



PATTERNS AND MECHANISMS OF VENTRICULOPERITONEAL SHUNT MALFUNCTION ACCORDING TO PROXIMAL VENTRICULAR CATHETER ENTRY POINT IN CHILDREN: A SCOPING REVIEW

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ABSTRACT

Introduction: Ventriculoperitoneal shunt (VPS) is the most common cerebrospinal fluid diversion procedure in pediatric hydrocephalus, yet it is the most failure-prone device. The proximal ventricular catheter is the dominant weak point, and the cranial entry point is a determinant entirely under the surgeon's control. This review maps the patterns and mechanisms of VPS malfunction according to proximal catheter entry point in children.

Methods: This scoping review followed JBI methodology and PRISMA-ScR reporting. Systematic searches were conducted in PubMed, [ClinicalTrials.gov](https://clinicaltrials.gov), Semantic Scholar, Elsevier, and Cochrane (2016–2026). Inclusion criteria comprised children <18 years with hydrocephalus undergoing primary or revision VPS, with entry point reported or proximal catheter mechanism studied. Two reviewers independently performed selection and data

charting. Risk of bias was assessed using RoB 2, ROBINS-I, and ROBINS-E.

Results: Twenty-seven reports (2 RCTs, 25 non-randomized; >12,000 children; ≥ 379 explanted catheters) were analyzed. Pooled cohort analysis showed an advantage for anterior entry (HR 0.68; 95% CI 0.56–0.83; $I^2=0\%$), although the HCRN RCT was non-significant ($p=0.062$). Proximal obstruction was less frequent with frontal entry (RR 0.16; 95% CI 0.05–0.57). Key mechanisms included ventricular wall and choroid plexus contact ($p=0.005$), distinct hole-occlusion patterns with parietal entry ($p=0.001$), and a universal, time-dependent microglia-to-astrocyte transition. Catheter migration was documented only with the frontal route in children <3 years, associated with non-burr-hole valves and right-angle adaptors. Age <6 months was the strongest risk modifier (HR 1.49; 95% CI 1.28–1.73). Image guidance improved accuracy (RR 0.41; 95% CI 0.21–0.78).

Discussion: The anterior advantage is modest and time-dependent, mediated primarily by tip environment and proximal obstruction rather than infection. Specific vulnerabilities of the anterior route in neonates and infants include trajectory error and migration, which are technically preventable. Only one quarter of the literature stratifies outcomes by entry site.

Conclusion: Proximal catheter entry point is a modifiable determinant of pediatric VPS malfunction. The anterior route is recommended as the default for first-time pediatric VPS, with age-specific risk mitigation through image guidance, cranial inclination control, and burr-hole valve or straight connector anchoring.

Keywords: pediatric hydrocephalus, ventriculoperitoneal shunt, catheter entry point, proximal obstruction, malfunction mechanism

INTRODUCTION

Background

Hydrocephalus is among the most common conditions managed by paediatric neurosurgeons worldwide. Global modelling estimates that nearly 400,000 new cases of paediatric hydrocephalus arise each year, with a congenital incidence higher in low- and middle-income countries (LMICs; 123 per 100,000 births) than in high-income countries (79 per 100,000 births), and with the African, Latin American and South-East Asian regions carrying about three-quarters of the global caseload.¹ Population-based meta-analysis places the paediatric prevalence at approximately 88 per 100,000, underlining that hydrocephalus is a chronic, life-long condition in which the durability of cerebrospinal fluid (CSF) diversion determines neurodevelopmental trajectory, quality of life and health-system cost.^{2,3}

Ventriculoperitoneal shunting remains the most frequently used definitive CSF diversion procedure, yet shunts are among the most failure-prone life-sustaining devices implanted in contemporary practice. Failure modes are broadly classified into obstruction, infection, mechanical failure (fracture, disconnection, migration), overdrainage and distal site-specific complications.⁴ In a Thai national cohort of 2072 children, cumulative failure reached 11.5%, 19.0% and 25.2% at 3, 6 and 12 months, respectively, and 33.7% over a median of 29.9 months; more than half of failures occurred within 180 days.⁵ In the United States Nationwide Readmissions Database, one in five children required revision within 6 months of index shunting, with a median time to revision of only 44.5 days.⁶

Among all modes of failure, the proximal ventricular catheter is the dominant weak point. The Hydrocephalus Clinical Research Network (HCRN) prospective cohort of 1036 first-time shunts recorded 265 malfunctions and 79 infections among 344 failures, identifying age below 6 months, cardiac comorbidity and endoscopic placement as independent risk factors.⁷ Explant studies demonstrate that ventricular catheter obstruction alone accounts for more than half of paediatric shunt failures, and that tissue aggregates composed of astrocytes, macrophages, microglia and choroid plexus occlude the drainage holes.^{8–10}

The cranial entry point of the proximal catheter is one of the few determinants of proximal performance that is entirely under the surgeon's control. Classic landmarks include Kocher's point (frontal, anterior to the coronal suture), Keen's point (posterior parietal, above and behind the pinna), Frazier's point (parieto-occipital) and Dandy's point (occipital). The anterior route offers a short, perpendicular trajectory that terminates in the choroid-poor

frontal horn anterior to the foramen of Monro; posterior routes require a longer intraventricular course through the atrium, where the choroidal glomus is bulkiest. A secondary analysis of three large paediatric datasets ($n = 858$) unexpectedly showed that entry site, not tip location, predicted survival, with anterior entry lowering the failure hazard by about one-third (HR 0.65, 95% CI 0.51–0.83).¹¹ The subsequent HCRN RCT ($n = 453$) found a non-significant difference in time to failure (posterior vs anterior HR 1.35, 95% CI 0.98–1.85; $p = 0.062$).¹²

Research gap

Four gaps motivate this review. First, the available comparative literature focuses on a single binary end point (time to shunt failure) and rarely reports which malfunction pattern — obstruction, malposition, migration, infection or overdrainage — differs by entry site. Second, mechanistic evidence (explant histology, cell-type kinetics, flow modelling, catheter–wall contact) has developed largely independently of clinical entry-site research and has never been mapped against entry point.^{13,14} Third, an existing meta-analysis pooled six studies of anterior versus posterior placement in children but addressed survival and infection only and did not integrate mechanistic data, age-dependent effects or technical modifiers such as valve type and image guidance.¹⁵ Fourth, evidence from LMICs, where postinfectious hydrocephalus, late presentation and macrocrania predominate, is fragmented and heterogeneous in design.^{1,16}

Novelty

To our knowledge, this is the first scoping review to (i) chart malfunction patterns and mechanisms simultaneously according to proximal entry point in children; (ii) integrate clinical cohorts, randomised evidence and explant-based mechanistic studies into a single evidence map; (iii) provide a visual evidence architecture (evidence map, gap heat map, radar chart and geographic map chart) that exposes where entry-site-specific knowledge is absent; and (iv) propose an integrative mechanistic model linking entry point → trajectory → tip environment → malfunction phenotype, with explicit host (age, aetiology) and technical (valve, connector, guidance) modifiers.

Objectives and review questions

The primary objective was to map the variables, patterns and mechanisms of VPS malfunction according to the entry point of the proximal ventricular catheter in children. Secondary objectives were to describe the characteristics of the evidence base, to identify effect modifiers (age, aetiology, guidance, hardware), to appraise methodological quality, and to identify research gaps. The review questions were: (RQ1) Which malfunction patterns

(type, site, timing) have been reported according to entry point? (RQ2) Which mechanisms (geometric, cellular, infectious, hydrodynamic, hardware-related) have been proposed or demonstrated? (RQ3) Which patient and technical factors modify the entry point–malfunction relationship? (RQ4) What are the principal evidence gaps?

Hypotheses

Although scoping reviews do not formally test hypotheses, three a priori working hypotheses guided charting: H1 — anterior entry is associated with fewer proximal malfunctions than posterior entry; H2 — the association is mediated chiefly by tip environment (ventricular wall and choroid plexus contact) and tissue ingrowth rather than by infection; H3 — the benefit of the anterior route is attenuated in neonates and infants by trajectory error and catheter migration, and is modified by image guidance and anchoring hardware.

Significance and benefits

For practising paediatric neurosurgeons, the review translates dispersed evidence into a decision framework that links a modifiable surgical choice to specific failure phenotypes, supporting individualised entry-point selection (for example, in neonates, in slit ventricles or with a closed fontanelle). For trainees (PPDS), it provides a structured synthesis for examination and practice. For researchers and guideline developers, the evidence map identifies precisely which mechanism–entry-point combinations lack data, informing the design of age-stratified RCTs, explant registries and standardised reporting. For health systems — particularly in Indonesia and other LMICs with a high burden of postinfectious hydrocephalus — reducing preventable proximal revisions has direct implications for cost, bed occupancy and neurodevelopmental outcome.

METHODS

Methodological framework and reporting standard

The review followed the JBI methodology for scoping reviews, which builds on the Arksey and O'Malley and Levac frameworks through five stages (identifying the question, identifying relevant studies, study selection, charting the data, and collating/summarising/reporting), and was reported in accordance with the PRISMA extension for Scoping Reviews.^{17–20}

Eligibility criteria (PCC framework)

Eligibility was defined using the Population–Concept–Context framework recommended by JBI.

Population–Concept–Context (PCC) framework

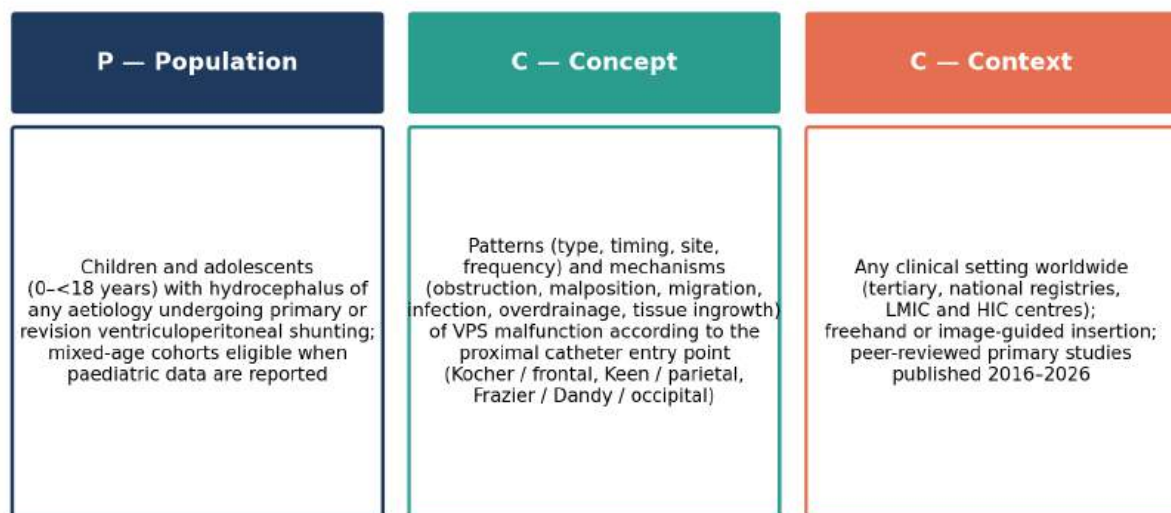


Figure 1. Population–Concept–Context (PCC) framework underpinning the eligibility criteria.

Table 1. PCC framework of the review

Element	Definition applied	Operational notes
Population (P)	Children and adolescents aged 0 to <18 years with hydrocephalus of any aetiology (post-haemorrhagic, postinfectious, myelomeningocele-associated, aqueductal stenosis, tumour-related, congenital) undergoing primary or revision VPS	Mixed-age cohorts eligible if paediatric patients were included and data relevant to children were reported or the cohort was predominantly paediatric
Concept (C)	Patterns (type, anatomical site, timing, frequency, recurrence) and mechanisms (malposition, migration, tissue obstruction, infection-associated obstruction, overdrainage/ventricular collapse, hardware failure) of VPS malfunction according to proximal catheter entry point	Entry points: Kocher/frontal (anterior); Keen/parietal, Frazier/parieto-occipital, Dandy/occipital (posterior). Studies of proximal-catheter mechanisms that modulate entry-point effects (trajectory, tip environment, anchoring, guidance) were eligible
Context (C)	Any clinical setting or country; any insertion technique (freehand, ultrasound,	Emphasis on the most recent 5–10 years; no language restriction

	neuronavigation, endoscopic); peer-reviewed primary studies published January 2016 – September 2026	applied at search stage
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Table 2. Inclusion and exclusion criteria derived from the PCC framework

Domain	Inclusion criteria	Exclusion criteria
Study design	Randomised controlled trials; prospective or retrospective cohort studies; case-control studies; cross-sectional studies; other observational or quasi-experimental primary studies; secondary analyses of prospective/trial data; explant-based clinical cohorts	Systematic reviews, meta-analyses (retained for Discussion only), narrative reviews, case reports, technical notes without outcome data, editorials, letters, conference abstracts without full data
Population	Patients <18 years, or mixed cohorts reporting paediatric data	Adult-only cohorts (≥ 18 years); animal (veterinary) studies
Intervention / exposure	VPS with a ventricular (proximal) catheter; entry point reported or proximal-catheter mechanism studied	Ventriculoatrial/ventriculopleural or lumboperitoneal shunts only; ETV-only; external ventricular drains only
Outcomes	Any malfunction pattern or mechanism (≥ 1 of O1–O14)	Studies reporting only distal/abdominal outcomes or valve-type comparisons without proximal data
Other	Full text or sufficiently detailed abstract available; publication 2016–2026	In vitro, computational or bench studies (used only for mechanistic context in Discussion); duplicate or overlapping datasets (most complete retained)

Search Strategy

The keywords used for this research based PICO :

PICO Element	Keyword 1	Keyword 2	Keyword 3
P (Population)	Pediatric hydrocephalus	Children with ventriculoperitoneal shunt	Infants and adolescents with hydrocephalus
I (Intervention)	Proximal ventricular catheter entry point	Anterior (Kocher) entry site	Frontal ventricular catheter

			placement
C (Comparison)	Posterior (Keen, Frazier, Dandy) entry	Parieto-occipital catheter trajectory	Non-anterior ventricular entry
O (Outcome)	Ventriculoperitoneal shunt malfunction	Proximal catheter obstruction	Shunt failure and revision

The Boolean MeSH keywords inputted on databases for this research are: (*"Pediatric hydrocephalus"* OR *"Children with ventriculoperitoneal shunt"* OR *"Infants and adolescents with hydrocephalus"*) AND (*"Proximal ventricular catheter entry point"* OR *"Anterior (Kocher) entry site"* OR *"Frontal ventricular catheter placement"*) AND (*"Posterior (Keen, Frazier, Dandy) entry"* OR *"Parieto-occipital catheter trajectory"* OR *"Non-anterior ventricular entry"*) AND (*"Ventriculoperitoneal shunt malfunction"* OR *"Proximal catheter obstruction"* OR *"Shunt failure and revision"*)

Selection of sources of evidence

Records were de-duplicated (Rayyan's automated duplicate detection has high sensitivity and was complemented by manual DOI matching) and screened in two stages — titles/abstracts and full text — using Rayyan, a free web and mobile application that supports blinded dual screening, labelling of exclusion reasons and conflict resolution.^{22,23} Rayyan and Covidence have been rated the most usable screening tools by systematic reviewers; Covidence is an acceptable alternative where institutional licences exist.²⁴ Two reviewers independently applied the eligibility criteria after a calibration exercise on 10% of records; disagreements were resolved by discussion or by a third senior reviewer.

Data charting process and data items

A standardised charting form was developed in Microsoft Excel, piloted on three reports and iteratively refined. Data were charted by one reviewer and verified by a second. Fourteen outcome domains (O1–O14) were pre-specified to capture malfunction patterns and mechanisms.

Table 3. Data-charting form: variables extracted

Category	Variables
Bibliographic	First author, year, journal, DOI, country, setting, number of centres, funding
Design	Study design (RCT, prospective/retrospective cohort, case-control, cross-sectional), recruitment period, follow-up duration, comparison groups

Population	Sample size (patients, procedures, explanted catheters), age (median/mean, strata), sex, aetiology (PHH, MMC, aqueductal stenosis, postinfectious, tumour), prior shunt history
Entry point & technique	Entry point(s) (Kocher, Keen, Frazier, Dandy, parieto-occipital), side, freehand vs ultrasound vs neuronavigation vs endoscopic, valve type (burr-hole vs non-burr-hole, programmable), connector/adaptor, catheter material, catheter length
Outcomes	O1–O14 (Table 6): numerators, denominators, effect estimates (HR, OR, RR), confidence intervals, p-values, time points
Mechanisms	Histology/immunohistochemistry, dominant cell type, tissue type (choroid plexus, glial, inflammatory), catheter-wall contact, tip environment, trajectory metrics (cranial inclination, deviation), flow/shear data
Authors' conclusions	Stated mechanism, limitations, recommendations

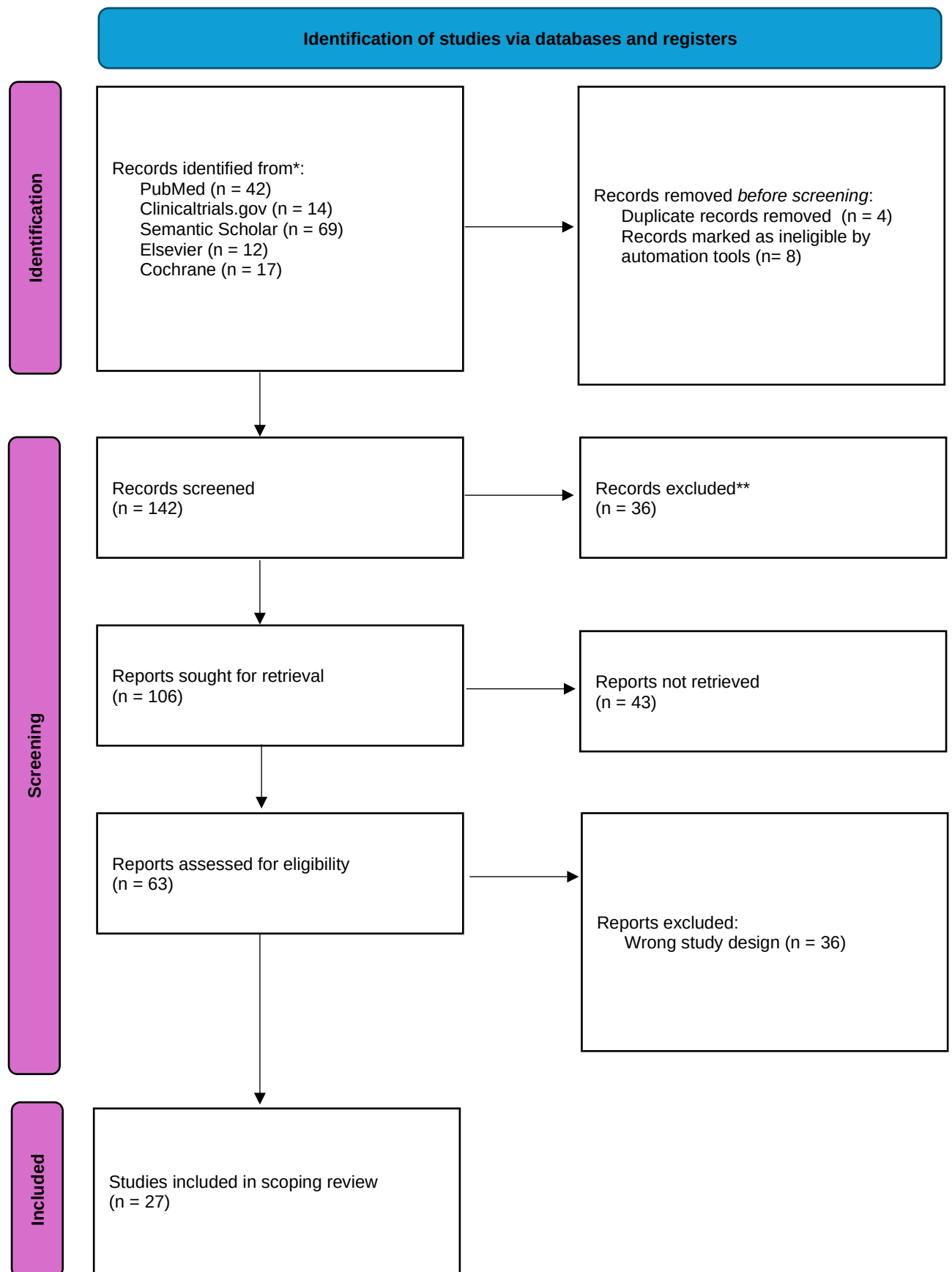
Table 4. Pre-specified outcome domains (n = 14)

Code	Outcome domain	Operational definition
O1	Overall shunt failure / survival	Revision, ETV conversion or infection-defined failure; time-to-event estimates
O2	Proximal catheter obstruction	Revision for ventricular catheter occlusion (clinical, radiological or intra-operative)
O3	Catheter malposition / placement accuracy	Tip outside intended ventricle, parenchymal/contralateral placement, graded accuracy (optimal/suboptimal)
O4	Ventricular catheter migration	Progressive withdrawal of catheter tip or deviation on serial imaging
O5	Shunt infection	Culture-proven or clinically diagnosed shunt infection
O6	Revision burden and timing	Revision rate, multiple revisions, time to first revision
O7	Histopathology of obstructing tissue	Tissue/cell composition of aggregates in explanted catheters
O8	Temporal failure pattern	Early (<30–180 days) versus late failure; dwell-time-dependent cellular pattern
O9	Tip environment / wall & choroid contact	Relation of catheter to ventricular wall, septum, choroid plexus, frontal horn

O10	Overdrainage / ventricular collapse	Overdrainage, slit ventricles, change in fronto-occipital horn ratio (FOHR)
O11	Age as effect modifier	Age-stratified failure, misplacement or migration
O12	Image guidance as effect modifier	Ultrasound, navigation or endoscopic guidance versus freehand
O13	Peri-operative complications	Intra-operative complications, haemorrhage, CSF leak, pseudomeningocele, seizures
O14	CSF / infection–obstruction interplay	CSF protein, infection-associated obstruction

Article Search Strategy

Database	Keywords	Hits
Pubmed	<i>("Pediatric hydrocephalus") AND ("Proximal ventricular catheter entry point" OR "Anterior (Kocher) entry site" OR "Frontal ventricular catheter placement" AND "Ventriculoperitoneal shunt malfunction" OR "Proximal catheter obstruction" OR "Shunt failure and revision")</i>	42
Clinicaltrials.gov	<i>("Pediatric hydrocephalus" OR "Children with ventriculoperitoneal shunt" OR "Infants and adolescents with hydrocephalus" AND "Proximal ventricular catheter entry point" OR "Anterior (Kocher) entry site" OR "Frontal ventricular catheter placement" AND "Ventriculoperitoneal shunt malfunction" OR "Proximal catheter obstruction" OR "Shunt failure and revision")</i>	14
Semantic Scholar	<i>("Pediatric hydrocephalus" OR "Children with ventriculoperitoneal shunt" OR "Infants and adolescents with hydrocephalus") AND ("Proximal ventricular catheter entry point" OR "Anterior (Kocher) entry site" OR "Frontal ventricular catheter placement") AND ("Posterior (Keen, Frazier, Dandy) entry" OR "Parieto-occipital catheter trajectory" OR "Non-anterior ventricular entry") AND ("Ventriculoperitoneal shunt malfunction" OR "Proximal catheter obstruction" OR "Shunt failure and revision")</i>	69
Elsevier	<i>("Pediatric hydrocephalus" OR "Children with ventriculoperitoneal shunt" OR "Infants and adolescents with hydrocephalus") AND ("Proximal ventricular catheter entry point" OR "Anterior (Kocher) entry site" OR "Frontal ventricular catheter placement") AND ("Posterior (Keen, Frazier, Dandy) entry" OR "Parieto-occipital catheter trajectory" OR "Non-anterior ventricular entry") AND ("Ventriculoperitoneal shunt malfunction" OR "Proximal catheter obstruction" OR "Shunt failure and revision")</i>	12
Cochrane	<i>("Pediatric hydrocephalus" OR "Children with ventriculoperitoneal shunt" OR "Infants and adolescents with hydrocephalus" AND "Proximal ventricular catheter entry point" OR "Anterior (Kocher) entry site" OR "Frontal ventricular catheter placement" AND "Ventriculoperitoneal shunt malfunction" OR "Proximal catheter obstruction" OR "Shunt failure and revision")</i>	17



Article search flowchart

Critical appraisal (risk of bias)

Critical appraisal is optional in scoping reviews but was undertaken to contextualise the strength of mapped evidence. RCTs were assessed with the revised Cochrane risk-of-bias tool (RoB 2; five domains: randomisation, deviations from intended interventions, missing outcome data, outcome measurement, selection of the reported result).²⁵ Non-randomised comparative studies were assessed with ROBINS-I (seven domains), and non-comparative exposure/mechanistic cohorts with the ROBINS-E–adapted instrument for non-randomised studies of exposures, using identical domain labels to permit a unified display.^{26,27}

Critical appraisal of individual sources

The HCRN RCT was judged at low risk of bias in all RoB 2 domains, owing to computer-based surgeon-stratified randomisation, blinded independent adjudication of an objective primary outcome and complete follow-up. The Egyptian randomised comparison raised some concerns in four domains (unreported sequence generation and allocation concealment, unblinded assessment, short follow-up, absent protocol), yielding an overall high risk of bias.^{12,28}

Among the 25 non-randomised studies, none was at low overall risk; 11 (44%) were at moderate, 13 (52%) at serious and 1 (4%) at critical risk (Table 10; Figures 7–8). Confounding was the most frequently compromised domain (serious in 14/25), reflecting allocation to entry site by surgeon preference, era effects, and inconsistent adjustment for age and aetiology. Explant studies carried serious selection bias because only removed catheters were analysed. The critical rating (Paul 2022) reflected loss to follow-up of 55% of the enrolled cohort.³⁶

Table 5. RoB 2 assessment of randomised controlled trials

Study	D1 Randomisation	D2 Deviations	D3 Missing data	D4 Measurement	D5 Reporting	Overall	Justification
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Study	D1 Randomisation	D2 Deviations	D3 Missing data	D4 Measurement	D5 Reporting	Overall	Justification
Whitehead 2021	Low	Low	Low	Low	Low	Low	Stratified web-based randomisation; blinded adjudication committee; objective outcome; registered protocol
Elmesallamy 2022	Some concerns	Some concerns	Low	Some concerns	Some concerns	High	Randomisation method and concealment not described; unblinded outcome assessment; 3-mo follow-up; no registered protocol

Table 6. ROBINS-I / ROBINS-E–adapted assessment of non-randomised studies (L = low, M = moderate, S = serious, C = critical)

Study	D1	D2	D3	D4	D5	D6	D7	Overall	Principal concern
Whitehead 2017	M	L	L	L	M	M	L	M	Pooled historical trials; entry site not randomised; era/surgeon adjusted
Riva-Cambrin 2016	M	L	L	L	M	L	L	M	Observational; entry site not analysed; short median follow-up

Study	D1	D2	D3	D4	D5	D6	D7	Overall	Principal concern
Kullmann 2018	S	M	L	L	M	M	M	S	Single centre; unadjusted comparison; 34% screened excluded
Hsu 2019	S	M	L	L	M	M	M	S	Small; valve choice by era/surgeon
Chang 2026	S	M	L	L	L	M	M	S	Small; loss of significance after age adjustment
Katano 2026	S	M	L	L	M	M	M	S	Mixed ages; single route; freehand
Kesilmez 2026	S	M	L	M	L	M	M	S	Historical/technique confounding; retrospective
Mansoor 2021	M	L	L	L	L	M	M	M	Mixed shunt types; entry not stratified
Sahin 2020	S	M	M	L	M	M	S	S	Single surgeon; unadjusted entry-site comparison; incomplete numeric reporting
Paul 2022	S	M	M	L	C	M	M	C	55% lost to follow-up
Patra 2016	M	M	L	L	M	M	M	M	Retrospective; radiological indices from mixed modalities
Hariharan 2021	S	S	L	L	M	M	L	S	Explant-only (failed catheters); centre heterogeneity
Hariharan 2023	S	S	M	L	M	M	L	S	Explant-only; entry-site classification incomplete
Garcia-Bonilla 2024	S	S	L	L	M	M	L	S	Explant-only; denominator not reported
Hanak 2016	S	S	L	L	M	L	M	S	Small explant bank; cautery artefact exclusions
Stuart 2025	M	L	L	L	L	M	L	M	Single region; CSF sampling not universal
Lazarus 2024	M	L	L	L	M	M	M	M	Index and revision shunts combined

Study	D1	D2	D3	D4	D5	D6	D7	Overall	Principal concern
Wilson 2016	M	M	L	L	M	M	L	M	Mixed ages; two institutions; guidance by surgeon choice
Sunderland 2022	M	L	L	L	L	L	M	M	Post hoc; entry site not recorded
Limwattananon 2021	M	L	M	L	L	M	L	M	Administrative coding of failure
Donoho 2021	M	L	M	L	M	M	L	M	Administrative data; revision proxy
Khalique 2025	S	M	L	M	L	S	M	S	Non-random allocation; mixed ages; small
Safdar 2025	S	M	L	L	L	S	M	S	Allocation by surgeon preference; composite outcome
Prajsnar-Borak 2022	S	M	L	L	M	M	M	S	No comparator; follow-up unit unclear
Pan 2018	M	M	L	L	M	M	M	M	Retrospective; aetiology-driven confounding

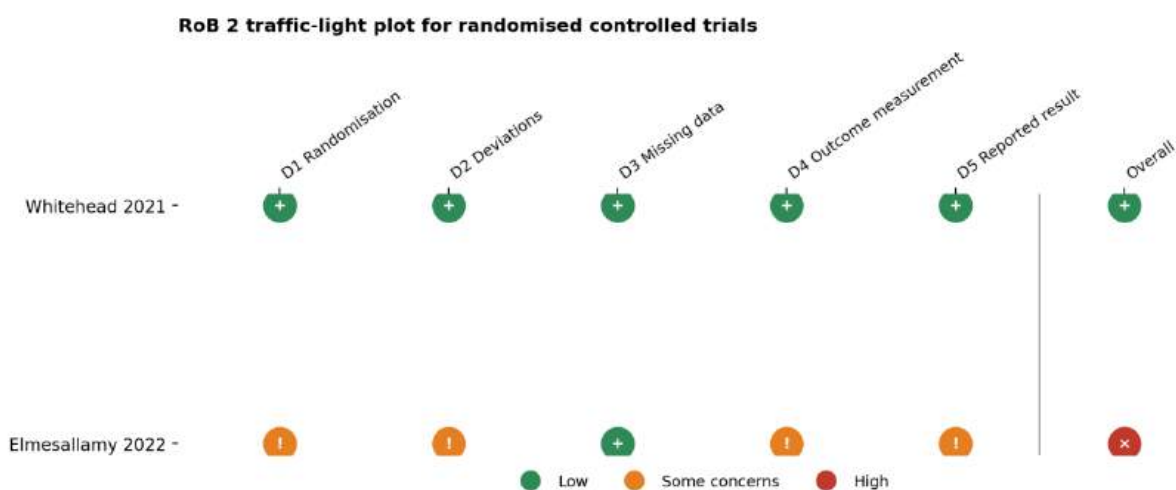


Figure 3. Risk-of-bias traffic-light plot for RCTs (RoB 2).

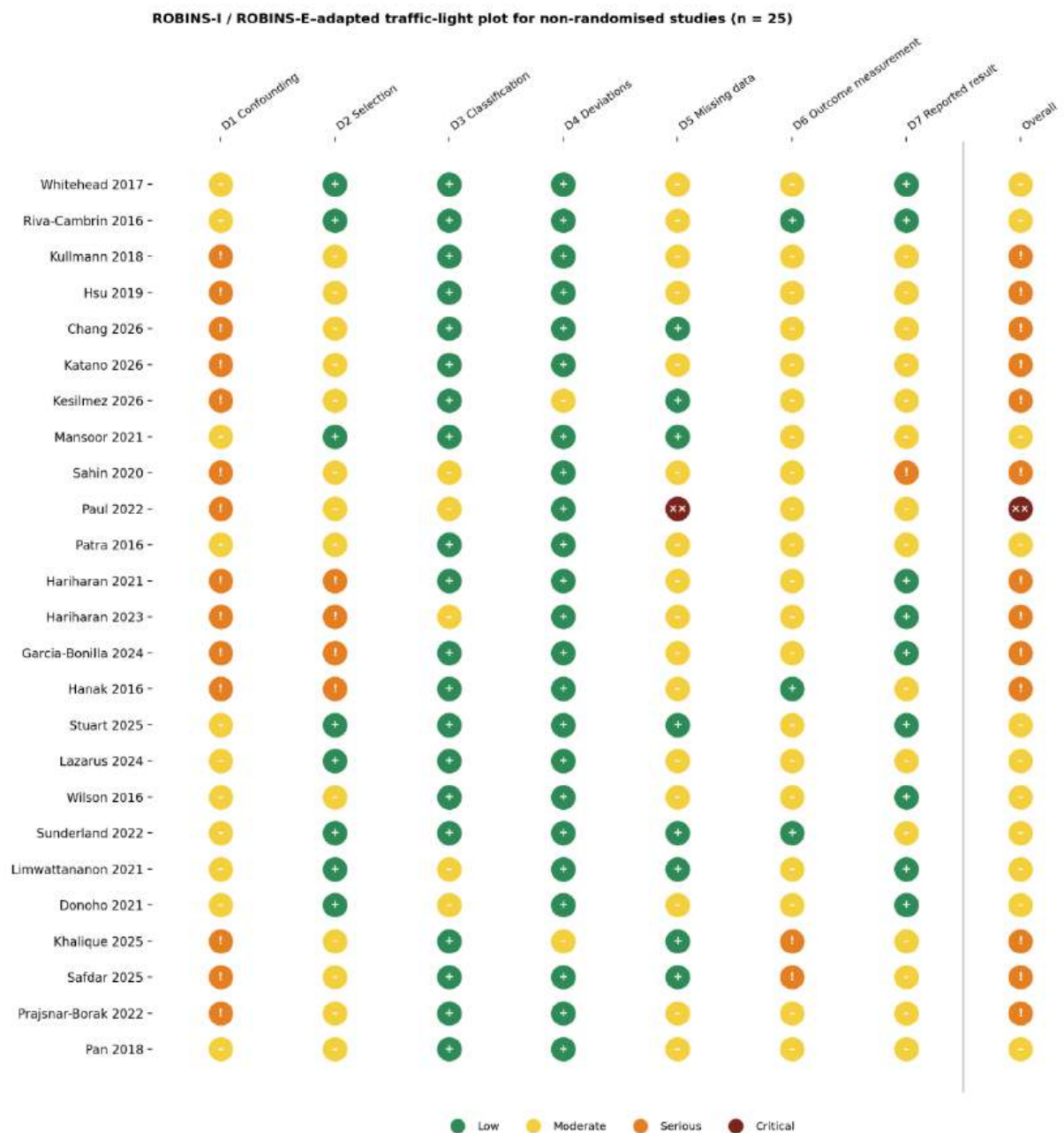


Figure 4. Risk-of-bias traffic-light plot for non-randomised studies (ROBINS-I / ROBINS-E-adapted).

Risk-of-bias summary plots (weighted by number of studies)

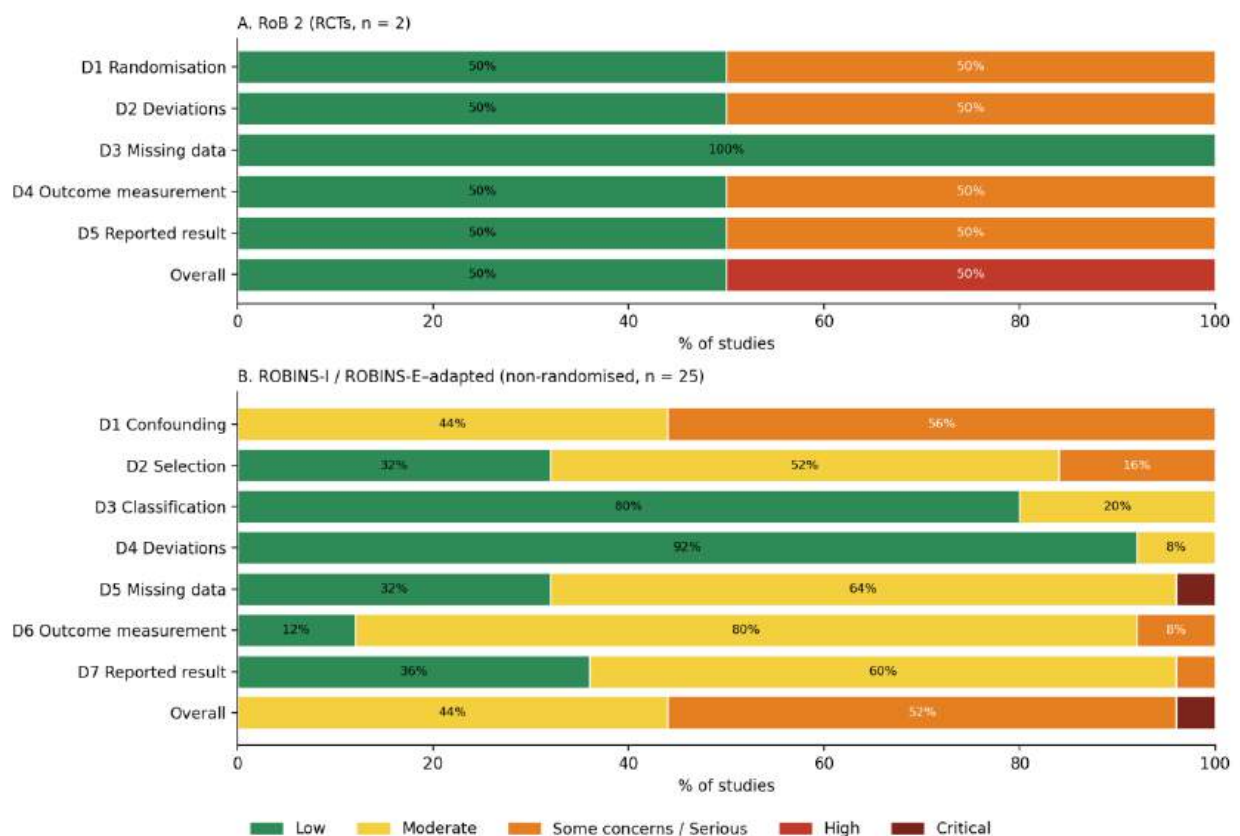


Figure 5. Weighted risk-of-bias summary plots for RCTs (A) and non-randomised studies (B).

Synthesis of results and visualisation

Consistent with PRISMA-ScR, results were synthesised descriptively (frequencies, proportions, ranges) and narratively by outcome domain and entry-point category (direct anterior-versus-posterior comparison; anterior only; posterior only/posterior subtypes; entry site not stratified). Visual evidence architecture comprised: a PRISMA-ScR flow diagram; a PCC diagram; an anatomical schematic of entry points; a temporal distribution chart; a geographic map chart (choropleth built with GeoPandas and Natural Earth boundaries); a word cloud weighted by charted term frequency (Python wordcloud); a bubble evidence map; an evidence-gap heat map; a radar chart; and an integrative mechanistic model.

Exploratory quantitative synthesis

Although meta-analysis is not an objective of scoping reviews, exploratory pooling was performed where at least two independent, conceptually comparable estimates were available, to aid interpretation. Hazard ratios were pooled on the log scale using inverse-variance weighting with standard errors derived from reported 95% confidence intervals; risk ratios were computed from 2×2 counts (0.5 continuity correction for zero cells); proportions were pooled on the logit scale. A DerSimonian–Laird random-effects model was applied

throughout; heterogeneity was quantified with Cochran's Q , τ^2 and I^2 . The posterior-versus-anterior HR of the HCRN RCT was inverted to express all estimates as anterior versus posterior. Analyses were performed in Python 3 (NumPy, SciPy) and results are presented as forest plots (Figures 13, 15, 16, 21 and 22). Given the small number of studies, pooled estimates are hypothesis-generating and were not graded for certainty.

RESULTS

Characteristics of sources of evidence

The 27 reports were published between 2016 and 2026, with 16 (59%) published in the most recent five years (2021–2026) (Figure 4). Designs comprised two RCTs (7.4%), six prospective or secondary-prospective studies (22.2%) and nineteen retrospective studies (70.4%), including four explant-based multicentre or single-centre cohorts. Studies originated from 14 countries across five continents; the United States contributed 10 reports (37%, including four HCRN-linked multicentre studies with Canadian participation), followed by Germany, Taiwan, Türkiye, India and Pakistan (two each). Collectively, the reports included 12,212 patients, 106 catheter insertions and at least 379 explanted ventricular catheters (one explant study did not report a total). Nineteen reports (70%) were exclusively paediatric and eight enrolled mixed-age cohorts with paediatric representation. Only 7 reports (26%) provided entry-site-stratified comparisons; 4 examined a single anterior route, 2 a single posterior route or posterior subtypes, and 14 (52%) did not stratify by entry site.

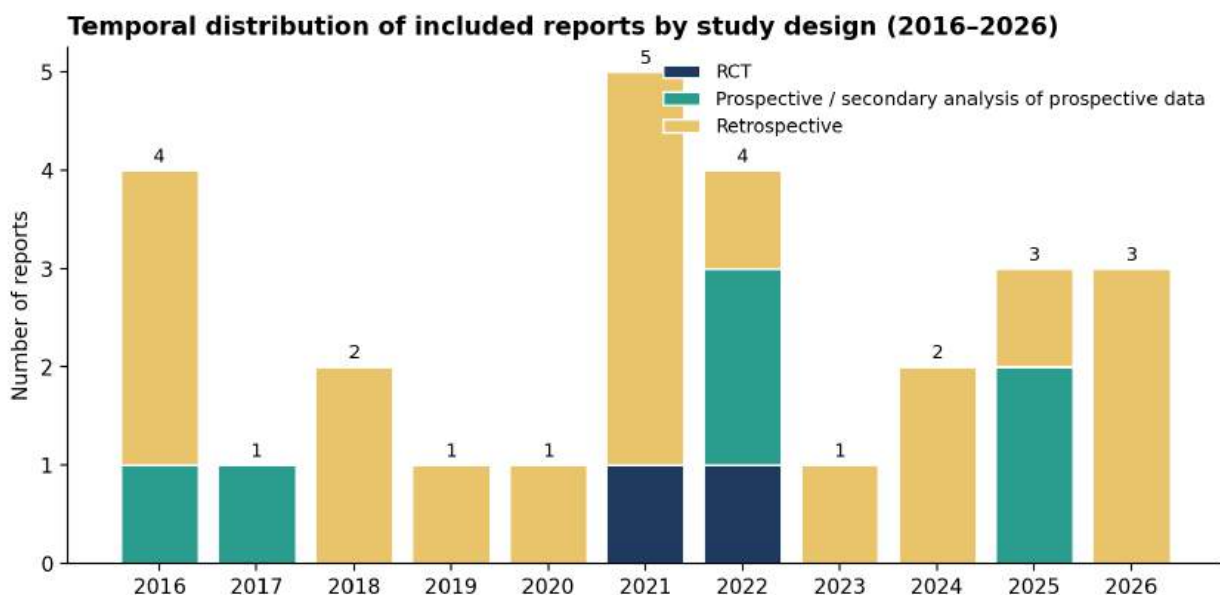


Figure 6. Temporal distribution of included reports by year and design.

Geographic map chart of included reports (Canada co-contributes to multicentre HCRN studies)



Figure 7. Geographic map chart (choropleth) of included reports by country of origin.

Table 7. Characteristics of included primary studies (n = 27 reports).

ID	Author, year	Country	Design	N	Age	Entry site(s) / technique	Follow-up	Principal pattern / mechanism findings
S1	Whitehead 2021 ¹²	USA/Canada (14 centres)	RCT (HCRN), parallel, surgeon-stratified	467 randomised; 453 analysed (224 anterior, 229 posterior)	Median 1.3 mo	Anterior vs posterior; first shunt	Min 18 mo	Time to failure NS (posterior vs anterior HR 1.35, 0.98–1.85; p = 0.062); no difference in passes, catheter location, infection, CSF leak, pseudomeningocele, skull fracture, seizures, haemorrhage
S2	Elmesallamy 2022 ²⁸	Egypt	Prospective randomised	60 (30 vs 30)	≤2 y	Anterior-fontanelle US-guided vs	3 mo	Adequate proximal location significantly better with US (p =

			comparative			conventional		0.0005); proximal obstruction 0/30 vs 3/30 (p = 0.237)
S3	Whitehead 2017 ¹¹	USA/Canada	Secondary cohort analysis of 3 studies (2 RCTs + HCRN study)	858	<18 y	Anterior vs posterior; tip location variables	Trial-dependent	Only age (p < 0.001) and entry site (p = 0.005) predicted survival; anterior HR 0.65 (0.51–0.83); frontal-horn tip advantage on univariate only
S4	Riva-Cambrin 2016 ⁷	USA/Canada (6 centres)	Prospective multicentre cohort (HCRN)	1036	<19 y	Not stratified; guidance examined	Mean 400 d	344 failures (265 malfunction, 79 infection); age <6 mo HR 1.6, cardiac HR 1.4, endoscopic placement HR 1.9; guidance not protective
S5	Kullmann 2018 ²⁹	Germany	Retrospective cohort	85 (of 128 screened)	Paediatric	Frontal 71% vs occipital 29%; US-guided	≥12 mo	95% in intended ventricle, 61% optimal; 12-mo obstruction 9/85; 7/9 non-optimal (p = 0.016); 7/9 occipital vs 2/9 frontal (p = 0.016)
S6	Hsu 2019 ³⁰	Taiwan	Retrospective cohort	60	<3 y (mean 5.1 mo)	Frontal only; burr-hole vs	Mean 50.9 mo	Migration 8/60; 7/8 with non-burr-hole valve; burr-

						non-burr-hole valve		hole valve, older age and longer catheter protective (Weibull-adjusted)
S7	Chang 2026 ³¹	Taiwan	Retrospective cohort	48	<3 y	Frontal; non-burr-hole valve; straight connector vs right-angle adaptor	2017–2022	Migration 18/48; right-angle 61.5% vs straight 9.1% (p = 0.0002); younger age (4.5 vs 10.1 mo); NS after age adjustment
S8	Katano 2026 ³²	Japan	Retrospective cohort	106 insertions	Neonates/ infants, 1–15 y, adults	Anterior only; freehand	NR	Accurate 76.4%; misplacement 39.3% infants vs 7.7% children vs 4.2% adults; inclination >37.2° and deviation >12.9° predicted misplacement and reduced survival
S9	Kesilmez 2026 ³³	Türkiye	Retrospective cohort	164 (48 guided, 116 freehand)	<18 y	US / frameless navigation vs freehand	≥12 mo	Optimal 81.25% vs 60.34% (p = 0.017); revision 16.67% vs 38.79% (p = 0.010); LOS shorter; infection NS
S10	Mansoor 2021 ³⁴	Norway	Retrospective cohort	81 patients / 206 operations	<18 y	Not stratified	1–10 y	58% ≥1 revision; proximal occlusion 30.4% of revisions,

				ns				misplacement 18.5%, infection 9.6%; 29.8% of first revisions due to misplacement
S11	Şahin 2020 ³⁵	Türkiye	Retrospective cohort (single surgeon)	210	≤16 y	Frontal vs occipitoparietal	≥1 y	Complications 86; infection 41; obstruction 53 (22 infection-related); infection lower with frontal entry; obstruction ≈3× higher with infection
S12	Paul 2022 ³⁶	Bangladesh	Prospective observational	140 (63 followed)	Paediatric	Freehand; tip location	2.5–4.5 y	Accurate placement 39.28%; 43/63 functioning (19 accurate, 7 suboptimal, 17 inaccurate)
S13	Patra 2016 ³⁷	India	Retrospective cohort	121	<18 y	Not stratified; radiological indices	Mean 49.9 mo	Revision 47.9%; FOHR reduction 20.16% (early) vs 6.4% (late) (p = 0.009); PVL associated with fewer revisions; <6 mo median revision-free survival 10.1 vs 94.1 mo
S14	Harihara	USA (5)	Multicenter	343	Mainly	Not	Implant	61.5% ≥1

	n 2021 ⁹	centres)	tre retrospec tive explant study	catheter s (54 histolog y)	paediatric	stratified	23.8–33.2 mo	occluded hole; macrophages & astrocytes ↑ in occluded; microglia 2–6%; CP 24%, glial 24%, lymphocytic 29%, FBGC 5%
S15	Harihara n 2023 ¹³	USA (5 centres)	Multicen tre retrospec tive explant study (same sample)	343 catheter s	Mainly paediatric	Parietal vs other entry	As above	Wall contact predicted obstruction (p = 0.005); age at first surgery predicted protruding aggregates (p = 0.002); parietal entry → more non-obstructive growth, fewer empty holes (p = 0.001)
S16	García- Bonilla 2024 ¹⁰	USA (5 hospital s)	Multicen tre retrospec tive explant study	NR (9 aetiolog ies)	Mainly paediatric	Not stratified	NR	Proximal obstruction 90.4% of removals; aggregates in 76.8% of obstruction removals; >40% holes occluded in MMC, congenital, tumour, PHH; no aetiology association

S17	Hanak 2016 ⁸	USA	Retrospective explant bank	36 imaged (24 analysed)	Paediatric	Not stratified	NA	Astrocytes and microglia dominant on surfaces; microglia-dominant 24.7 ± 6.7 d vs astrocyte-dominant 1183 ± 642 d (p = 0.027)
S18	Stuart 2025 ³⁸	Australia	Retrospective cohort (10 y)	427 new VPS	Mean 5.2 y	Not stratified	10 y	Revisions: proximal obstruction 51/173 (29%), infection 29/173 (17%), valve 23/173 (13%); CSF protein >300 mg/L shortened time to failure
S19	Lazarus 2024 ¹⁶	South Africa	Retrospective cohort	340 patients / 494 operations	Mean 3.4 mo	Not stratified	2015–2019	Failure 31.2%; blockage 13.6%, infection 7.3%, disconnection 3.6%; revision shunts fail more (34.7% vs 27.3%); 65% head circumference >+3 Z
S20	Wilson 2016 ³⁹	USA (2 centres)	Retrospective cohort	257	Mixed	Parieto-occipital only; guided vs	2005–2013	Accurate 81.2% guided vs 67.3% freehand; proximal failure

						freehand		30.7%; accurate placement OR 3.42 and guidance OR 2.39 for freedom from proximal failure
S21	Sunderland 2022 ⁴⁰	United Kingdom	Post hoc cohort of BASICS RCT	1594	All ages incl. neonates	Not stratified	Trial follow-up	Mechanical failure sHR 1.51 (<1 mo) and 1.31 (1 mo–<1 y); infection sHR 4.48 (<1 mo); antibiotic catheters protective against infection
S22	Limwattananon 2021 ⁵	Thailand (71 hospitals)	Retrospective national cohort	2072	Median 8.8 mo	Not stratified	Median 29.9 mo	Failure 33.7%; 11.5/19.0/25.2% at 3/6/12 mo; <1 y HR 1.45 (1.20–1.76); 35.8% multiple failures; 52.9% within 180 d
S23	Donoho 2021 ⁶	USA (NRD)	Retrospective national cohort	3520	Paediatric	Not stratified	≥6 mo	20% revision within 6 mo; median 44.5 d to revision; grade 3–4 IVH ↑ malfunction
S24	Khalique 2025 ⁴¹	Pakistan	Prospective quasi-experimental	60 (30 vs 30)	10–60 y	Kocher (frontal) vs Frazier (occipital)	6 mo	Success 80% vs 66%; malposition 6.67% vs 13.3%; obstruction 3.33% vs 10%;

								overdrainage 0 vs 6.67%; infection 10% vs 3.3%
S25	Safdar 2025 ⁴²	Pakistan	Prospective non-randomised controlled trial	438 (219 vs 219)	Mean $\approx$ 18–19 y	Frazier vs Keen (posterior subtypes)	Post-operative CT	Effective placement 79.9% Frazier vs 60.7% Keen ($p < 0.0001$)
S26	Prajsnar-Borak 2022 ⁴³	Germany	Retrospective cohort	51 children / 65 procedures	Mean 5.1 y	ShuntScope (transluminal endoscopy)	Mean 39.7 (unit as reported)	Ideal placement 77%; proximal-occlusion revision 4.61%; image grade not correlated with accuracy
S27	Pan 2018 ⁴⁴	India	Retrospective cohort	137	Mean 20.7 mo	Not stratified	NR	Complications 35.76%; revision 27%; of revisions: blockade 45.94%, infection 16.21%, migration 10.81%, pseudocyst 10.81%; TBM and IVH $\uparrow$ multiple revisions

Table 8. Distribution of reports by entry-site evidence category

Entry-site category	Reports (n)	Study IDs	Main outcome domains
Direct anterior vs posterior comparison	6	S1, S3, S5, S11, S15, S24	O1, O2, O3, O5, O9, O13
Posterior subtypes compared (Keen vs Frazier)	1	S25	O3
Anterior / frontal route only	4	S2, S6, S7, S8	O3, O4, O11, O12
Posterior (parieto-occipital) route only	1	S20	O2, O3, O12
Entry site not stratified (mechanism / pattern)	15	S4, S9, S10, S12–S14, S16–S19, S21–S23, S26, S27	O1, O2, O5–O8, O10, O11, O14
Total	27		

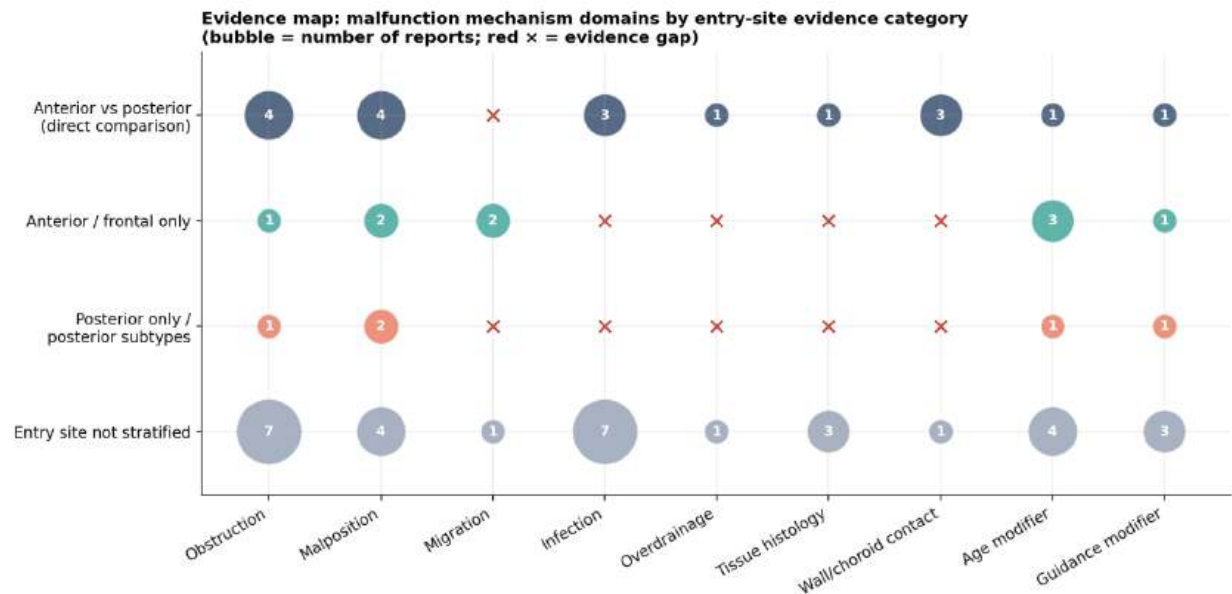


Figure 8. Bubble evidence map of mechanism domains by entry-site category; red crosses indicate evidence gaps.



Figure 9. Evidence-gap heat map of outcome domains reported by each included report; column totals are shown beneath the matrix.

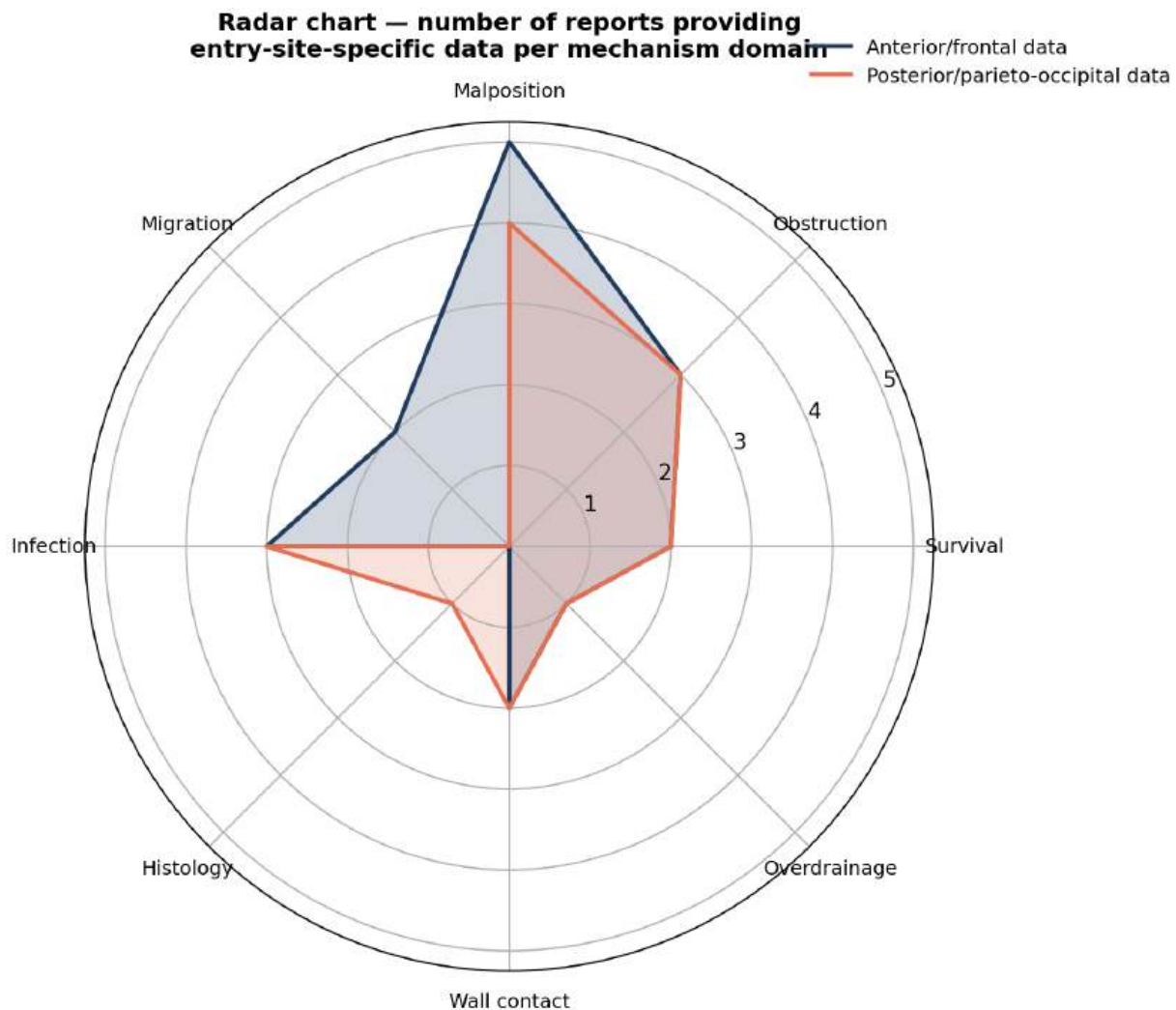


Figure 10. Radar chart of entry-site-specific evidence per mechanism domain.

Results of individual sources by outcome domain

O1 — Overall shunt failure and survival

Two independent paediatric datasets compared time to failure by entry site. In the pooled secondary analysis of 858 first-time shunts, only age and entry site were independently associated with survival in Cox regression, and anterior entry reduced the hazard of failure (HR 0.65, 95% CI 0.51–0.83); the catheter tip location did not remain significant ($p = 0.37$).¹¹ In the HCRN RCT, the posterior-versus-anterior HR was 1.35 (0.98–1.85; $p = 0.062$); expressed as anterior versus

posterior, this corresponds to HR 0.74 (0.54–1.02).¹² Exploratory random-effects pooling yielded HR 0.68 (95% CI 0.56–0.83; $p = 0.0001$) with no statistical heterogeneity ($I^2 = 0\%$; $Q p = 0.52$), the cohort contributing 63% of weight (Figure 13; Table 11). In adults, a propensity-matched two-centre study found no entry-site difference in misplacement revision (4.7% vs 4.6%) or dysfunction revision (4.7% vs 4.2%), suggesting that the effect may be age-dependent.⁴⁵

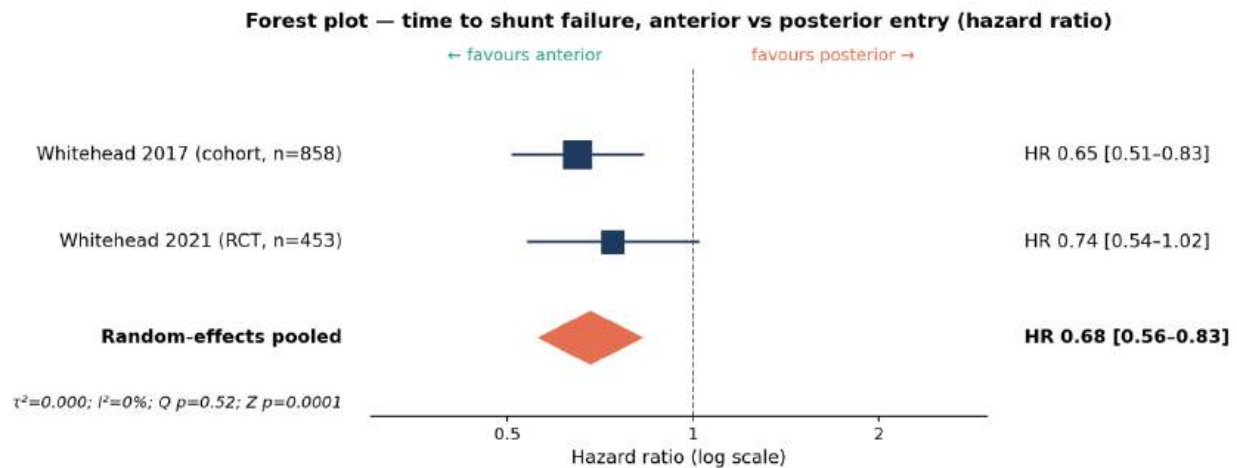


Figure 11. Forest plot — time to shunt failure, anterior versus posterior entry (random-effects, hazard ratio).

Table 9. Overall failure and survival outcomes by entry site

Study	Comparison	Estimate	Interpretation
Whitehead 2017 (n = 858)	Anterior vs posterior	HR 0.65 (0.51–0.83)	≈35% lower failure hazard with anterior entry; tip location not independent
Whitehead 2021 RCT (n = 453)	Anterior vs posterior	HR 0.74 (0.54–1.02)*	Non-significant; direction concordant
Exploratory pooled	Anterior vs posterior	HR 0.68 (0.56–0.83); I^2 0%	Consistent modest advantage, hypothesis-generating
Khalique 2025	Kocher vs Frazier	Success 80% vs 66%	Descriptive; underpowered

(n = 60, mixed age)			
Katano 2026 (anterior only)	Trajectory deviation >12.9°	Reduced survival	Within-route geometry determines survival

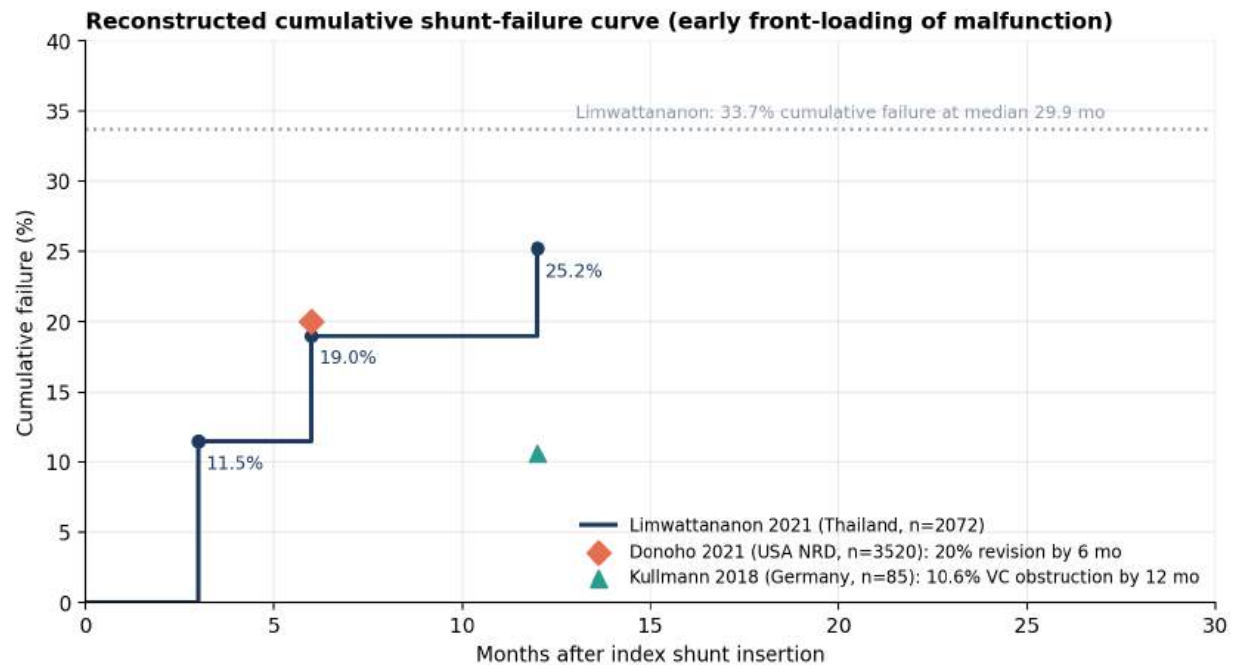


Figure 12. Reconstructed cumulative shunt-failure curve from national and cohort data, illustrating front-loading of malfunction within the first 6–12 months.

O2 — Proximal catheter obstruction

Entry-site-specific obstruction data were available from four reports. In an ultrasound-guided paediatric cohort (71% frontal), 9 of 85 ventricular catheters (10.6%) obstructed within 12 months; seven of nine were in a non-optimal position, and seven of nine had been inserted through an occipital burr hole (2/60 frontal vs 7/25 occipital; RR 0.12, 95% CI 0.03–0.53).²⁹ A prospective frontal-versus-occipital comparison recorded obstruction in 3.33% versus 10%.⁴¹ Exploratory pooling of these two studies gave RR 0.16 (0.05–0.57; $I^2 = 0\%$) in favour of frontal entry (Figure 15), acknowledging the very small event count and the mixed-age population of the second study.

In a single-surgeon paediatric series of 210 children, 22 of 53 obstructions were infection-related, and obstruction was approximately three times more frequent in infected shunts; infection was lower after frontal insertion.³⁵ Across unstratified paediatric cohorts, proximal obstruction was the leading revision indication (29–46% of revisions).^{16,34,38,44}

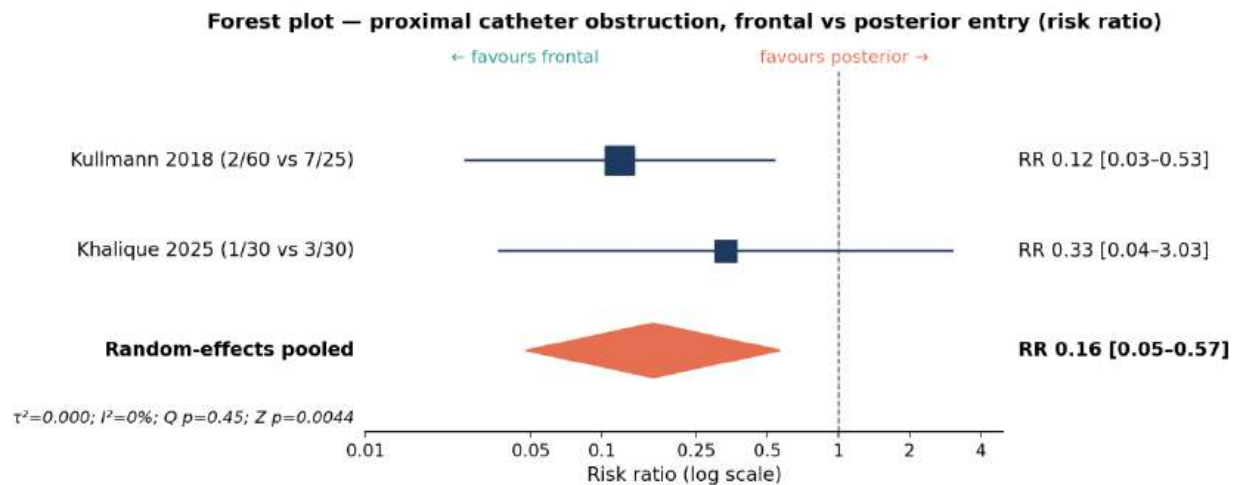


Figure 13. Forest plot — proximal catheter obstruction, frontal versus posterior entry (random-effects, risk ratio).

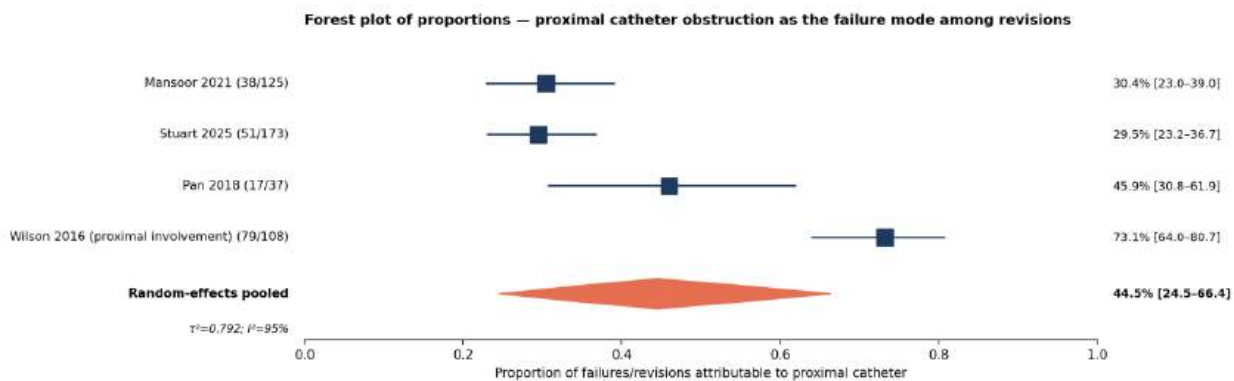


Figure 14. Forest plot of proportions — proximal catheter involvement among failures/revisions (logit random-effects).

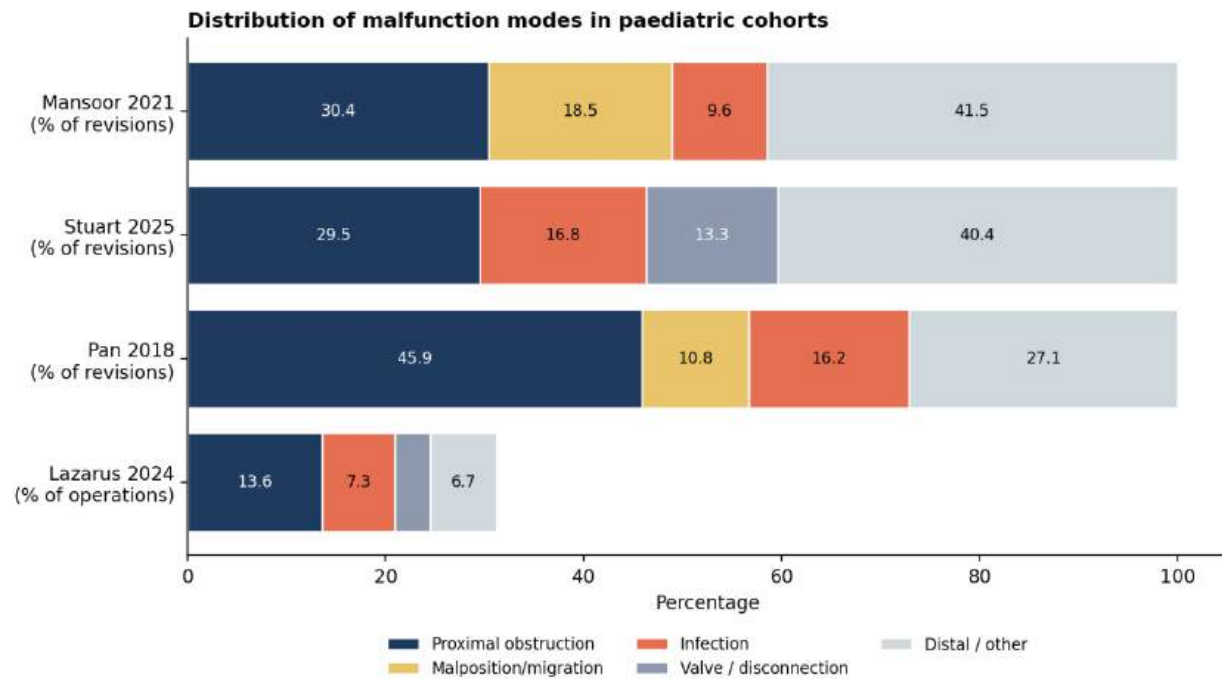


Figure 15. Distribution of malfunction modes across paediatric cohorts (percentages as reported; 'distal/other' is the residual).

Table 10. Proximal catheter obstruction

Study	Entry site	Obstruction data	Mechanistic note
Kullmann 2018	Frontal vs occipital	2/60 vs 7/25; RR 0.12 (0.03–0.53)	7/9 obstructed catheters non-optimally positioned
Khalique 2025	Kocher vs Frazier	1/30 vs 3/30; RR 0.33 (0.04–3.03)	Mixed-age; 6-month follow-up
Şahin 2020	Frontal vs occipitoparietal	53/210 obstructions (22 infection-related)	Infection triples obstruction risk; <i>S. epidermidis</i>
Elmesallamy 2022	Anterior (US vs conventional)	0/30 vs 3/30	Malposition as upstream cause
Wilson 2016	Parieto-	79/257 proximal failures	Accurate placement OR 3.42

	occipital only	(30.7%)	for freedom from proximal failure
Mansoor / Stuart / Pan	Not stratified	30.4% / 29.5% / 45.9% of revisions	Proximal occlusion commonest revision cause
García-Bonilla 2024	Not stratified	90.4% of hardware removals	Tissue aggregates in 76.8%
Pooled proportion	—	44.5% (24.5–66.4%); I ² 94.5%	High heterogeneity (definitions, denominators)

O3 — Catheter malposition and placement accuracy

Placement accuracy varied from 39% with freehand technique in Bangladesh to 81% with image guidance (Figure 18).^{33,36,39} Anterior-only insertion achieved accurate placement in 76.4% overall, but misplacement reached 39.3% in neonates and infants versus 7.7% in older children; cranial inclination greater than 37.2° and trajectory deviation greater than 12.9° (coronal >12.1°) were independent predictors of misplacement and were associated with reduced survival.³² Among posterior subtypes, Frazier's point achieved effective placement more often than Keen's point (79.9% vs 60.7%; $p < 0.0001$).⁴² In the HCRN RCT, ventricular catheter location and the number of passes did not differ by entry site, suggesting that expert multicentre surgeons can achieve comparable placement from either route.¹² Misplacement accounted for 18.5% of all paediatric revisions and 29.8% of first revisions in Norway.³⁴

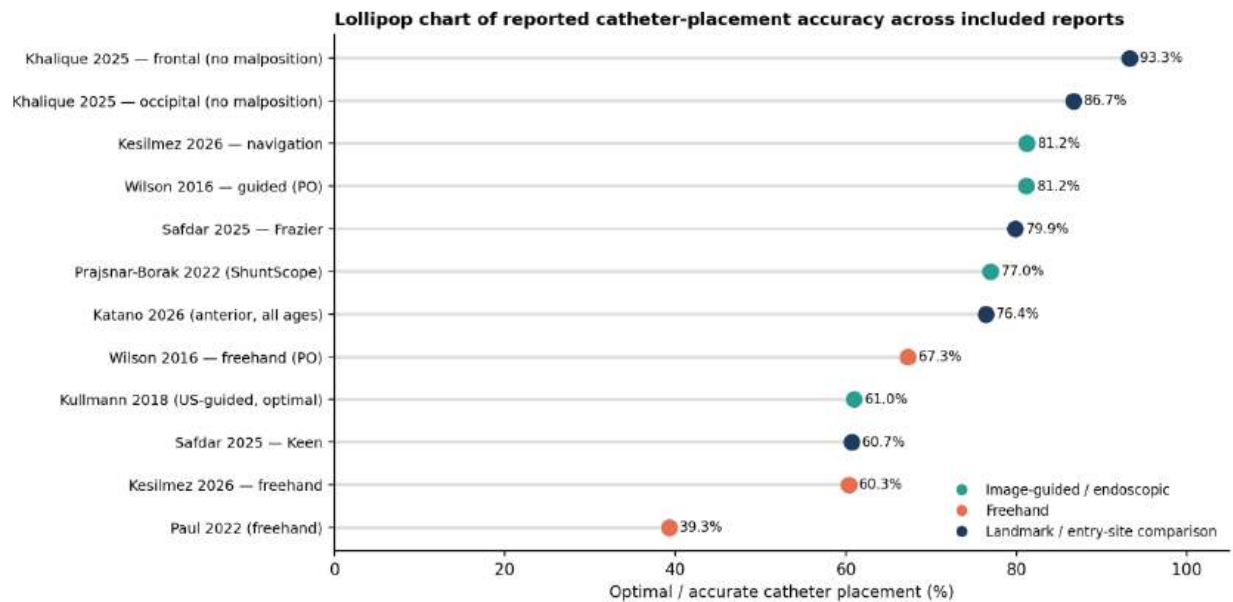


Figure 16. Lollipop chart of catheter-placement accuracy by study and technique.

Table 11. Malposition and placement accuracy

Study	Route / technique	Accuracy or malposition	Predictor / mechanism
Katano 2026	Anterior, freehand	Misplacement 39.3% (infants), 7.7% (children), 4.2% (adults)	Cranial inclination >37.2°; deviation >12.9°
Safdar 2025	Frazier vs Keen	Effective 79.9% vs 60.7%	Posterior subtype matters
Khalique 2025	Kocher vs Frazier	Malposition 6.67% vs 13.3%	Longer posterior trajectory
Kesilmez 2026	Navigation vs freehand	Optimal 81.25% vs 60.34%	Guidance improves accuracy
Wilson 2016	Parieto-occipital guided vs freehand	81.2% vs 67.3%	Age reduces accuracy (OR 0.983/y)

Kullmann 2018	US-guided (71% frontal)	61% optimal; 95% intended ventricle	Non-optimal position → obstruction
Paul 2022	Freehand	39.28% accurate	High inaccuracy in LMIC setting
Prajsnar-Borak 2022	ShuntScope	77% ideal	Endoscopic visual confirmation
Mansoor 2021	Not stratified	Misplacement 18.5% of revisions	Leading cause of first revision

O4 — Ventricular catheter migration

Migration evidence was confined to the frontal route in children younger than 3 years. In a Taiwanese cohort of 60 frontal shunts, 8 catheters (13.3%) migrated; 7 of 8 involved non-burr-hole valves, corresponding to migration in 7 of 13 non-burr-hole versus 1 of 47 burr-hole systems (53.8% vs 2.1%). The burr-hole valve remained protective after Weibull adjustment for age and catheter length.³⁰ A subsequent cohort of 48 frontal non-burr-hole shunts documented migration in 18 (37.5%), with markedly higher rates using a right-angle adaptor (61.5%) than a straight connector (9.1%; $p = 0.0002$), although significance was lost after age adjustment.³¹ In an Indian paediatric series, migration accounted for 10.8% of revisions.⁴⁴ The mechanism proposed is progressive withdrawal of the catheter toward the burr hole during rapid skull and scalp growth, amplified when the valve lies remote from the burr hole on the convexity.

Age- and hardware-dependent mechanisms with the anterior (frontal) route

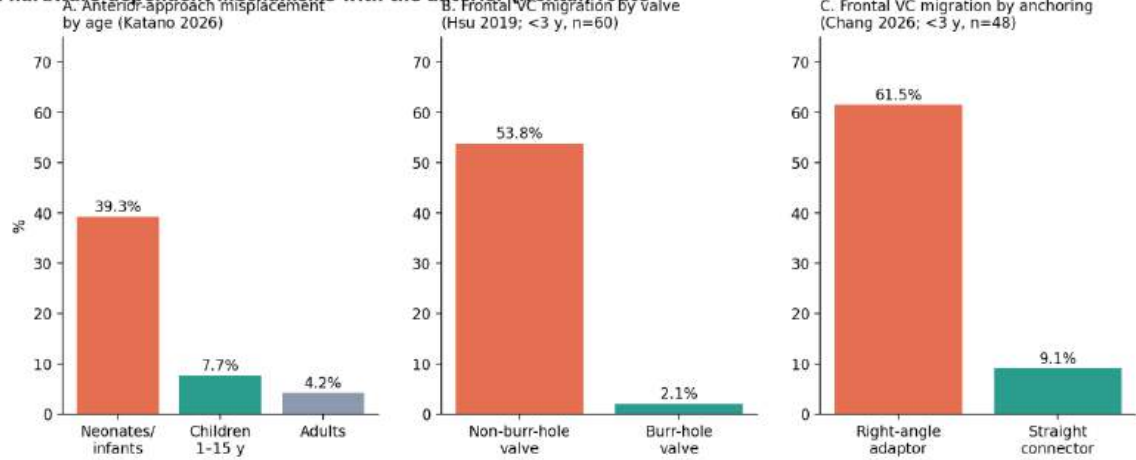


Figure 17. Age- and hardware-dependent mechanisms with the anterior (frontal) route: (A) misplacement by age; (B) migration by valve type; (C) migration by anchoring connector.

Table 12. Ventricular catheter migration

Study	Population / route	Migration	Protective / risk factors
Hsu 2019	<3 y; frontal	8/60 (13.3%)	Burr-hole valve (1/47 vs 7/13 non-burr-hole), older age, longer catheter
Chang 2026	<3 y; frontal; non-burr-hole	18/48 (37.5%)	Straight connector 9.1% vs right-angle 61.5%; younger age (4.5 vs 10.1 mo)
Pan 2018	Children; not stratified	10.81% of revisions	—

O5 — Shunt infection

The RCT found no difference in shunt infection between entry sites.¹² In contrast, a single-surgeon series reported lower infection with frontal than occipitoparietal insertion, and a small mixed-age trial reported the opposite (10% frontal vs 3.3% occipital).^{35,41} Across unstratified cohorts, infection accounted for 7–17% of revisions, and infection risk was driven primarily by young age (sHR 4.48 for age <1 month) and mitigated by antibiotic-impregnated catheters.^{16,38,40}

Table 13. Shunt infection

Study	Entry site	Infection finding
Whitehead 2021	Anterior vs posterior	No significant difference
Şahin 2020	Frontal vs occipitoparietal	Lower with frontal; infection–obstruction coupling
Khalique 2025	Kocher vs Frazier	10% vs 3.3% (n = 30 each)
Kesilmez 2026	Navigation vs freehand	2.08% vs 9.48% (NS)
Sunderland 2022	Not stratified	Age <1 mo sHR 4.48; antibiotic catheter sHR 0.43
Stuart / Lazarus / Pan	Not stratified	17% / 7.3% / 16.2% of revisions or operations

O6 and O8 — Revision burden and temporal pattern

Revision burden was substantial: 58% of Norwegian children required at least one revision over 1–10 years; 47.9% of Indian children with obstructive hydrocephalus required revision, half within 90 days; and 35.8% of Thai children with failure experienced multiple failures, with each subsequent failure more likely than the preceding one.^{5,34,37} Failure was front-loaded, with 52.9% occurring within 180 days and a median time to revision of 44.5 days in the United States (Figure 14).^{5,6} At the cellular level, microglia dominated catheters explanted after short dwell times (mean 24.7 days), whereas astrocytes dominated after long dwell times (mean 1183 days), and catheters with occlusions had been implanted longer (33.2 vs 23.8 months).^{8,9}

O7 — Histopathology of obstructing tissue

In 343 explanted catheters from five centres, 61.5% had at least one occluded hole, although 70% of all holes were patent. Occluded catheters contained more macrophages and astrocytes; microglia comprised only 2–6% of aggregates. Histology showed lymphocytic inflammation (29%), choroid plexus occlusion (24%), vascularised glial tissue (24%) and foreign-body giant-cell reactions (5%); ependyma was absent.⁹ In a nine-aetiology analysis, tissue aggregates occupied more than 40% of holes in myelomeningocele, other congenital, tumour-related and post-

haemorrhagic hydrocephalus, without a conclusive aetiology association.¹⁰ Astrocytes served as an interface for secondary attachment of ependymal cells and choroid plexus.⁸

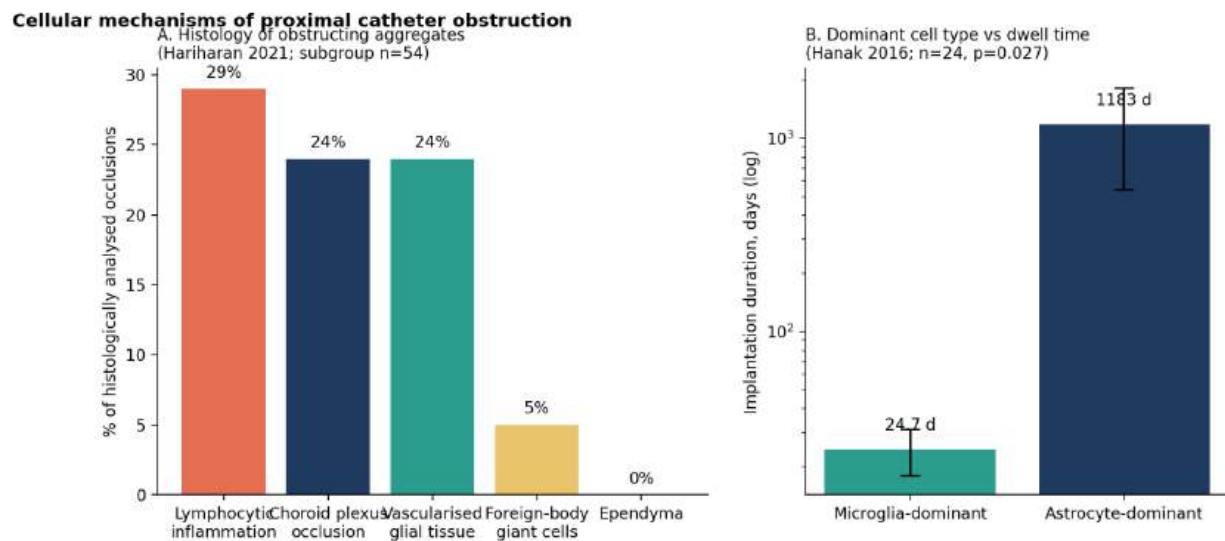


Figure 18. Cellular mechanisms: (A) histological composition of obstructing aggregates; (B) dominant cell type versus implantation duration.

Table 14. Histopathological and temporal mechanisms (O7–O8)

Study	Sample	Key finding	Entry-point relevance
Hariharan 2021	343 VCs (54 histology)	Macrophages/astrocytes ↑; CP 24%, glial 24%, lymphocytic 29%, FBGC 5%	Choroid contact more likely along posterior trajectory
Hariharan 2023	Same 343 VCs	Wall contact predicts obstruction (p = 0.005); parietal entry alters hole pattern (p = 0.001)	Direct entry-site association
García-Bonilla 2024	Multicentre, 9 aetiologies	Aggregates in 76.8% of obstruction removals; no aetiology link	Mechanism ubiquitous across aetiologies
Hanak 2016	24 VCs	Microglia early (24.7 d) → astrocytes late (1183 d)	Temporal phenotype independent of site

O9 — Tip environment and ventricular wall/choroid contact

Contact of the catheter with the ventricular wall robustly predicted overall obstruction status in multinomial regression ($p = 0.005$), and catheters implanted via the parietal entry site displayed more holes with non-obstructive growth and fewer empty holes than catheters inserted via other approaches ($p = 0.001$).¹³ In the paediatric pooled analysis, a frontal-horn tip conferred a univariate survival advantage (log-rank $p = 0.0015$) that was not independent of entry site.¹¹ In Bangladesh, 17 of 43 functioning shunts had inaccurate tips, illustrating that tip location alone incompletely explains function.³⁶

Table 15. Tip environment and wall/choroid contact

Study	Variable	Finding
Hariharan 2023	Catheter–wall contact; entry site	Wall contact $p = 0.005$; parietal entry → distinct hole-occlusion pattern ($p = 0.001$)
Whitehead 2017	Tip location, environment, choroid relation, midline crossing	Frontal-horn tip advantage only univariate; entry site independent ($p = 0.005$)
Kullmann 2018	Optimal (mid-ventricle) vs near wall	7/9 obstructions in non-optimal position
Paul 2022	Accurate vs suboptimal vs inaccurate	Function 19/7/17 among 43 functioning shunts

O10 — Overdrainage and ventricular collapse

Overdrainage was reported only after occipital (Frazier) insertion (6.67% vs 0%) in one small trial.⁴¹ In paediatric obstructive hydrocephalus, early revision was associated with a greater postoperative reduction in the fronto-occipital horn ratio (20.16% vs 6.4%; $p = 0.009$), and greater preoperative occipital horn dilation predicted fewer multiple revisions, supporting a mechanism in which excessive ventricular decompression collapses the ventricle onto the catheter holes.³⁷

Table 16. Overdrainage and ventricular morphology

Study	Finding	Implication
Khalique 2025	Overdrainage 0% frontal vs 6.67%	Possible route-dependence;

	occipital	underpowered
Patra 2016	FOHR reduction 20.16% (early revision) vs 6.4%; high OHI / low FOIR → fewer multiple revisions	Ventricular collapse around catheter drives early failure

O11 — Age as effect modifier

Every study that examined age identified the youngest stratum as the most vulnerable. Pooling three independent hazard estimates (age <6 months, <1 year, and <1 month for mechanical failure) yielded HR 1.49 (95% CI 1.28–1.73; $I^2 = 0\%$).^{5,7,40} Age interacted with entry route: infants had a fivefold higher anterior misplacement rate, and catheter migration after frontal insertion clustered in infants aged 4–5 months.^{31,32}

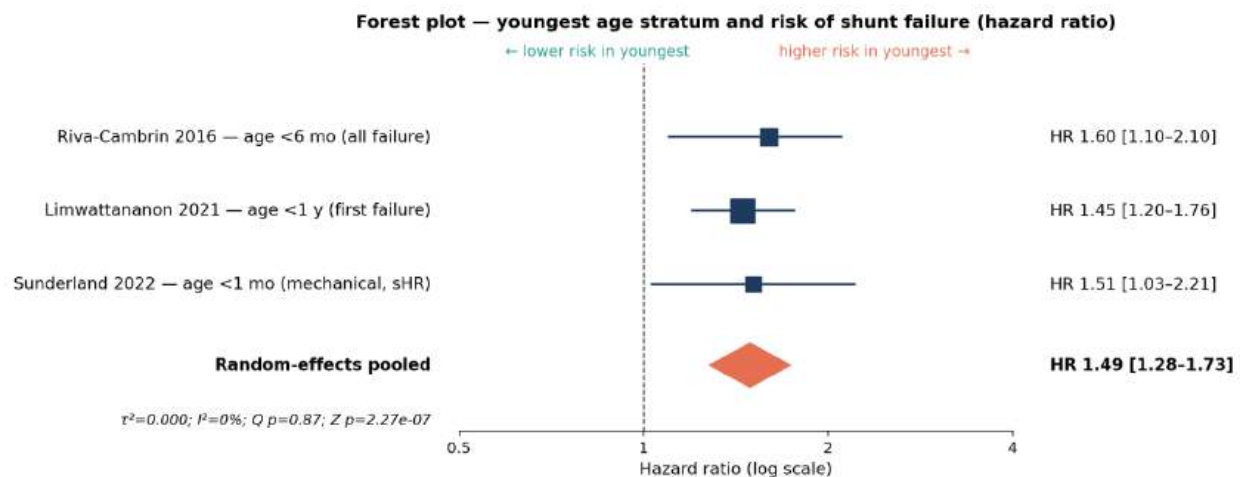


Figure 19. Forest plot — youngest age stratum and risk of shunt failure (random-effects, hazard ratio).

Table 17. Age as effect modifier

Study	Age contrast	Estimate
Riva-Cambrin 2016	<6 mo vs older	HR 1.6 (1.1–2.1)
Limwattananon 2021	<1 y vs 1–17 y	HR 1.45 (1.20–1.76); failure 37.8% vs 28.9%

Sunderland 2022	<1 mo vs trial reference age group	Mechanical sHR 1.51 (1.03–2.21)
Patra 2016	<6 mo vs ≥6 mo	Median revision-free survival 10.1 vs 94.1 mo
Katano 2026	Infants vs children	Anterior misplacement 39.3% vs 7.7%
Hariharan 2021	Age at first surgery	Occluded 3.25 vs non-occluded 5.29 y

O12 — Image guidance as effect modifier

Guidance improved accuracy for both routes: posterior (81.2% vs 67.3%) and paediatric mixed-route insertion (81.25% vs 60.34%).^{33,39} Exploratory pooling of paediatric studies reporting proximal failure or revision showed RR 0.41 (0.21–0.78; $I^2 = 0\%$) favouring guidance (Figure 22). The HCRN prospective cohort, however, found no independent survival benefit from ultrasound or stereotactic guidance, and endoscopic placement increased failure risk (HR 1.9), cautioning that guidance benefits may depend on implementation.⁷

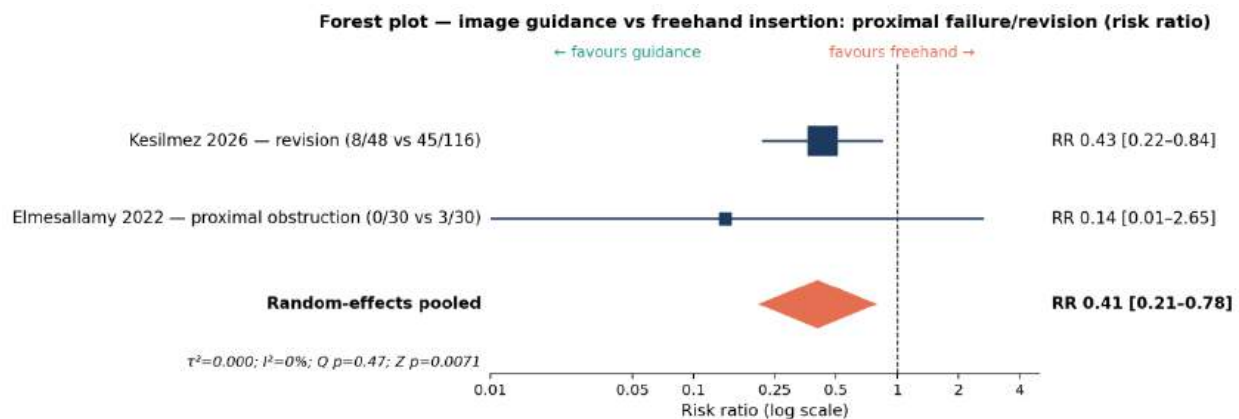


Figure 20. Forest plot — image guidance versus freehand insertion for proximal failure/revision (random-effects, risk ratio).

Table 18. Image guidance as effect modifier

Study	Guidance	Outcome
Kesilmez 2026	US / frameless navigation	Revision 16.67% vs 38.79%; RR 0.43 (0.22–0.84)

Elmesallamy 2022	Transfontanellar US	Obstruction 0/30 vs 3/30; placement p = 0.0005
Wilson 2016	US / frameless (parieto-occipital)	Freedom from proximal failure OR 2.39
Riva-Cambrin 2016	US / stereotactic; endoscopic	Guidance NS; endoscopic HR 1.9
Prajsnar-Borak 2022	ShuntScope	77% ideal; 4.6% proximal-occlusion revision

O13 and O14 — Peri-operative complications and CSF–infection interplay

The RCT found no entry-site differences in surgical duration, intra-operative complications, CSF leak, pseudomeningocele, skull fracture, postoperative seizures, new-onset epilepsy or intracranial haemorrhage.¹² Intra-operative CSF protein above 300 mg/L was associated with shorter time to failure (AUC 0.625), and infection-related obstruction accounted for 42% (22/53) of obstructions in a paediatric series, indicating that inflammatory CSF may be an entry-site-independent amplifier of proximal occlusion.^{35,38}

Table 19. Peri-operative complications and CSF–infection interplay

Study	Domain	Finding
Whitehead 2021	O13	No differences in duration, passes, CSF leak, pseudomeningocele, fracture, seizures, epilepsy, haemorrhage
Stuart 2025	O14	CSF protein >300 mg/L → shorter time to failure (AUC 0.625)
Şahin 2020	O14	Obstruction $\approx 3\times$ higher with infection; obstruction in one-third of <i>S. epidermidis</i> infections

Summary of exploratory pooled analyses

Table 20. Exploratory random-effects pooled estimates

Comparison	Studies	Pooled	p	I ²	Comment
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		estimate (95% CI)			
Failure: anterior vs posterior	Whitehead 2017; Whitehead 2021	HR 0.68 (0.56–0.83)	0.0001	0%	Paediatric; largest evidence
Proximal obstruction: frontal vs posterior	Kullmann 2018; Khaliq 2025	RR 0.16 (0.05–0.57)	0.004	0%	Few events; mixed age
Proximal failure/revision: guidance vs freehand	Kesilmez 2026; Elmesallamy 2022	RR 0.41 (0.21–0.78)	0.007	0%	Outcome definitions differ
Failure: youngest age stratum	Riva-Cambrin; Limwattananon; Sunderland	HR 1.49 (1.28–1.73)	<0.001	0%	Different age cut-offs
Proximal share of failures	Mansoor; Stuart; Pan; Wilson	44.5% (24.5–66.4%)	—	94.5%	Very high heterogeneity

Synthesis: mapped mechanisms by entry point

Posterior entry (Keen, Frazier, Dandy) is characterised by a long intraventricular course through the atrium, a higher obstruction frequency associated with wall/choroid contact, a distinct hole-occlusion pattern, sensitivity to the precise posterior landmark, and a possible propensity to overdrainage. Infection and cellular temporal patterns appear largely entry-site-independent.

Integrative mechanistic model linking proximal entry point to malfunction phenotype

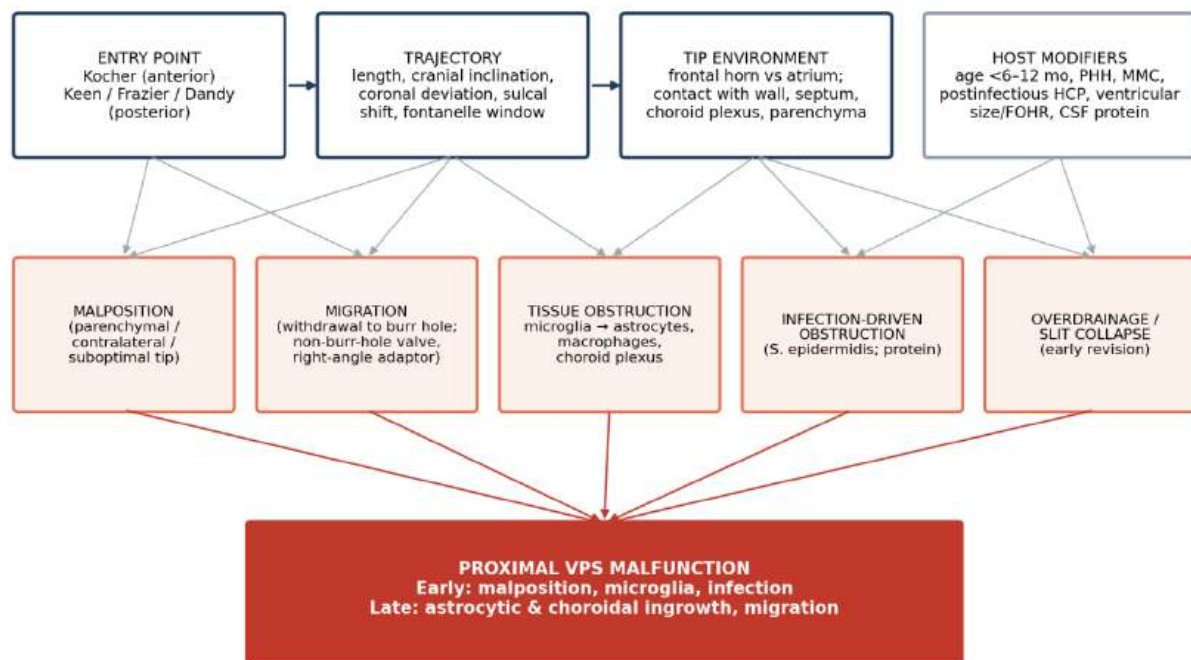


Figure 21. Integrative mechanistic model linking proximal entry point to malfunction phenotype.

Table 21. Entry-point-specific patterns and mechanisms (synthesis)

Dimension	Anterior / frontal (Kocher)	Posterior (Keen, Frazier, Dandy)	Strength of mapped evidence
Overall survival	Lower failure hazard (pooled HR 0.68)	Higher late failure	Moderate (1 RCT + 1 large cohort)
Obstruction	Less frequent (RR 0.16)	More frequent; wall/choroid contact	Low (small studies)
Malposition	Age-dependent (39% in infants); trajectory angle	Landmark-dependent (Frazier > Keen)	Low-moderate
Migration	Present in <3 y; valve and connector dependent	Not studied	Low (anterior only)
Tissue	Not stratified	Parietal: distinct hole	Low (1 explant)

histology		pattern	study)
Infection	No consistent difference	No consistent difference	Moderate (RCT null)
Overdrainage	Not reported	Reported in one study	Very low
Main modifiers	Age, burr-hole valve, straight connector, guidance	Guidance, landmark selection, ventricular size	—

DISCUSSION

Summary of principal findings

This scoping review mapped 27 primary reports (2 RCTs and 25 non-randomised studies; >12,000 children and ≥ 379 explanted catheters) addressing patterns and mechanisms of paediatric VPS malfunction in relation to the proximal catheter entry point. Five principal findings emerge. First, the best available paediatric evidence converges on a modest advantage for anterior entry (exploratory pooled HR 0.68), although the only adequately powered RCT narrowly missed significance. Second, the entry-site effect appears to operate through proximal obstruction and tip environment — catheter contact with the ventricular wall and choroid plexus — rather than through infection. Third, the anterior advantage is not unconditional: in neonates and infants, trajectory error and catheter migration are specific vulnerabilities of the frontal route, modifiable by image guidance, burr-hole valves and straight connectors. Fourth, cellular mechanisms (microglia-to-astrocyte transition, macrophage and choroid plexus ingrowth) are largely universal and time-dependent, so entry point determines the probability of exposure to these mechanisms rather than their nature. Fifth, only one quarter of the literature stratifies outcomes by entry site, which represents the dominant evidence gap.

Entry point and overall shunt survival: reconciling the cohort and the RCT

The apparent discordance between the 2017 secondary analysis (HR 0.65) and the 2021 RCT (HR 1.35 posterior vs anterior, $p = 0.062$) is more apparent than real. Both point estimates

favour anterior entry, their confidence intervals overlap substantially, and the RCT was powered to detect a 10% absolute difference in 1-year failure — an effect larger than the approximately 5–7% absolute difference implied by the cohort HR at the observed baseline failure rates.^{11,12} Consistent with our exploratory pooling, a 2022 meta-analysis of six paediatric studies (two RCTs, four retrospective cohorts; 1808 patients) found no difference at 6 and 12 months but significantly greater survival with anterior placement at 2 years (OR 1.91) and 5 years (OR 1.62), and a trend toward more revisions with posterior shunts (OR 0.72; $p = 0.06$).¹⁵ Together, these data suggest that the entry-site effect is time-dependent, emerging as late failures accumulate — a pattern biologically coherent with the late astrocytic and choroidal ingrowth described in explant studies.^{8,9}

By contrast, adult data do not show an entry-site effect. In a propensity-matched two-centre study of 539 adults, misplacement revision (4.7% vs 4.6%), dysfunction revision and infection were similar with frontal and parietal entry.⁴⁵ Electromagnetic-guided parieto-occipital insertion into slit-like ventricles achieved accuracy and 5-year survival equivalent to frontal insertion, and a CT-planned occipital-parietal point reduced suboptimal placement and mechanical malfunction in adults.^{46,47} A modified Keen's point approach likewise achieved optimal placement in 90.1% of 188 adults.⁴⁸ The contrast with paediatric data implies that the infant brain — with larger ventricles relative to skull, open sutures, rapid growth and a proportionally larger choroidal glomus — is where entry-point effects are most expressed. A single-centre mixed series with 94 patients found no significant difference in revision across Dandy, Frazier, Keen and Kocher points, but lacked paediatric stratification.⁴⁹

Mechanism 1 — Tip environment, wall contact and choroid plexus

The most direct mechanistic link between entry point and obstruction comes from the multicentre explant programme, in which catheter contact with the ventricular wall was the strongest predictor of obstruction and the parietal entry site was associated with a distinct hole-occlusion pattern.¹³ Posterior trajectories traverse the atrium, where the choroidal glomus is bulkiest, and deliver the catheter toward the frontal horn along a long, curved path in which the proximal (hole-bearing) segment may rest against the choroid or lateral wall. Computational fluid dynamics in paediatric patient-specific ventricles showed that occipital placement concentrated

more than 81% of CSF inflow into the most distal catheter segment across all ventricular sizes, whereas frontal and parietal placements produced flow distributions dependent on ventricular morphology; in a moderately sized ventricle, parenchymal contact occluded distal holes and redirected flow proximally.¹⁴ Such flow concentration creates both high-shear jets and low-shear stagnation zones; in vitro, low wall-shear-stress regions favour astrocyte adhesion, whereas pulsatile flow reduced cell attachment by 63%.^{50,51} These data provide a physical explanation for why entry point — through the trajectory it imposes — could modify obstruction risk independently of tip location.

Choroid plexus is a recognised cause of proximal obstruction; radiological demonstration of choroid plexus enveloping an occipital-horn catheter tip in an 18-month-old boy illustrates both the phenomenon and the haemorrhagic risk of catheter removal.⁵² High-resolution 3D MRI (CISS) now allows non-invasive assessment of catheter side-hole position and luminal filling defects, with enhancing defects suggesting choroid plexus ingrowth.⁵³ Such imaging could enable prospective, entry-site-stratified studies of obstruction mechanisms without reliance on explants.

Mechanism 2 — Cellular and inflammatory biology

The cellular sequence of obstruction appears conserved: microglia dominate catheters removed within weeks, whereas astrocytes dominate those removed after years, acting as a scaffold for secondary attachment of ependymal cells and choroid plexus.⁸ Macrophages and astrocytes are enriched in occluded catheters, lymphocytic inflammation is present in nearly one-third, and foreign-body giant-cell reactions occur in 5%.⁹ Obstructed shunts contain a higher proportion of A2 reactive astrocytes, and CSF from obstructed systems has higher interleukin-6, a cytokine that induces astrocyte proliferation; neutralising cytokines reduced astrocyte growth in vitro.⁵⁴ Upstream, choroid plexus inflammation via CCL2–CCR2-mediated macrophage recruitment drives CSF hypersecretion in post-haemorrhagic hydrocephalus, and post-haemorrhagic hydrocephalus of prematurity is associated with tight-junction disruption and activated macrophages in the choroid plexus.^{55–57} Because these processes are most intense in the choroid-rich atrium, a posterior catheter path may increase exposure of the hole-bearing segment to an inflammatory microenvironment — a plausible but untested entry-site-specific hypothesis.

The observation that tissue aggregates were present across all nine aetiologies without etiological specificity suggests that the catheter–tissue interface, rather than the underlying disease, dominates obstruction biology.¹⁰ Material science is therefore a complementary target: polyvinylpyrrolidone-coated catheters reduced choroid plexus and astrocyte adhesion and improved flow–pressure performance in phantom models, and electrospun multilayered fibrous coatings reduced astrocyte density; however, a clinical case demonstrated that choroid plexus can still obstruct a PVP-coated catheter by mechanical ingrowth without an immune reaction, emphasising hole geometry and position.^{58–61} High-throughput pulsatile bioreactors now enable testing of these interactions under physiological flow.⁶²

Mechanism 3 — Trajectory geometry, landmarks and malposition

Malposition is a leading and preventable cause of first revision in children.³⁴ For the anterior route, the most important finding of this review is the strong age dependence of misplacement (39.3% in neonates and infants vs 7.7% in older children), with cranial inclination and trajectory deviation as quantifiable predictors.³² Standard external landmarks are unreliable in infants: in scaphocephalic children, the positions of Kocher's and Frazier's points relative to nasion and inion varied significantly with age, particularly below one year.⁶³ Cerebral sulci beneath Kocher's point necessitated entry-point shifts in more than one-third of patients in a CT simulation study, and navigation reduced suboptimal placement from 33% to 13%.⁶⁴ Individualised radio-anatomical freehand techniques and 3D-printed guides achieve accuracy comparable to navigation and are attractive where navigation is unavailable.^{65,66} For the posterior route, the choice of landmark matters: Frazier's point achieved effective placement more often than Keen's point in a large Pakistani trial.⁴²

Mechanism 4 — Catheter migration and hardware

Migration was documented only after frontal insertion in children younger than 3 years, and was strongly associated with non-burr-hole valves and right-angle adaptors.^{30,31} With a non-burr-hole system, the valve lies on the convexity behind the burr hole; rapid calvarial and scalp growth then exerts traction on the ventricular catheter, withdrawing it toward the burr hole or deviating it toward the midline or anterior wall. A burr-hole valve or a straight connector anchored at the burr

hole removes this lever arm. Because posterior-entry migration has not been studied, the absence of this mechanism with posterior routes cannot be inferred; nevertheless, the finding identifies a readily modifiable technical factor for surgeons who favour the frontal route in infants.

Mechanism 5 — Infection, CSF composition and overdrainage

Infection did not differ by entry site in the RCT, and conflicting small-study signals are likely confounded by surgeon, era and case mix.^{12,35,41} Infection risk is instead governed by age, antibiotic-impregnated catheters and standardised prevention bundles; in the HCRN-Quality network, iodine-based skin preparation and antibiotic-impregnated catheters independently reduced infection (OR ≈ 0.5).^{40,67} Infection nonetheless interacts with obstruction: infected shunts obstructed approximately three times more often, and elevated intra-operative CSF protein shortened time to failure.^{35,38} Overdrainage and ventricular collapse emerge as an under-studied early-failure mechanism: greater postoperative FOHR reduction predicted early revision, and overdrainage was reported only with occipital insertion in one small study.^{37,41} The CFD finding that parenchymal contact redirects flow in smaller ventricles provides a mechanistic bridge between overdrainage, collapse and proximal obstruction.¹⁴

Effect modifiers: age and image guidance

Young age was the most consistent modifier across the evidence base (pooled HR 1.49), influencing mechanical failure, infection and misplacement alike.^{5,7,32,40} A systematic review of children younger than 2 years similarly identified obstruction and infection as the leading causes of failure.⁶⁸ Image guidance improved placement accuracy for both routes and reduced proximal failure in paediatric cohorts (pooled RR 0.41), yet guidance was not independently protective in the HCRN prospective cohort, and endoscopic placement increased risk.^{7,33,39} In adults, combining neuronavigation with laparoscopic distal placement and an infection bundle eliminated proximal failures in a quality-improvement programme.⁶⁹ Guidance should therefore be regarded as a means of achieving the intended trajectory rather than as an independent protective intervention; its greatest value is likely in infants, small or asymmetric ventricles, and posterior routes.

Contextualisation with systematic reviews and meta-analyses

Four systematic reviews informed, but were not charted in, this review. The paediatric anterior-versus-posterior meta-analysis supports a late survival advantage for anterior shunts.¹⁵ A review restricted to children younger than 2 years confirmed obstruction and infection as dominant failure modes.⁶⁸ A meta-analysis of 38,095 adult shunt surgeries found a pooled 2-year failure of at least 32%, with the distal catheter as the most common failure site — a contrast to the proximal predominance in children.⁷⁰ A systematic review of paediatric valve types found no universally superior valve (RR 1.12, 95% CI 0.91–1.36) and identified obstruction as the predominant failure type across valves.⁷¹ None of these reviews integrated mechanistic explant data with entry point, which is the distinctive contribution of this scoping review.

Implications for clinical practice

For the practising paediatric neurosurgeon, the mapped evidence supports the following pragmatic, evidence-informed approach, pending definitive trials: (1) favour an anterior (Kocher) entry for first-time paediatric VPS where anatomy permits, recognising that the benefit is modest and emerges over years; (2) in neonates and infants, mitigate the anterior route's specific vulnerabilities by using transfontanellar ultrasound or navigation, controlling cranial inclination and coronal deviation, and anchoring with a burr-hole valve or straight connector to prevent migration; (3) when a posterior route is chosen (e.g., for cosmetic, positioning or scalp reasons), prefer image guidance, select the landmark deliberately (Frazier outperformed Keen in one large study), avoid excessive catheter length, and aim to keep the hole-bearing segment away from the atrial choroid and ventricular wall; (4) apply a standardised infection-prevention bundle irrespective of entry site; (5) obtain postoperative imaging documenting tip position and wall contact to enable early recognition of high-risk configurations; and (6) in LMIC settings with late presentation, macrocrania and postinfectious aetiology, prioritise accuracy-enhancing, low-cost techniques such as transfontanellar ultrasound and individualised radio-anatomical planning.^{16,28,30,31,42,65,67}

Implications for research

The evidence map identifies clear priorities: (a) age-stratified, adequately powered RCTs of anterior versus posterior entry with a minimum 5-year follow-up and pre-specified secondary outcomes by malfunction mode; (b) mandatory reporting of entry site, trajectory, catheter length,

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valve position and tip–wall relationship in all shunt outcome studies, ideally through a core outcome set and standardised multicentre decision rubrics, which have been shown to minimise centre effects in HCRN studies;⁷² (c) explant registries that link histology and hole-occlusion patterns to entry point and dwell time; (d) prospective studies of migration after posterior insertion and of overdrainage by route; (e) use of high-resolution MRI and CFD modelling to test the trajectory–flow–obstruction hypothesis in vivo; and (f) LMIC-led multicentre studies, including in Indonesia, where the burden of postinfectious hydrocephalus is high and the evidence base is sparse.^{1,14,53}

Strengths

Strengths include a pre-specified PCC framework, a broad mechanistic lens integrating clinical and explant evidence, 14 outcome domains, dual risk-of-bias appraisal, extensive visual evidence mapping and exploratory quantitative synthesis clearly labelled as hypothesis-generating.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Proximal catheter entry point is a modifiable determinant of paediatric VPS malfunction. The mapped evidence supports a modest, time-dependent survival advantage for anterior (Kocher) entry, mediated predominantly by a lower frequency of proximal obstruction linked to tip environment — ventricular wall and choroid plexus contact along the longer posterior trajectory — rather than by infection. The anterior route carries its own age-specific vulnerabilities, namely trajectory-related misplacement in neonates and infants and migration with non-burr-hole valves or right-angle adaptors, both of which are technically preventable. Cellular obstruction mechanisms (microglia-to-astrocyte transition, macrophage and choroid plexus ingrowth) are universal and time-dependent, and entry point appears to modulate exposure to them rather than their nature. The evidence base is dominated by retrospective, unstratified studies, and only one quarter of reports provide entry-site-specific data.

Recommendations

For clinical practice: adopt anterior entry as the default for first-time paediatric VPS where feasible; use image guidance (transfontanellar ultrasound or navigation) in infants and whenever a

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posterior route is chosen; anchor frontal catheters with burr-hole valves or straight connectors in children younger than 3 years; plan catheter length and trajectory on preoperative imaging; apply standardised infection-prevention bundles; and document tip position and wall contact on postoperative imaging. For research: conduct age-stratified RCTs with long-term, mode-specific outcomes; adopt standardised entry-site-stratified reporting; link explant histology to entry point; investigate migration and overdrainage by route; and support LMIC-led multicentre registries.

DECLARATIONS

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