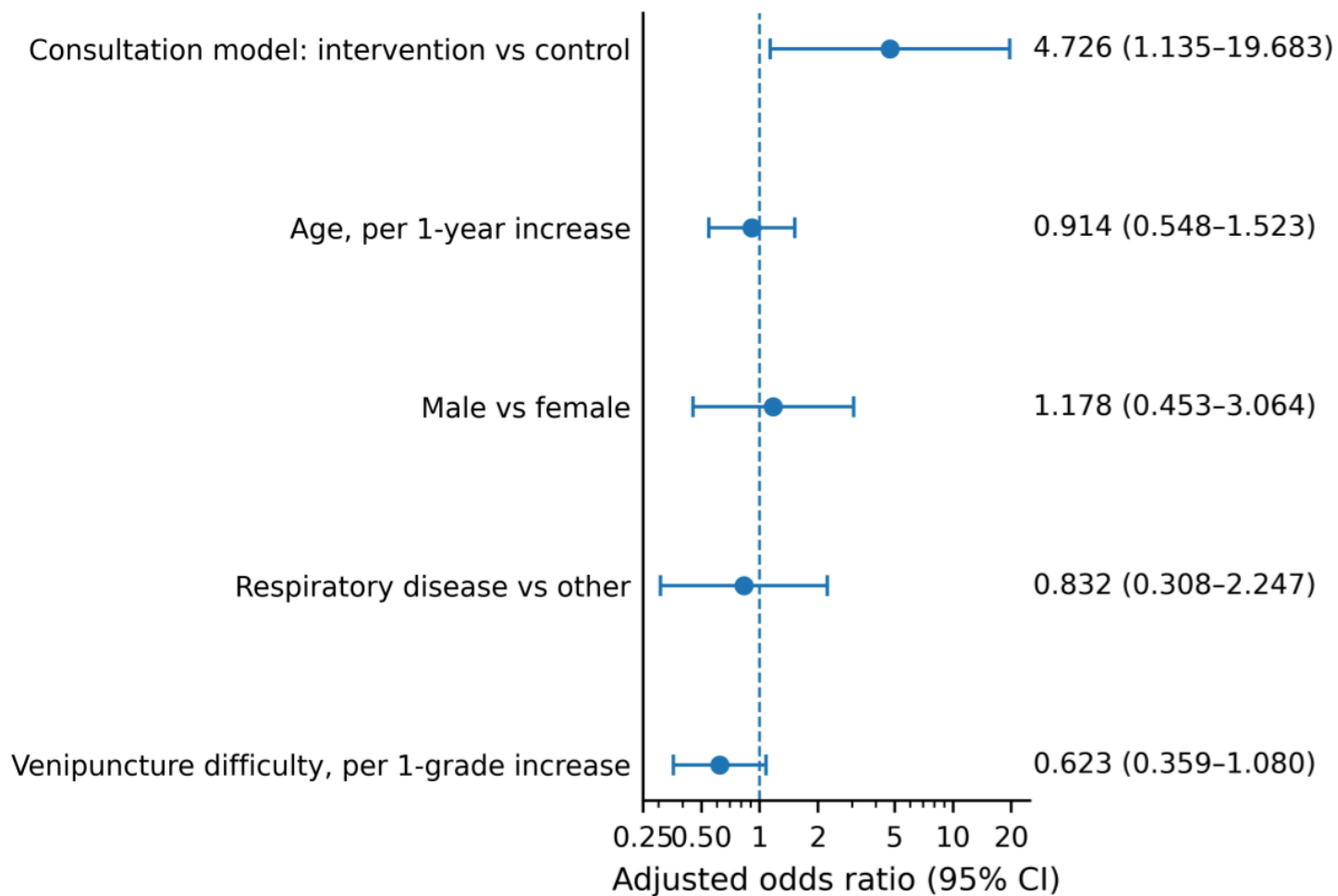


Figure 4

Forest Plot of Firth Penalized Logistic Regression Analysis