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Review

Conduction System Pacing in Children: Current Evidence and Considerations for Lifelong Physiological Pacing

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Abstract

Conduction system pacing (CSP) is a potential physiological alternative to conventional right ventricular pacing for children expected to require long-term ventricular stimulation. CSP is most relevant in congenital or postoperative atrioventricular block and congenital heart disease (CHD), where lifelong pacing, repeat procedures, venous preservation, and pacing-related ventricular dysfunction are major concerns. This narrative review synthesises the available paediatric and congenital CSP literature, with a separate appraisal of His bundle pacing (HBP), left bundle branch area pacing (LBBAP), conventional right ventricular pacing, epicardial pacing, and cardiac resynchronisation therapy (CRT). Evidence remains limited to small observational cohorts, mixed paediatric and adult congenital series, and case reports. The available data indicate procedural feasibility in selected children of school age, adolescents, and CHD populations. LBBAP has generally shown lower chronic capture thresholds than HBP in mixed paediatric cohorts, while data supporting recovery of ventricular function after CSP are uncontrolled and limited to selected patients. No paediatric randomised trial has established CSP as superior to optimised epicardial pacing, conventional transvenous pacing, or CRT for long-term clinical outcomes. Children differ from adults in septal thickness, cardiac anatomy, growth, venous access, future lead burden, and extraction planning. Therefore, CSP should be considered an individualised strategy within experienced paediatric and congenital electrophysiology programmes, with explicit documentation of capture, lead position, and long-term device planning.

Keywords: conduction system pacing; His bundle pacing; left bundle branch area pacing; left ventricular septal pacing; paediatric pacing; congenital heart disease

1. Introduction

Conduction system pacing (CSP) has emerged as a physiological alternative to conventional right ventricular pacing. It aims to produce a more physiological pattern of ventricular activation than right ventricular pacing, rather than to reproduce native activation in every patient. This distinction is important for left bundle branch area pacing (LBBAP), where left-sided conduction system recruitment may coexist with transseptal myocardial activation of the right ventricle. Adult guidelines recognise CSP as a cardiac physiological pacing strategy in selected settings, but paediatric evidence remains limited and cannot be assumed to mirror adult outcomes [1,2].

Since the 2021 European Society of Cardiology (ESC) pacing guideline and the 2023 HRS/APHRS/LAHRS physiological pacing guideline, the 2025 ESC clinical consensus statement has provided more detailed advice on CSP indications. In adults with atrioventricular block and left ventricular ejection fraction (LVEF) >40%, CSP may be appropriate when the anticipated ventricular pacing burden exceeds 20%. In atrioventricular block with LVEF <40%, CSP may be considered in lieu of biventricular pacing in selected patients with an anticipated ventricular pacing burden >20%, and CSP is advised as a rescue strategy when a coronary sinus lead cannot be implanted [3]. In heart failure with left bundle branch block, biventricular cardiac resynchronisation therapy (CRT) remains the best-established standard, while CSP is an increasingly used alternative or rescue strategy whose selection should be individualised according to anatomy, ventricular function, conduction substrate, operator expertise, and the strength of comparative evidence [4,5,6]. These adult indications provide important context but cannot be transferred directly to children.

Children who require permanent pacing may be exposed to decades of ventricular stimulation, generator changes, lead revisions, venous obstruction, infection, and possible pacing-induced ventricular dysfunction. These concerns are particularly relevant in congenital complete

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atrioventricular block and congenital heart disease (CHD), where pacing dependency can begin early and anatomy may be altered by congenital lesions or previous surgery. Paediatric device guidance therefore emphasises individualised lead selection, venous preservation, growth-related lead management, and planning for future interventions [7].

CSP is attractive because it may reduce pacing-related electrical dyssynchrony without a coronary sinus lead. However, direct paediatric comparative data are sparse. The current literature cannot establish whether CSP improves long-term ventricular function, exercise capacity, heart failure events, device complications, or quality of life compared with optimised conventional transvenous pacing, epicardial pacing, or CRT. This review separates paediatric evidence from adult extrapolation and focuses on the practical questions that remain unresolved.

2. Terminology and Scope

CSP is an umbrella term for pacing strategies intended to recruit the intrinsic His-Purkinje conduction system. His bundle pacing (HBP) refers to pacing at the His bundle. LBBP refers to direct capture of the left bundle branch, whereas LBBAP is a broader term for deep septal pacing in the anatomical left bundle branch region that may or may not meet accepted criteria for direct left bundle branch capture. Left ventricular septal pacing (LVSP) or deep septal pacing denotes myocardial pacing from the left-sided septum without demonstrated conduction system capture. These terms should not be used interchangeably.

In children, adult-derived electrocardiographic criteria for definitive left bundle branch capture may not be validated because of smaller ventricular dimensions, developmental changes in cardiac orientation, variable septal thickness, and CHD-related distortion. Paediatric reports should therefore state the exact implant target, the capture evidence obtained, and whether the result represents confirmed conduction system capture, probable LBBAP, or deep septal/LVSP.

3. Literature Search and Scope

This narrative review was informed by a structured literature search of PubMed/MEDLINE, PubMed Central, and major professional society websites from database inception to 31 July 2026. Search terms included “conduction system pacing”, “His bundle pacing”, “left bundle branch pacing”, “left bundle branch area pacing”, “left ventricular septal pacing”, “deep septal pacing”, “paediatric”, “pediatric”, “child”, “congenital heart disease”, “adult congenital heart disease”, “atrioventricular block”, and “cardiac resynchronisation therapy”. Reference lists of relevant reviews and primary studies were also screened. We prioritised peer-reviewed paediatric studies, mixed paediatric and congenital cohorts, guidelines, consensus documents, and studies reporting paediatric pacing alternatives. Adult CSP studies were included only to provide technical background, capture definitions, or provide extraction context, and are identified explicitly as adult extrapolation. Abstract-only reports were not used as primary evidence. The review does not use formal systematic-review methods, risk-of-bias assessment, or meta-analysis. The graphical abstract provides a visual overview of the rationale for CSP, the current paediatric evidence base, and the key paediatric-specific considerations, while emphasising that current evidence remains derived mainly from small observational studies, case reports, and expert consensus.

4. Rationale for Physiological Pacing and Relation to Existing Strategies

The rationale for physiological pacing in children derives mainly from concern about chronic dyssynchronous ventricular activation. In congenital complete atrioventricular block, chronic right ventricular apical pacing has been associated with left ventricular dilatation, asymmetric remodelling, and impaired ventricular function in selected cohorts [8]. A multicentre paediatric study found that pacing site influenced long-term ventricular mechanics, with worse outcomes reported for right ventricular free-wall epicardial pacing than for alternative sites in many patients [9]. These studies establish the importance of the pacing site but do not prove that CSP is superior to every conventional strategy.

Conventional transvenous right ventricular pacing remains effective and widely available but can create an activation pattern that differs substantially from intrinsic conduction. Epicardial pacing remains important in infants, patients with limited venous access, and those undergoing cardiac surgery. Its performance depends on ventricular site, lead type, anatomy, and individual surgical context. CRT can improve ventricular function in selected children and patients with CHD who have dyssynchrony and ventricular dysfunction, but delivery may be limited by coronary venous anatomy, access, prior surgery, and the need for additional leads [10,11].

CSP may offer a transvenous alternative when a physiological activation pattern is sought and conventional CRT is anatomically difficult. This is a mechanistic and feasibility-based argument. Direct paediatric comparisons among CSP, optimised epicardial left ventricular pacing, conventional right ventricular pacing, and CRT remain insufficient to define a preferred strategy for a given age group or lesion.

5. Paediatric Indications and Candidate Selection

Paediatric device guidance remains indication-based rather than technique-based. The 2021 Pediatric and Congenital Electrophysiology Society (PACES) consensus and its recent appraisal emphasise the pacing indication, age and body size, anatomy, venous access, growth, and lifelong lead strategy, but do not establish CSP as a first-line pac-

Table 1. Pacing strategies in children and congenital heart disease.

Modality	Evidence and current role	Potential advantages	Key limitations and evidence gaps
Conventional transvenous right ventricular pacing	Established therapy for children in whom transvenous access is suitable. Outcomes vary with pacing site, burden, ventricular substrate, and follow-up duration [7,8,9,17].	Widely available. Familiar lead technology. Straightforward implantation and follow-up.	Can create electrical dyssynchrony. Long-term risk of ventricular dysfunction is not uniform but remains clinically important in pacing-dependent children.
Epicardial pacing	Important in infants, children with limited venous access, and those undergoing cardiac surgery. Ventricular site influences long-term mechanics [7,9].	Avoids transvenous lead burden. Enables surgical access and site selection.	Requires surgery. Lead longevity and reintervention burden remain relevant. Direct comparative data versus CSP are lacking.
Cardiac resynchronisation therapy	Used for selected patients with ventricular dysfunction and dyssynchrony. Paediatric and CHD experience is heterogeneous [10,11].	Can improve synchrony without reliance on direct conduction system capture.	May require additional leads. Coronary venous anatomy and prior surgery can limit delivery. Comparative data versus CSP are sparse.
His bundle pacing	Paediatric experience consists of small observational series and case reports [18,19].	Proximal conduction system recruitment when stable His capture is achieved.	Small target. Threshold rise and generator longevity are concerns. Long-term paediatric lead revision data are unavailable.
Left bundle branch area pacing or deep septal pacing	Growing paediatric experience in selected children and mixed paediatric/CHD cohorts [14,15,16,20,21,22].	Typically low capture thresholds and strong sensing. May be useful when his bundle pacing thresholds are unfavourable.	Definitive left bundle capture is not always demonstrated. Thin septa, perforation concern, and long-dwell extraction uncertainty require caution.

Abbreviations: CHD, congenital heart disease; CSP, conduction system pacing.

ing modality [7,12]. Recent paediatric reviews and emerging series suggest that CSP is most relevant when a child is expected to have a high ventricular pacing burden, particularly with congenital or post-interventional atrioventricular block, when pacing-induced ventricular dysfunction is present or an upgrade is being considered, or when a physiological alternative to conventional right ventricular pacing or CRT is sought in selected congenital anatomy [13,14,15]. Mixed paediatric and adult congenital data also support feasibility but not superiority [16]. The indication for permanent pacing should therefore be established independently, after which CSP may be considered as the pacing technique in selected patients following comparison with optimised epicardial pacing, conventional transvenous pacing, and CRT.

Table 1 (Ref. [7,8,9,10,11,14,15,16,17,18,19,20,21,22]) summarises the principal pacing strategies used in children and patients with congenital heart disease, highlighting their current role, potential advantages, and evidence gaps relevant to CSP decision-making.

6. Evidence for His Bundle Pacing

HBP is the most anatomically proximal CSP modality and can preserve or restore rapid ventricular activation when reliable His capture is achieved. In a single-centre report of eight paediatric and congenital patients aged 8 to 18 years, six underwent HBP and two underwent LBB pacing. In two patients with pacing-induced cardiomyopathy, LVEF improvements of 14% and 16% were reported following non-selective His bundle pacing. However, the original publication does not clearly specify whether these represent absolute percentage-point increases or relative percentage changes [18].

A later single-centre cohort included 24 paediatric and congenital patients, of whom 23 underwent HBP. The median age was 14 years, 12 patients had CHD, and the reported median threshold was 0.5 V at 0.4 ms. Median follow-up was 610 days, with no procedural complications reported. This cohort supports feasibility in selected patients but does not provide long-term comparative effectiveness data [19].

HBP has practical limitations in paediatric lifelong pacing. The target is small, thresholds can be higher or increase during follow-up, and loss of His capture may result in myocardial pacing or loss of ventricular capture in pacing-dependent patients. Adult observational data report threshold rise and lead revision after HBP, but those rates cannot be applied directly to children [2,23]. In paediatric

practice, HBP should therefore be selected only after careful assessment of target stability, expected threshold, safety margin, and future generator longevity.

7. Evidence for Left Bundle Branch Area Pacing

LBBAP is increasingly used because deep septal fixation can provide robust sensing and lower capture thresholds than HBP. A 19-patient paediatric series reported a median LBBAP threshold of 0.7 V at 0.5 ms, a median sensed R-wave amplitude of 14.7 mV, and a median paced QRS duration of 92 ms, with no acute adverse events during short follow-up [20].

In a cohort of 31 children aged 7 years or younger scheduled for LBBAP, successful lead deployment was reported in 22 patients (70.9%). The success rate illustrates that LBBAP is technically feasible in some young children but remains challenging in the smallest hearts [21].

In a comparison of 48 children with LBBAP or right ventricular septal pacing, LBBAP was associated with a narrower paced QRS duration than right ventricular septal pacing, 100.2 ± 9.3 ms versus 115.4 ± 15.1 ms, and a lower capture threshold at follow-up, 0.79 ± 0.18 V versus 1.20 ± 0.56 V, $p = 0.008$. The study also reported more favourable mechanical synchrony measures with LBBAP. Its non-randomised design and modest follow-up preclude conclusions about long-term clinical outcomes [22]. In a mixed paediatric and adult congenital cohort of 31 patients with 32 CSP systems, left bundle area pacing was associated with lower chronic thresholds than HBP, while procedure and fluoroscopy times were similar. These findings support an electrical advantage for LBBAP over HBP in selected patients, but the study was single centre and included adult congenital patients [16].

More recent paediatric experience supports this selective approach. Karagöz et al. [14] reported 18 consecutive children undergoing LBBAP, with a mean age of 12.3 ± 5.8 years. Thirteen (72%) had congenital atrioventricular block and 5 (28%) had post-interventional atrioventricular block. No procedural or follow-up complications were observed over a mean 13.5 ± 7.5 months, and the mean paced QRS duration was 94 ± 13 ms [14]. A separate three-child case series also reported successful LBBAP for complete atrioventricular block with stable short-term electrical parameters [15]. These reports broaden the age range and contemporary experience but remain small, non-randomised, and too short to define long-term safety or comparative effectiveness.

These data should not be interpreted as proof that LBBAP is the default CSP approach for all children. In small hearts, thin septa, uncertain capture criteria, congenital septal abnormalities, and unknown long-term extraction behaviour remain important limitations. Where definitive left bundle branch capture is not shown, the term LBBAP or deep septal pacing is more appropriate than confirmed LBB pacing.

Table 2 (Ref. [14,16,18,19,20,21,22]) summarises the key paediatric and mixed paediatric/congenital CSP studies, including study design, cohort characteristics, quantitative findings, and major limitations.

8. Congenital Heart Disease-Specific Considerations

CHD creates anatomical and procedural challenges that are not represented in most adult CSP cohorts. The atrioventricular conduction axis may be displaced by the congenital lesion or surgical repair, and septal patches, baffles, abnormal venous pathways, and systemic right ventricles can alter access, target identification, and lead trajectory. Pre-procedural review of operative history and imaging is therefore important.

In a multicentre CHD study comparing CSP with conventional CRT, both strategies were associated with improved systemic ventricular ejection fraction at 1 year, while CSP produced greater QRS narrowing. This cohort was predominantly adult congenital and should be interpreted as CHD background evidence rather than paediatric proof of superiority [24]. A collaborative study of congenitally corrected transposition of the great arteries reported the feasibility of permanent CSP in a complex lesion with abnormal conduction anatomy [25].

The decision between CSP, conventional transvenous pacing, epicardial pacing, and CRT in CHD should remain lesion-specific. Factors include systemic ventricular morphology, previous surgical pathways, septal accessibility, venous patency, coronary venous anatomy, anticipated pacing burden, and the feasibility of future revision or extraction. Specialist paediatric and congenital electrophysiology input is essential for complex cases.

9. Implantation Strategy and Lead Planning

Current CSP leads and delivery systems were designed largely for adults. In smaller children, standard sheaths may require careful modification or selection to obtain stable septal contact without excessive pressure. The commonly used SelectSecure 3830 lumenless lead (Medtronic) has a 9-mm tip-to-ring interelectrode spacing, a device-specific characteristic that may warrant consideration when interventricular septal thickness is limited [26]. These features may complicate interpretation of bipolar signals and increase the importance of defining lead depth and pacing vector.

Lead planning should include body size, venous access, cardiac anatomy, septal thickness, pacing dependency, and the expected need for future leads. Historical paediatric selective-site pacing reports used deliberate lead slack to accommodate growth, but no CSP-specific paediatric study defines an optimal slack configuration [27]. In

Table 2. Selected paediatric and mixed paediatric/congenital conduction system pacing studies.

Study design	Study	Cohort and pacing approach	Quantitative findings	Interpretation and limitations
Single-centre observational case series	Jimenez et al. [18]	8 patients aged 8–18 years. HBP in 6 and LBB pacing in 2.	Two patients with pacing-induced cardiomyopathy showed reported LVEF improvements of 14% and 16% following non-selective His bundle pacing (absolute versus relative changes not specified). No acute procedural complications were reported	Very small, single-centre, uncontrolled cohort. Functional recovery cannot be attributed to CSP with certainty.
Single-centre observational cohort	Gordon et al. [19]	24 paediatric and congenital patients. HBP in 23. Median age 14 years, range 8–39 years. CHD in 12.	Median threshold 0.5 V at 0.4 ms. Median follow-up 610 days. No procedural complications reported.	Includes adult congenital patients. Limited long-term safety and comparative data.
Paediatric observational cohort	Ballı et al. [20]	19 paediatric LBBAP implants.	Median threshold 0.7 V at 0.5 ms. Median R-wave amplitude 14.7 mV. Median paced QRS 92 ms. No acute adverse events reported.	Short follow-up and selected population. Capture definitions require careful interpretation.
Single-centre feasibility cohort	Li et al. [21]	31 children aged 7 years or younger scheduled for LBBAP.	Successful LBBAP in 22 patients, 70.9%.	Shows feasibility in young children but also procedural challenge in small hearts. Single-centre experience.
Non-randomised comparative cohort	Li et al. [22]	48 children with LBBAP or right ventricular septal pacing.	Paced QRS 100.2 ± 9.3 ms with LBBAP versus 115.4 ± 15.1 ms with right ventricular septal pacing. Capture threshold 0.79 ± 0.18 V versus 1.20 ± 0.56 V, $p = 0.008$.	Non-randomised comparison. Clinical outcome and long-term lead data remain unavailable.
Single-centre mixed paediatric/adult congenital cohort	Harris et al. [16]	31 paediatric or adult congenital patients, 32 CSP systems. HBP versus left bundle area pacing.	Comparable procedure and fluoroscopy times. Chronic sensing and capture thresholds favoured left bundle area pacing.	Mixed cohort and single-centre design. Not a paediatric randomised comparison.
Paediatric observational cohort	Karagöz et al. [14]	18 paediatric LBBAP implants. Mean age 12.3 ± 5.8 years. Congenital AV block in 13 and post-interventional AV block in 5.	Mean paced QRS 94 ± 13 ms. No procedural or follow-up complications over mean 13.5 ± 7.5 months. Ventricular pacing threshold 0.25–0.75 V.	Short-term, single-centre observational experience. No comparator group and no long-term paediatric lead or extraction data.

Abbreviations: HBP, His bundle pacing; LBBAP, left bundle branch area pacing; LVEF, left ventricular ejection fraction.

small children, transthoracic or transoesophageal echocardiography may be helpful when septal depth is uncertain. Radiation should be minimised using standard paediatric as low as reasonably achievable (ALARA) principles. Fluoroscopy, electrogram guidance, and three-dimensional mapping can be combined according to anatomy and institutional expertise [28,29].

In CHD, pre-procedural imaging and review of operative anatomy should guide access and target selection. Three-dimensional mapping can help identify a His signal or an appropriate septal target when standard fluoroscopic landmarks are unreliable. These technical adaptations are based mainly on expert practice, small series, and adult-derived implantation guidance rather than comparative paediatric trials [28,30,31].

10. Capture Confirmation and Reporting

Capture confirmation is central to CSP reporting [28]. For HBP, operators should document the His electrogram when available, the capture threshold, paced QRS morphology, and any transition between non-selective and selective His capture. For LBBAP, an integrated approach is needed. Relevant observations include paced QRS morphology, V6 R-wave peak time or left ventricular activation time, output-dependent transitions, evidence of selective or non-selective capture, and correction of baseline bundle-branch block when applicable.

No paediatric-specific threshold values for these criteria have been validated. Adult consensus definitions are useful but must be interpreted cautiously in children because cardiac size, orientation, baseline conduction, and CHD anatomy influence surface electrocardiography (ECG) appearance. A visibly narrower QRS complex alone

does not confirm left bundle branch capture. When objective criteria are incomplete, reports should describe the implant as probable LBBAP or deep septal/LVSP rather than confirmed left bundle branch pacing [28,30,31].

11. Complications, Lead Revision, and Extraction Planning

The incidence of septal perforation, lead dislodgement, loss of conduction system capture, threshold rise, lead revision, infection, venous obstruction, and extraction outcomes has not been defined robustly for paediatric CSP. The available CSP series are small, have short follow-up, and may under-represent unsuccessful implants or late complications. No paediatric CSP-specific complication rate should therefore be inferred from current reports.

Deep septal implantation introduces concerns about excessive lead depth, septal perforation, and possible transition from conduction system capture to myocardial pacing. HBP raises separate concerns about threshold rise, battery depletion, and capture instability. Paediatric case reports have described HBP lead dysfunction in the setting of activity-related lead issues, but the frequency and mechanism of this problem remain uncertain [32].

Recent adult LBBAP literature has better defined procedure-specific safety signals. In a prospective 61-patient study using systematic septal contrast imaging, septal venous channel perforation was identified in 8 patients (13.1%). Three required lead repositioning, but no acute or early adverse clinical sequelae were observed [33]. This finding suggests that septal vascular injury may be underrecognised when it is not actively sought, and the adult event rate should not be extrapolated to children. Contemporary reviews describe transseptal myocardial perforation, septal venous or coronary injury, septal haematoma, lead dislodgement, delayed capture or threshold changes, and extraction uncertainty as LBBAP-specific concerns requiring structured follow-up [34]. Current-of-injury amplitude can support assessment of lead-tissue interaction and depth, but it varies with filter settings, ventricular pacing, and lead type, so it should be interpreted within a multimodal implant assessment rather than as a stand-alone safety marker [35]. In children, thinner septa, somatic growth, physical activity, and decades of lead dwell make long-term safety surveillance especially important.

Established paediatric pacing data provide context rather than direct CSP estimates. In transvenous paediatric pacing, venous obstruction, lead fracture, and infection are recognised long-term concerns, particularly after repeated procedures [36,37,38,39]. The relevance of these risks to CSP depends on lead calibre, venous history, dwell time, number of systems, and future revision burden. Venous imaging may be appropriate before a major revision or upgrade in children with longstanding transvenous leads.

Extraction planning is especially important because children may face several device life cycles. Adult series demonstrate the feasibility of extracting lumenless His and deep septal leads, but reported dwell times are relatively short and the evidence does not answer the question of extraction after decades of implantation [40,41]. Long-dwell paediatric CSP extraction data are a major evidence gap.

12. Follow-Up

Follow-up should be tailored to pacing dependency, lead type, threshold stability, and local paediatric device practice. PACES guidance supports early post-implant assessment, remote monitoring when available, and at least annual in-person evaluation for paediatric cardiac implantable electronic devices [7].

For CSP, follow-up should include device interrogation and a 12-lead ECG at programmed output to document the intended capture pattern. HBP requires particular attention to threshold change and battery longevity. Echocardiography should be performed when clinically indicated, especially in children with high pacing burden, prior ventricular dysfunction, CHD, or a change in symptoms. The framework in Table 3 is expert opinion derived from paediatric device guidance and CSP consensus, not a validated paediatric protocol [7,28]. Table 3 summarises expert opinion framework for paediatric CSP planning and follow-up.

13. Limitations and Future Research

The evidence base is constrained by small samples, heterogeneous ages and lesions, variable definitions of capture, and short follow-up. Most studies report electrical endpoints rather than patient-centred outcomes [42]. Publication bias is plausible because early experience from specialised centres is more likely to be reported.

Implementation is also constrained by service capacity. The 2025 ESC-European Heart Rhythm Association (EHRA) Atlas reported that electrophysiology or cardiac implantable electronic device (CIED) procedures in children were performed in a median of only 0.3 hospitals per million population across participating ESC countries. Six countries reported no such centre and 12 reported only one [42]. The Atlas also documented wide cross-country variation in electrophysiology and device infrastructure and access. Because paediatric CSP requires specialised implantation skills, congenital anatomy expertise, and long-term lead management, the limited number and uneven distribution of paediatric electrophysiology centres may slow routine adoption and make multicentre registries and collaborative training particularly important.

Future paediatric studies should compare CSP with optimised conventional transvenous pacing, epicardial pacing, and CRT in well-defined clinical strata. Priority outcomes include ventricular function and strain, exercise capacity, hospitalisation, quality of life, battery longevity, lead revision, venous obstruction, infection, and extraction. Studies should also report implant success, capture criteria,

Table 3. Expert-opinion framework for paediatric CSP planning and follow-up.

Domain	Framework	Evidence status
Candidate selection	Consider pacing burden, ventricular function, CHD anatomy, venous status, body size, and future lead requirements. Compare CSP with transvenous right ventricular pacing, epicardial pacing, and CRT for the individual patient.	Individualised expert opinion. No validated paediatric CSP selection algorithm.
Pre-implant planning	Review surgical history and imaging. Define anticipated septal target, access route, pacing dependency, and a plan for growth-related lead slack.	Supported by paediatric device guidance and procedural consensus, with limited CSP-specific paediatric data.
Capture documentation	Record a 12-lead ECG, intracardiac electrograms when available, threshold testing, paced morphology, and output-dependent transitions. State whether capture is confirmed or probable.	Adult-derived criteria applied cautiously. Paediatric criteria are not validated.
Early follow-up	Perform device interrogation and 12-lead ECG at programmed output. Reassess thresholds, sensing, impedance, and clinical status.	Paediatric device guidance supports early device review. CSP-specific intervals are not validated.
Long-term surveillance	Use remote monitoring where available. Tailor in-person assessment, ECG, echocardiography, and imaging to pacing dependency, CHD, threshold trends, and growth.	Expert opinion informed by paediatric device guidance and CSP consensus.
Revision and extraction planning	Document venous access and lead history. Consider venous imaging before major revision or upgrade. Plan extraction strategy early in patients expected to need multiple device life cycles.	Strong clinical rationale, but long-dwell paediatric CSP extraction evidence is lacking.

This framework is not a recommended clinical algorithm and should be adapted to the child's anatomy, pacing indication, institutional expertise, and evolving evidence. CRT, cardiac resynchronisation therapy; ECG, electrocardiography.

programmed outputs, fluoroscopy exposure, septal imaging, and lead status longitudinally.

Paediatric-specific capture criteria, smaller delivery systems, lead designs suitable for thin septa, and long-dwell extraction registries are needed. Multicentre registries with prespecified definitions and extended follow-up are likely to be more achievable initially than large randomised trials. Until these data are available, CSP should not be portrayed as a universal replacement for existing paediatric pacing strategies.

Emerging artificial intelligence approaches may also complement future paediatric pacing care through improved device diagnostics, remote monitoring, therapy optimisation, and prediction of ventricular arrhythmias. However, current evidence in these areas is derived predominantly from adult CIED and arrhythmia populations, and paediatric-specific validation will be required before such tools can be incorporated into routine CSP pathways [43,44].

14. Conclusions

Current evidence suggests that CSP is a feasible physiological pacing strategy in selected children and patients with CHD. Current paediatric evidence supports short-term feasibility and favourable electrical parameters, with lower chronic thresholds reported for LBBAP than HBP in mixed cohorts. The literature does not yet establish long-term clinical superiority over conventional transvenous pacing, epicardial pacing, or CRT.

Careful patient selection, explicit capture documentation, venous preservation, growth-related lead planning, and future extraction considerations are central to paediatric CSP. Clinical decisions should remain individualised and concentrated in experienced paediatric and congenital electrophysiology programmes while prospective comparative evidence develops.

Author Contributions

IA, ME, and AA contributed to conceptualisation, methodology, literature search, evidence synthesis, and drafting. KMT, EYML, HD, VB, RS, CK, GAN, and MI contributed to conceptualisation, methodology, critical review and editing. All authors approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Not applicable.

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Conflicts of Interest

The authors declare no conflicts of interest.

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