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CARDIOLOGY (W LAI AND W ZUCKERMAN, SECTION EDITORS)

Evaluation and Management of the Asymptomatic Child with Wolff–Parkinson–White

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Abstract Wolff–Parkinson–White (WPW) describes an accessory pathway (AP) that connects the atria and ventricles and allows preexcitation of the ventricle, manifested on the electrocardiogram (ECG) as a short PR interval and a delta wave. WPW syndrome describes the abnormal ECG pattern in patients with associated clinical cardiovascular symptoms, whereas "isolated ventricular preexcitation," "asymptomatic WPW," or "asymptomatic WPW syndrome" all refer to the abnormal ECG pattern without associated clinical cardiovascular symptoms. The clinical presentation of symptomatic WPW in young patients with structurally normal hearts can vary based on age and accessory pathway properties. Unfortunately, sudden cardiac death (SCD) can be the first manifestation in patients with WPW. Non-invasive modalities (ECG, ambulatory monitoring, and exercise testing) are used to risk stratify patients. A more invasive test (electrophysiology study) can then be used to identify high-risk pathways. Finally, radiofrequency and/or cryoablation are used to eliminate the accessory pathway and eliminate the risk of arrhythmia and SCD.

Keywords Wolff–Parkinson–White · Asymptomatic · Children · Electrocardiogram · Ambulatory monitor · Exercise stress test · Electrophysiology study · Ablation

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Background

Louis Wolff, Sir John Parkinson, and Paul Dudley White first described their now eponymous Wolff–Parkinson–White findings in a landmark 1930 manuscript, which reported patients susceptible to sudden tachycardia due to a shorter electrical conduction time from atrium to ventricle [1]. Through observation by anatomists and electrophysiologists, understanding of WPW has evolved over nearly a century to describe the characteristics of the APs. An AP is an extra connection that allows direct passage of electrical signal from the atria to the ventricle without traveling through the AV node. Conduction through an AP can result in the electrical signal reaching the ventricle faster, initiating depolarization before the signal that traveled through the AV node can depolarize the entire ventricular mass. Early depolarization of the ventricle via an AP is therefore said to "preexcite" the ventricle, and manifests on the ECG as a delta wave with a short PR interval (Fig. 1). WPW syndrome describes the abnormal ECG pattern in patients with associated clinical cardiovascular symptoms, whereas "isolated ventricular preexcitation," "asymptomatic WPW," or "asymptomatic WPW syndrome" all refer to the abnormal ECG pattern without associated clinical cardiovascular symptoms. The purpose of this review article is to provide an overview of the literature regarding evaluation, management, and the risk of SCD in the asymptomatic young patient with WPW ECG pattern.

Presentation of WPW in the Symptomatic and Asymptomatic Young Patient

Definition of Symptoms

To understand the significance of asymptomatic patients with WPW, first we need to review which symptoms might

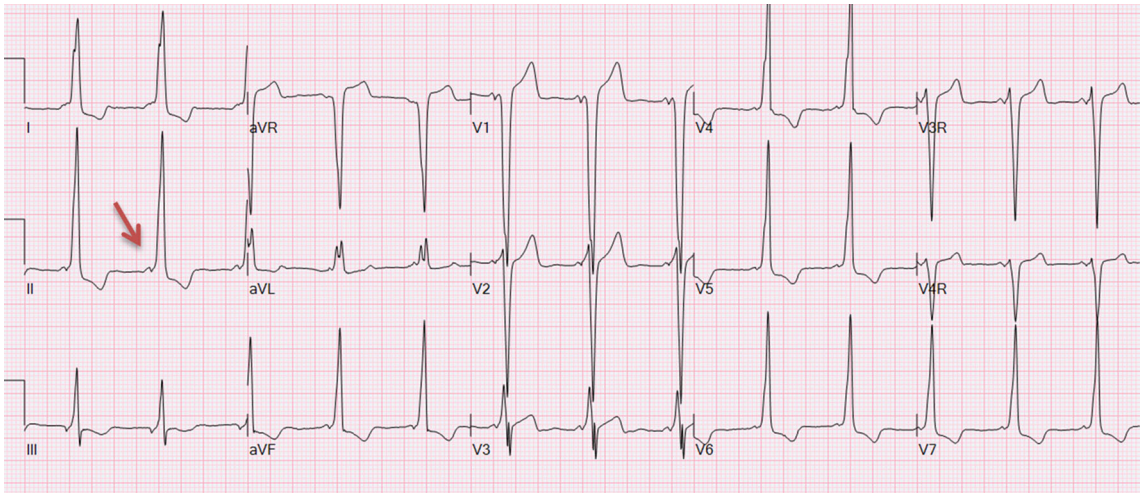

Fig. 1 Wolff–Parkinson–White pattern with short PR interval and delta wave (*arrow*)

be associated with WPW. The symptomatic patient with WPW as defined by the Pediatric and Congenital Electrophysiology Society (PACES) and Heart Rhythm Society (HRS) commonly presents with palpitations, chest pain, and/or pre-syncope [2••]. Infants may present with feeding difficulty, respiratory distress, and/or changes in behavior including lethargy. Uncommon but concerning initial symptoms include syncope, aborted sudden cardiac arrest, and/or SCD as the first manifestation of WPW syndrome [3]. The asymptomatic young patient with WPW has an abnormal ECG pattern with ventricular preexcitation but without cardiovascular symptoms.

Definition of Arrhythmias

Atrioventricular reentrant tachycardia (AVRT) is one type of tachycardia that occurs in WPW syndrome due to a circuit consisting of two distinct pathways: the normal AV conduction system and an AP.

AVRT can be further characterized as either orthodromic reentrant tachycardia (ORT) or antidromic reentrant tachycardia (ART), according to the electrical direction through the accessory pathway. ORT comprises 90–95 % of the reentrant tachycardia associated with WPW syndrome [4]. In ORT, the wave of electrical depolarization is conducted anterograde down the AV node. ECG findings associated with ORT include a regular narrow QRS complex tachycardia (in the absence of an underlying conduction system disease or aberrancy); and inverted P waves visible just after the QRS complex, which represent retrograde conduction from the ventricle to the atrium via the pathway.

ART comprises <10 % of reentrant tachycardia associated with WPW syndrome [5]. In ART, electrical impulses travel anterograde through the AP and retrograde through the AV node. ECG findings associated with ART include a regular wide QRS complex tachycardia and inverted P waves following the QRS complex.

Patients with WPW may also develop atrial fibrillation, which can in turn cause ventricular fibrillation (VF). If the AP has a short refractory period, it could possibly conduct signals from a rapidly fibrillating atrium directly to the ventricle causing VF and SCD [6]. Unfortunately, this rare event can be the first presenting symptom in a patient with WPW [1].

Natural History of WPW

Large-scale population studies of children and adults estimate the prevalence of WPW to be approximately 1 to 3 per 1000 individuals [7, 8]. Familial studies estimate the incidence to be approximately 5.5 per 1000 individuals among first-degree relatives of a patient with WPW [9]. An estimated 65 % of adolescents and 40 % of patients over 30 years of age with WPW pattern on ECG are asymptomatic [10].

The clinical presentation of symptomatic WPW in young patients without congenital heart disease (CHD) can vary based on age and the electrical properties of the AP. The initial ECG in symptomatic infants can often document the AVRT, and then greater than 90 % will have decreased frequency of AVRT during the first year of life [11]. If by 5 years of age, patients continue to demonstrate WPW with evidence of tachycardia, greater than 75 % of these patients will continue to have symptoms after 10 years [6].

A population-based study followed a cohort of pediatric and adult WPW patients from 1953 to 1989 to determine the natural history including the presentation, development

of arrhythmias and incidence of sudden death. Half of the patients with WPW were asymptomatic at diagnosis, with 30 % of those initially asymptomatic then developing symptoms related to arrhythmias by 10 years of follow-up. Two cases of SCD occurred with an overall SCD rate of 0.15 % per patient-year. Importantly, the authors found no instances of SCD in patients who were asymptomatic at diagnosis [10].

Similarly, to examine the natural history of patients with WPW syndrome diagnosed in childhood, Cain et al. followed 446 patients with a median age of 7 years (range 0–20 years) at a single institution for a median follow-up of 3 years. Of these patients, 64 % were symptomatic at presentation, including 38 % with documented supraventricular tachycardia (SVT), 22 % with palpitations, 5 % with chest pain, 4 % with syncope, 0.4 % with atrial fibrillation, and 0.2 % with SCD. Of the infants less than 3 months old at presentation, 35 % had resolution of preexcitation compared to only 6 % of those diagnosed older than 3 months ($p < 0.0001$). There were 6 sudden cardiac deaths during follow-up, yielding a rate of SCD of 0.3 % per patient-year. Four of these patients had CHD [12•]. There are similar rates of SCD in adult populations. Pappone et al. prospectively followed asymptomatic adults with WPW for a mean of 38 months and found rate of SCD of 0.4 % per patient-year [13].

Multiple studies have examined the risk of SCD as the initial presentation of WPW. In 1979, Klein et al. analyzed 25 patients with WPW who presented with VF and noted that those who were previously asymptomatic were all children [6]. Russell et al. examined 60 asymptomatic children with WPW, 10 % of whom presented with a life-threatening symptom [14]. Deal et al. analyzed 42 pediatric patients with WPW and cardiac arrest, and found that the cardiac arrest was the first sign of WPW in 48 % of the patients [11]. Etheridge et al. retrospectively identified 33 patients with WPW syndrome who experienced a life-threatening event (LTE) including atrial fibrillation with rapid conduction, aborted SCD or SCD. In 55 % of the patients, the LTE was the presenting symptom, and the LTE occurred at rest in 33 % of these patients [15••]. Additional population studies have found variable incidences of life-threatening arrhythmias causing SCD in patients with WPW; however, the majority of these studies reported an overall low incidence of SCD [4, 7, 12•].

Risk Stratification/Work-up in Asymptomatic WPW

Although the risk is proven to be low, since the consequences of an event are catastrophic, asymptomatic young patients with WPW pattern on ECG should be risk stratified to determine their risk for SCD. Although initial history is important, determining which patients with WPW who are at highest risk for life-threatening arrhythmia by history alone is not currently possible. Cohen et al. propose that significant clinical risk factors may include age <30 years, male, history of atrial fibrillation, prior syncope, associated congenital or other heart disease, and family history of WPW [2••]. However, for the majority of patients, further evaluation needs to be made using non-invasive modalities, including ambulatory monitoring (Holter monitoring) and exercise stress testing (EST). If a patient cannot be identified as low risk based on non-invasive evaluation, then invasive modalities such as an electrophysiology study (EPS) and possible ablation should be performed.

Non-invasive Evaluation of Asymptomatic WPW

Non-invasive evaluation of the asymptomatic child with WPW includes serial ECGs, ambulatory monitoring, and EST.

ECG and Ambulatory Monitoring

ECG and ambulatory monitoring can be used to assess the anterograde electrical properties of the AP. For example, these modalities can demonstrate intermittent loss of the delta wave during physiologic non-exertional heart rates, which indicates intermittent preexcitation (Fig. 2). Some early studies suggested that intermittent loss of preexcitation during sinus rhythm indicates a low risk of cardiac arrest. However, more recent research has suggested that intermittent preexcitation may not represent a low-risk pathway. Mah et al. performed a retrospective study of patients with preexcitation who had undergone EPS and discovered intermittent preexcitation in 12.5 %. In these patients, APs with intermittent preexcitation had a longer refractory period compared to APs with persistent preexcitation. However, the incidence of pathways with refractory periods less than or equal to 250 ms, indicating a pathway with the potential to rapidly conduct, was not significantly different between the two groups. Therefore, these similar conduction characteristics suggest that APs with persistent or intermittent preexcitation are potentially both at similar risk for rapid conduction [16•]. This study highlights that intermittent preexcitation on serial ECGs or ambulatory monitoring does not rule out potentially high-risk pathways.

Multiple APs may be discovered on serial ECGs or ambulatory monitoring through observation of different preexcited morphologies. Multiple APs have been shown to be a risk factor for VF [17]. In addition to conferring increased risk, these patients are also more likely to be symptomatic [18].

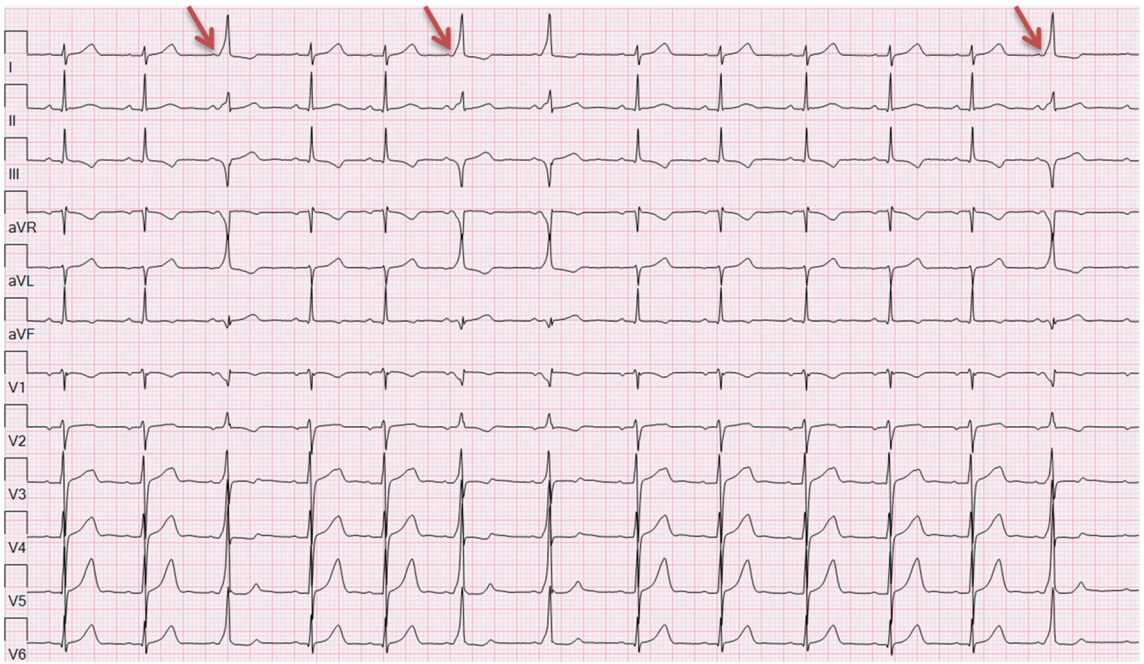

Fig. 2 Intermittent preexcitation (*arrows*)

Finally, serial ambulatory monitoring can be important to uncover sub-clinical arrhythmias such as paroxysmal SVT or atrial fibrillation, especially in a patient who is unable to recognize or describe symptoms. Santinelli et al. performed a prospective study of 184 asymptomatic children with WPW followed for 5 years during which biannual ambulatory monitors demonstrated paroxysmal atrial fibrillation in 22 patients (12 %) [19].

Exercise Stress Testing

EST can demonstrate abrupt beat-to-beat loss of preexcitation during exercise (Fig. 3). This can act as a non-invasive surrogate of the AP refractory period [20]. Loss of preexcitation indicates that the anterograde refractory period of the AP is longer than the refractory period of the AV node. A long anterograde accessory pathway effective refractory period (APERP) indicates that atrial impulses cannot be conducted to the ventricle in rapid succession via the AP. If a patient develops atrial fibrillation, it is unlikely that the AP can transmit atrial signals to the ventricle fast enough to induce VF. Therefore, the likelihood of VF as a result of atrial fibrillation is low, and the pathway is considered low risk. Daubert et al. demonstrated that only abrupt and complete loss of preexcitation during exercise confirmed a long anterograde APERP [21]. During exercise, increased sympathetic stimulation accelerates AV node conduction, which may lead to a gradual loss of preexcitation, potentially hiding persistent preexcitation [22]. Spar et al. investigated WPW patients with EST that had undergone EPS. The authors found that the sudden beat-to-beat loss of preexcitation correlated with a longer refractory period of the AP. Additionally, the AP conduction characteristics were similar in both patients with gradual loss of preexcitation and persistent preexcitation. The authors concluded that the gradual loss of preexcitation during EST has an unclear risk of rapid AP conduction [23•].

ECG, ambulatory monitoring, and EST can be used to determine multiple characteristics of APs that can help assess the asymptomatic child with WPW. Abrupt loss of preexcitation on ambulatory monitoring as the heart rate accelerates or during EST indicates an AP with a longer refractory period and thus a low-risk pathway; therefore, further invasive evaluation would not be indicated. The presence of intermittent preexcitation at rest but persistent preexcitation with exercise, asymptomatic paroxysmal SVT or atrial fibrillation, gradual loss of preexcitation, and uncommonly, multiple APs on non-invasive evaluation indicates a need for further evaluation by EPS.

Invasive Evaluation of Asymptomatic WPW

An EPS can be performed in order to evaluate the anterograde electrical properties of the AP, identify the subgroup of patients at increased risk for SCD, and determine if an ablation is indicated. An EPS should include measurements regarding number and location of APs,

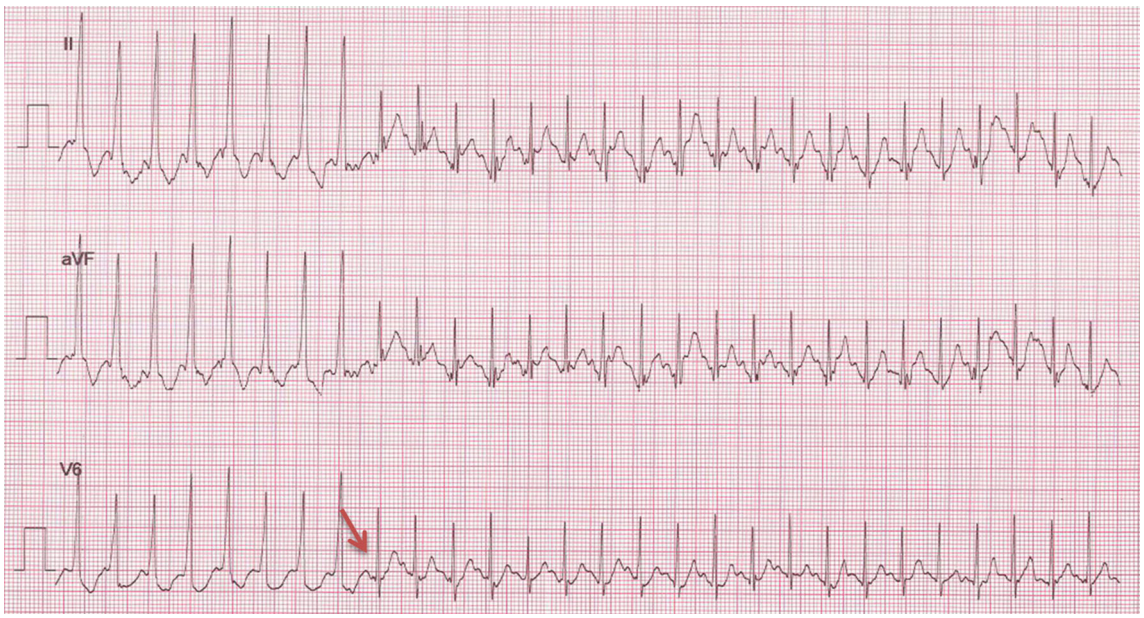

Fig. 3 Abrupt loss of preexcitation with exertion (*arrow*)

assessment of the conduction characteristics of the AP(s) and AV node, shortest preexcited R-R interval (SPERRI) during induced atrial fibrillation, and the APERP of the pathway at multiple heart rates [2••]. A short SPERRI or APERP indicates that the AP can conduct atrial beats more rapidly to the ventricle.

An EPS can be performed using trans-esophageal pacing (by inserting a pacing catheter via the mouth or nose to the esophagus and stimulating the atrium that is anterior to it) or trans-venous pacing (by placing a pacing catheter via the femoral vein directly into the atrium). In those patients undergoing EPS under general anesthesia, an infusion of isoproterenol can be used to assess the conduction characteristics at higher heart rates to simulate exercise.

Multiple natural history studies have been done to identify risk factors for potentially life-threatening arrhythmic events in order to determine when ablation is indicated. Klein et al. compared patients with WPW syndrome and a history of VF to patients with WPW syndrome without VF. Patients with a history of VF had a significantly higher prevalence of reentrant tachycardia, atrial fibrillation, and multiple accessory pathways. During EPS, patients with a history of VF also had a significantly shorter SPERRI during atrial fibrillation compared to those patients without VF [6].

Santinelli et al. followed 184 asymptomatic children with WPW who underwent EPS. During a median follow-up of nearly 6 years, 51 children experienced an arrhythmic event, including 3 cardiac arrests. Univariate analysis identified tachyarrhythmia inducibility, multiple accessory pathways, and APERP $\leq$ 240 ms ($p < 0.001$) as risk factors for potentially life-threatening arrhythmic events. All three children with cardiac arrests related to VF had very high-risk pathways at initial EPS including APERP $<$ 220 ms, SPERRI $<$ 200 ms, and multiple APs. The authors concluded that SPERRI 220–250 ms and especially $<$220 ms are more commonly found in WPW patients who have had a cardiac arrest [19].

Pappone et al. performed a prospective clinical trial of 46 asymptomatic children with WPW considered high risk for arrhythmias due to inducible atrial fibrillation or SVT. Approximately half underwent prophylactic ablation and half had no treatment. Over 3-year follow-up, 5 % of children in the ablation group and 44 % in the control group had arrhythmic events. Specifically, two children in the control group had VF, with one sudden death; evidence of multiple APs was the only independent predictor of arrhythmic events. The authors concluded that prophylactic ablation in high-risk children with WPW reduces the chance of a life-threatening arrhythmia. However, the authors initially randomized 60 patients and subsequently 10 patients withdrew from the ablation group of the study, which may have affected the conclusions of the study [17]. Sarrubi et al. studied 57 asymptomatic children with WPW, 48 % of whom had sustained SVT on initial EPS and received medical treatment or ablation. In the remaining patients, over a mean follow-up of 48 months, 8.7 % of patients demonstrated symptomatic SVT and one patient experience SCD [24].

Campbell et al. surveyed 43 pediatric electrophysiologists and found that 84 % used some form of invasive EPS to risk stratify asymptomatic children with WPW.

Indications for ablation included a SPERRI <240 ms in 77 % of those surveyed, APERP < 240 ms in 47 %, and induction of SVT in 26 % [25]. In general, electrophysiologists proceed with ablation of accessory pathways if the APERP is less than or equal to 250 ms or the presence of multiple APs.

Success Rates, Risks and Complications of EPS and Ablation in WPW

Success Rates

A successful ablation identifies the AP and uses radiofrequency and/or cryoablation therapy to eliminate its potential for conduction. The Pediatric Electrophysiology Society established the Pediatric Radiofrequency Ablation Registry after the first successful radiofrequency ablation procedures in children in the early 1990s. Registry data were divided into early (1991–1995) and late era (1996–1999). Published data demonstrated a significant increase in success rates of ablation from 90 % in the early era to 95 % in the later era. Specifically, success rates for AP ablation increased from 89 to 94 % [26]. Van Hare et al. performed a multicenter prospective study in children with SVT due to APs excluding CHD and found a success rate of 96 % using radiofrequency energy [27]. Ceresnak et al. performed a retrospective analysis of 651 WPW patients undergoing ablation to assess the success rates for ablation with the use of 3D mapping. The authors found a significantly higher success rate of 97 % for ablation using 3D mapping compared to a 91 % success rate using fluoroscopy alone [28••].

Risks and Complications

Multiple adult and pediatric studies that have evaluated the risks and complications associated with performing an EPS have demonstrated that despite being an invasive procedure, it has a very low-risk profile.

Data from the Pediatric Radiofrequency Ablation Registry demonstrated an overall decrease in complication rates for EPS with radiofrequency ablation from 4.3 % in the early era to 3 % in the later era. The three most common complications included 2nd or 3rd degree AV block (0.7 %), catheter perforation/pericardial effusion, and thrombi/emboli (0.3 %) [26]. Van Hare et al. reported complication rates of 4.2 % for EPS and 4.0 % for radiofrequency ablation with no mortality [27]. More recent data have shown a significant decrease in complication rate to 0.3 % [28••]. The most common complication following radiofrequency ablation is catheter site hematoma. Atrioventricular block, cardiac perforation, coronary artery injury, and thromboembolic event are very uncommon complications. Complete AV block is generally limited to ablation of septal APs and has significantly decreased with the use of cryotherapy compared to radiofrequency ablation [29].

The use of 3D mapping as an alternative or adjunct to fluoroscopy during EPS has increased leading to a decrease in radiation exposure. The Pediatric Radiofrequency Ablation Registry demonstrated a 21 % decrease in fluoroscopy time between the early and late era [26]. More recent data suggest that ablations could be done using minimal fluoroscopy time with excellent results [28••, 30].

Conclusion

Evaluation of the asymptomatic young patient with WPW pattern on ECG presents a challenge to the treating physician. A basic approach to the evaluation and

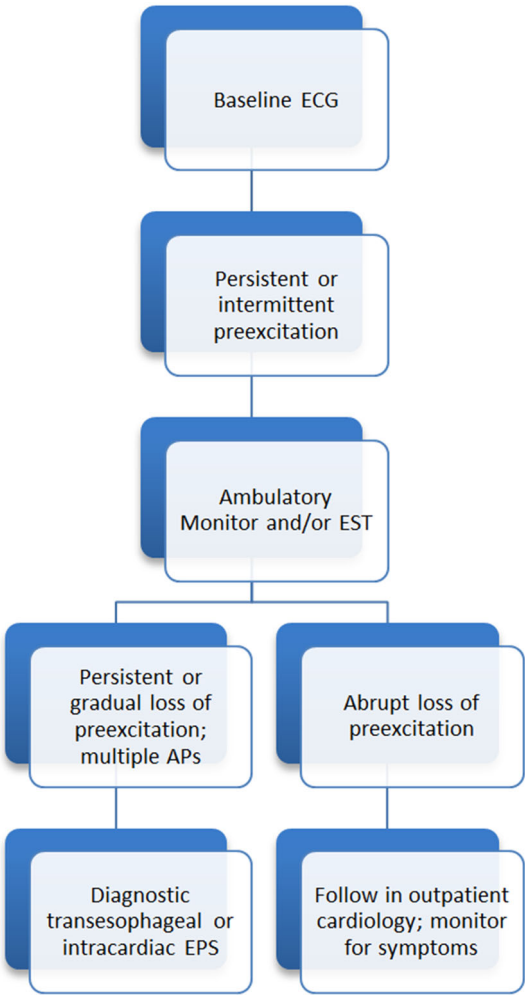

Fig. 4 Algorithm for work-up of asymptomatic patient with WPW ECG pattern. *ECG* electrocardiogram, *EST* exercise stress testing, *AP* accessory pathway

management of the asymptomatic patient is proposed in Fig. 4. PACES and HRS have developed recommendations based on both literature and clinical expert consensus. The abrupt loss of preexcitation at elevated heart rates demonstrated on ambulatory monitoring or exercise stress testing, indicates a low-risk accessory pathway and no further evaluation is indicated. All other patients should undergo evaluation by invasive EPS to assess the conduction characteristics of the AP. In patients with high-risk AP, an ablation should be strongly considered due to the increased risk of SCD. If a previously asymptomatic patient develops cardiac symptoms, evaluation by EPS and ablation should be pursued regardless of the anterograde characteristics of the accessory pathway [2••].

Compliance with Ethics Guidelines

Conflict of Interest Caitlin S. Haxel, Eric S. Silver, and Leonardo Liberman declare that they have no conflict of interest. Jonathan N. Flyer has received non-financial support from Sagent Pharmaceuticals and St. Jude Medical, Inc outside of the submitted.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. Wolff L, Parkinson J, White PD. Bundle-branch block with short P-R interval in healthy young people prone to paroxysmal tachycardia. Am Heart J. 1930;5:685–704.
2. •• Cohen MI, Triedman JK, Cannon BC, Davis AM, Drago F, Janousek J, et al. PACE/HRS Expert Consensus statement on the management of the asymptomatic young patient with a Wolff–Parkinson–White (WPW, pre-excitation) electrocardiographic pattern. Heart Rhythm. 2012; 9:1007–24. *A recent, important consensus statement discussing the evaluation and management of the asymptomatic patient with WPW.*
3. Timmermans C, Smeets JL, Rodriguez LM, Vrouchos G, van den Dool A, Wellens HJ. Aborted sudden death in Wolff–Parkinson–White Syndrome. Am J Cardiol. 1995;76:492–4.
4. Josephson ME. Preexcitation syndromes. Clinical cardiac electrophysiology. Philadelphia: Lea & Febiger; 1993. p. 311.
5. Kuck KH, Brugada P, Wellens HJ. Observations on the antidromic type of circus movement tachycardia in the Wolff–Parkinson–White syndrome. J Am Coll Cardiol. 1983;2:1003.
6. Klein GJ, Bashore TM, Sellers TD, Pritchett EL, Smith WM, Gallagher JJ. Ventricular fibrillation in Wolff–Parkinson–White syndrome. N Engl J Med. 1979;301:1080–5.
7. Hiss RG, Lamb LE. Electrocardiographic findings in 122,043 individuals. Circulation. 1962;25:947–61.
8. Swiderski J, Lees MH, Nadas AS. The Wolff–Parkinson–White syndrome in infancy and childhood. Br Heart J. 1962;24:561–80.
9. Vidaillet HJ Jr, Pressley JC, Henke E, Harrell FE Jr, German LD. Familial occurrence of accessory atrioventricular pathways (preexcitation syndrome). N Engl J Med. 1987;317:65–9.
10. Munger TM, Packer DL, Hammill SC, Feldman BJ, Bailey KR, Ballard DJ, Holmes DR, Gersh BJ. A population study of the natural history of Wolff–Parkinson–White Syndrome in Olmstead County, Minnesota, 1953–1989. Circulation. 1993;87:866–73.
11. Deal BJ, Keane JF, Gillette PC, Garson A Jr. Wolff–Parkinson–White syndrome and supraventricular tachycardia during infancy: management and follow-up. J Am Coll Cardiol. 1985;5:130–5.
12. • Cain N, Irving M, Webber S, Beerman L, Arora G. Natural history of Wolff–Parkinson–White syndrome diagnosed in childhood. Am J Cardiol. 2013;112:961–5. *A recent, large study of a pediatric population highlighting the presentation and evolution of symptomatic and asymptomatic WPW patients.*
13. Pappone C, Santinelli V, Rosanio S, Vicedomini G, Nardi S, Pappone A, Tortoriello V, Manguso F, Mazzone P, Gulletta S, Oreto G, Alfieri O. Usefulness of invasive electrophysiologic testing to stratify risk of arrhythmic events in asymptomatic patients with Wolff–Parkinson–White pattern: results from a large prospective long-term follow-up study. J Am Coll Cardiol. 2003;41:239–44.
14. Russell MW, Dick MD. Incidence of catastrophic events associated with Wolff–Parkinson–White syndrome in young patients: diagnostic and therapeutic dilemma. *Circulation.* 1993:484(a).
15. •• Etheridge SP, et al. AB 19-05 life threatening event risk in children with Wolff–Parkinson–White syndrome: a multicenter study. Heart Rhythm. 2016:12;5. *An important publication highlighting the high rate of LTEs.*
16. • Mah DY, Sherwin ED, Alexander ME, Cecchin F, Abrams DJ, Walsh EP, Triedman JK. The electrophysiological characteristics of accessory pathways in pediatric patients with intermittent preexcitation. Electrophysiology. 2013;36:1117–22. *An important publication regarding the conduction characteristics of accessory pathways in intermittent preexcitation.*
17. Pappone C, Manguso F, Santinelli R, Vicedomini G, Sala S, Paglino G, Mazzone P, Lang CC, Gulletta S, Augello G, Santinelli O, Santinelli V. Radiofrequency ablation in children with asymptomatic Wolff–Parkinson–White syndrome. N Engl J Med. 2004;351:1197–205.
18. Weng KP, Wolff GS, Young ML. Multiple accessory pathways in pediatric patients with Wolff–Parkinson–White syndrome. Am J Cardiol. 2003;91:1178–83.
19. Santinelli V, Radinovic A, Manguso F, Vicedomini G, Gulletta S, Paglino G, Mazzone P, Ciconte G, Sacchi S, Sala S, Pappone C. The natural history of asymptomatic ventricular pre-excitation. J Am Coll Cardiol. 2009;53:275–80.
20. Bricker JT, Porter CJ, Garson A Jr, Gillette PC, McVey P, Traweek M, McNamara DG. Exercise testing in children with Wolff–Parkinson–White syndrome. Am J Cardiol. 1985;55:1001–4.
21. Daubert C, Ollitrault J, Descaves C, Mabo P, Ritter P, Gouffault J. Failure of the exercise test to predict the anterograde refractory period of the accessory pathway in Wolff Parkinson White syndrome. Pacing Clin Electrophysiol. 1988;11:1130–8.
22. Perry JC. Giuffre Rm, Garson A Jr, Clues to the electrocardiographic diagnosis of subtle Wolff–Parkinson–White syndrome in children. J Pediatr. 1990;117:871–5.
23. • Spar DS, Silver ES, Hordof AJ, Liberman L. Relation of the utility of exercise testing for risk assessment in pediatric patients with ventricular preexcitation to pathway location. Am J Cardiol. 2012;109:1011–4. *A recent study demonstrating similar conduction characteristics with gradual loss of preexcitation and persistent preexcitation, highlighting that gradual loss of preexcitation has an unclear risk of rapid conduction.*

24. Sarrubi B, Scognamiglio G, Limongelli G, Mercurio B, Pacileo G, Pisacane C, Russo MG, Calabro R. Asymptomatic ventricular pre-excitation in children and adolescents: a 15 year follow up study. Heart. 2003;89:215–7.
25. Campbell RM, Strieper MJ, Frias PA, Collins KK, Van Hare GF, Dubin AM. Survey of current practice of pediatric electrophysiologists for asymptomatic Wolff–Parkinson–White syndrome. Pediatrics. 2003;111:e245–7.
26. Kugler JD, Danford DA, Houston KA, Felix G. Pediatric radiofrequency catheter ablation registry success, fluoroscopy time, and complication rate for supraventricular tachycardia: comparison of early and recent eras. J Cardiovasc Electrophysiol. 2002;13:336–41.
27. Van Hare GF, Javitz H, Carmell D, Saul JP, Tanel RE, Fischbach PS, Kanter RJ, Schaffer M, Dunnigan A, Colan S, Serwer G. Prospective assessment after pediatric cardiac ablation: demographics, medical profiles and initial outcomes. J Cardiovasc Electrophysiol. 2004;15:759–70.
28. •• Ceresnak SR, Dubin AM, Kim JJ, Valdes SO, Fishberger SB, Shetty I, Zimmerman F, Tanel RE, Epstein MR, Motonaga KS, Capone CA, Nappo L, Gates GJ, Pass RH. Success rates in pediatric WPW ablation are improved with 3-dimensional mapping systems compared with fluoroscopy alone: a multicenter study. J Cardiovasc Electrophysiol. 2015;26:412–6. *An important publication regarding the success of 3D mapping and decreased fluoroscopy time during ablations.*
29. Gaita F, Montefusco A, Riccardi R, Scaglione M, Grossi S, Caponi D, Caruzzo E, Giustetto C, Bocchiardo M, Di Donna P. Acute and long-term outcome of transvenous cryothermal catheter ablation of supraventricular arrhythmias involving the perinodal region. J Cardiovasc Med. 2006;7:785–92.
30. Nagaraju L, Dipika M, Aziz PF. Use of 3D electro-anatomical navigation (CARTO-3) to minimize or eliminate fluoroscopy use in the ablation of pediatric supraventricular tachyarrhythmias. Pacing Clin Electrophysiol. 2016;. doi:10.1111/pace.12830.