Concealed conduction in accessory atrioventricular pathways: an important determinant of the expression of arrhythmias in patients with Wolff-Parkinson-White syndrome

George J. Klein, M.D., F.R.C.P.(C), F.A.C.C., Raymond Yee, M.D., and Arjun D. Sharma, M.D., F.R.C.P.(C)

ABSTRACT Concealed conduction into accessory atrioventricular pathways has been postulated to explain variability of R-R intervals during atrial fibrillation in patients with Wolff-Parkinson-White syndrome. We examined the occurrence of concealed conduction into atrioventricular pathways using extrastimulus techniques in 26 consecutive patients undergoing electrophysiologic studies for the Wolff-Parkinson-White syndrome. Anterograde pathway concealment was demonstrated (10 patients) by introducing a second atrial extrastimulus (A2) after block in the accessory pathway occurred following the first extrastimulus (A1). The apparent effective refractory period (ERP) of the atrioventricular pathway with A1 (after A2 blocked in the pathway), or ERPb, was always greater than the ERP of the atrioventricular pathway (505 ± 100 vs 323 ± 105 msec, mean ± SD; p < .001), a finding explained by concealment into the pathway by the blocked A2. A measure of the apparent prolongation of refractoriness due to anterograde concealment (Δ ERPb), defined as the difference between ERP and ERPb at a given cycle length, was derived. The average R-R interval in atrial fibrillation correlated better with Δ ERPb (r = .8, p < .01) than with the ERP (r = .6, p = NS), supporting the influence of anterograde atrioventricular pathway concealment in modulating the ventricular response during atrial fibrillation. By similar techniques, concealed retrograde conduction in the atrioventricular pathway could be demonstrated in 16 of 26 patients. In two of these patients "bystander" atrioventricular pathway conduction during orthodromic reciprocating tachycardia that did not involve the atrioventricular pathway did not occur, even though the ERP of the pathway should have permitted it, a finding readily explained by repetitive retrograde concealment into the atrioventricular pathway during tachycardia. Concealed conduction can be demonstrated in most patients with Wolff-Parkinson-White syndrome and is an important factor in the clinical expression of their arrhythmias.


Concealed conduction has been defined as the conduction of excitation through certain parts of the cardiac tissue that does not produce an identifiable waveform on the electrocardiogram but can be indirectly implicated by its effects on subsequent impulse formation or conduction.1-2 Concealed conduction has been described in most cardiac tissues, including the atrium, sinus node, atrioventricular node, intraventricular conduction tissue, and ventricular myocardium.1 In patients with Wolff-Parkinson-White (WPW) syndrome, concealed conduction into accessory pathways has been suggested as an explanation for the variability of R-R intervals during atrial fibrillation3-7 and the presence or absence of "bystander" accessory pathway participation in atrioventricular nodal reentrant tachycardia.8 Individual examples of retrograde concealment into accessory pathways, as demonstrated by the extrastimulus technique, have been described.9,10 We used the extrastimulus technique to demonstrate changes in the refractoriness of the accessory pathway that could only be accounted for by concealed conduction in a consecutive series of patients with WPW syndrome and related this phenomenon to the manifestation of their clinical arrhythmias.
Methods

Patients. The study population consisted of 26 consecutive patients with WPW syndrome who underwent electrophysiologic studies in the clinical electrophysiology laboratory between February 1983 and September 1983 (table 1). No patient had coexistent heart disease. Written and verbal informed consent was obtained before the study.

Electrophysiologic evaluation. The method of study of patients with preexcitation in our laboratory has been described. All patients were studied while in the nonsedated, postabsorptive state after all antiarrhythmic medications had been discontinued for at least five drug half-lives. The study included incremental atrial and ventricular pacing and atrial (right atrium) and ventricular extrastimulus testing at multiple cycle lengths. Standard criteria for determining the participation of the accessory pathway in reentrant circuits and for localizing the accessory pathway were used. Atrial fibrillation was induced by rapid atrial pacing if it did not occur during the course of the study. In some patients, atrial fibrillation could only be maintained by rapid atrial pacing. Intervals were measured over a 1 min sample of stable atrial fibrillation and included the shortest R-R interval between preexcited beats (SRR), the average R-R interval (ARR), and the longest R-R interval (LRR) between any 2 beats.

![Table 1](http://circ.ahajournals.org/)

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**Table 1** Summary of data

Age is reported in years and intervals in milliseconds.

AF = atrial fibrillation; AP = accessory pathway; CNM = cannot measure; Dx = diagnosis; LL = left lateral; Nd = no documented arrhythmia; Other = determined by V<sub>2</sub>V<sub>3</sub> and/or V<sub>2</sub>A<sub>3</sub> technique, as described in text; PAT = reciprocating tachycardia; PS = posteroseptal; Px = preexcited; RAS = right anteroseptal.

Demonstration of concealment. We used the occurrence of an "apparent" prolongation of refractoriness of the accessory pathway in the cycle after block in the pathway to demonstrate partial (or concealed) conduction into the accessory pathway. Anterograde concealment in an accessory pathway was demonstrated as follows. After a drive of eight atrial stimuli (A<sub>1</sub>), a single atrial extrastimulus (A<sub>2</sub>) was made progressively more premature until complete block in both the accessory pathway and atrioventricular node was observed. At this point, a second atrial extrastimulus (A<sub>3</sub>) was introduced and made progressively more premature until loss of preexcitation in the QRS after A<sub>3</sub> was observed. Anterograde concealment into the accessory pathway was considered to have occurred if subsequent omission of A<sub>2</sub> resulted in return of preexcitation after A<sub>3</sub> (A<sub>2</sub>A<sub>3</sub> technique; figure 1). The atrial electrogram closest to the atrioventricular pathway was used for measurement.

Retrograde concealment into the accessory pathway was demonstrated in one of three ways. (1) A ventricular extrastimulus (V<sub>2</sub>) after a ventricular drive (V<sub>1</sub>) was made progressively more premature until complete retrograde block was observed. At this point, an atrial extrastimulus (A<sub>3</sub>) was introduced and made progressively more premature until loss of preexcitation was observed after A<sub>3</sub>. Retrograde concealment into the accessory pathway was considered to have occurred if subsequent...
omission of V2 at this point resulted in return of preexcitation after A3 (V2A3 technique; figure 2). (2) A premature ventricular extrastimulus (V2) after a drive (V1) was made progressively premature until total retrograde block was observed. At this point, a third ventricular extrastimulus (V3) was introduced and made progressively more premature until retrograde block in the accessory pathway was observed. Retrograde concealment was considered to have occurred if resumption of retrograde conduction over the accessory pathway with V1 occurred after omission of V2 (V1V2V3 technique; figure 3). This method could only be used if the retrograde atrial activation sequence clearly distinguished the accessory pathway from atrioventricular nodal conduction. (3) An atrial extrastimulus (A3) was introduced after a drive of eight atrial extrastimuli (A1) and made progressively more premature until block in the accessory pathway occurred and the QRS resulting from A2 normalized. At this point, a second atrial extrastimulus (A3) was introduced and made progressively more premature until loss of preexcitation occurred after A1. Clearly, this method could only be applied if normalization of A2 was not accompanied by an atrial echo beat. Retrograde concealment into the accessory pathway was considered to have occurred if preexcitation resumed with A3 after omission of A2 (A2A3 technique; figure 4). The reason for considering this to represent retrograde concealment into the accessory pathway will be discussed.

**Definitions.** The anterograde effective refractory period (ERPAP) of the accessory pathway is the longest A1A2 not conducted with preexcitation at a specified pacing site and drive rate. A1A2 is measured at the atrial electrogram closest to the accessory pathway.

The apparent anterograde effective refractory period of the accessory pathway with a second atrial extrastimulus (A2) after total block of the QRS following A2 is designated as ERPAP. ERPAP can only be considered to be independent of atrioventricular nodal refractoriness if the ERPAP is less than or approximately equal to the effective refractory period of the atrioventricular node.

The apparent anterograde effective refractory period of the accessory pathway with a second atrial extrastimulus (A3) observed after normalization of the QRS after A3 is designated ERPAP.

The difference between the ERPAP and the ERPAP is designated as \( \Delta ERPAP \) and will be considered a measure of refractoriness of the atrioventricular pathway after anterograde concealment. The difference between ERPAP and ERPAP will be designated as \( \Delta ERPAP \) and will be considered a measure of refractoriness of the atrioventricular pathway after retrograde concealment.
Results

Anterograde concealment. Anterograde concealment into the accessory pathway could be demonstrated in 10 patients, retrograde concealment could be demonstrated in 16, and both anterograde and retrograde concealment could be demonstrated in six. Concealment could only be demonstrated if the anterograde and retrograde refractory periods of the accessory pathway exceeded the atrial and ventricular functional refractory periods, respectively. The occurrence of repetitive atrial or ventricular responses at close coupling intervals also limited accuracy of this technique.

Anterograde concealment into the accessory pathway was demonstrated in 10 patients by the A2A3 technique (figure 1). In seven of these 10 patients, ERP_{AP} was less than the effective refractory period of the atrioventricular node, so that shortening of A2A3 to the point of total block of the QRS in the measurement of ERP_{B} was not merely a reflection of atrioventricular nodal refractoriness. ERP_{B} was always greater than ERP_{AP} (505 ± 100 vs 323 ± 105 msec, mean ± SD; p < .001; figure 5), a finding that could only be explained by concealment of the blocked A2 into the accessory pathway.

Retrograde concealment. Determination of ERP_{N} was possible in 10 patients. ERP_{N} was always greater than ERP_{AP} (841 ± 237 vs 336 ± 108 msec; p < .001; figure 5), a difference that could only be explained by concealment into the accessory pathway.

The prolongation of ERP_{N} was considered to be due to retrograde concealment into the accessory pathway by an aborted atrial echo after normalization of the QRS following A2 for the following reasons: (1) In five patients (figure 4) the extrastimulus A3 at the effective refractory period of the accessory pathway could result in either a normal or a preexcited QRS. Under these circumstances, the presence or absence of preexcitation after a second atrial extrastimulus (A3) at a given coupling interval was invariably determined by the presence or absence of preexcitation after A2. That is, if A2 was preexcited, A3 would invariably be preexcited, and if A2 normalized, A3 would invariably be normalized. With omission of A2, A3 was always preexcited. This phenomenon can best be explained by retrograde concealment into the accessory pathway of an aborted echo, which could only occur after normalization of the QRS following A2. (2) It can be seen in figure 5 that the ERP_{N} is significantly greater than the ERP_{B}. Clearly, only anterograde concealment into the accessory pathway is possible after total block of A2 (ERP_{B}), but either anterograde or retrograde concealment is feasible after normalization of the QRS following A2. That is, the greater ERP_{N} can be accounted for by the increased time that A2 requires to conduct over the normal atrioventricular conduction system and conceal into the accessory pathway in a retrograde manner. Both ERP_{B} and ERP_{N} could be determined in three patients (table 1). ERP_{N} was greater than ERP_{B} by 350, 320, and 600 msec, respectively. This difference could not be accounted for by the decrease in A2 required to calculate ERP_{B} (25, 95, and 350 msec, respectively).

Retrograde concealment was demonstrated in 10 patients by the A2A3 technique, in 11 patients by the V2A3 technique, and in one patient by the V2V3 technique.

Observations during atrial fibrillation. During atrial fibrillation, the QRS complexes were entirely preexcit-
ED in two patients, predominantly preexcited (greater than 90%) in 12 patients, both normal and preexcited in 10 patients, and entirely normal in the remaining two. In all patients manifesting a mixture of both normal and preexcited QRS during atrial fibrillation, a similar pattern of conduction was observed in that runs of consecutive normal QRS complexes were interspersed with runs of consecutive preexcited QRS com-

FIGURE 4. See legend opposite page.
plexes (figure 6). Also, relatively prolonged pauses that were considerably longer than the SRR could be observed in all patients.

To test the hypothesis that the variability of preexcited R-R intervals during atrial fibrillation is a manifestation of concealed conduction into the accessory pathway, we measured the difference between the LRR and SRR as an index of variability. This was related to our measures of refractoriness after concealment, which were independently derived by the extrastimulus technique, namely the ΔERP after anterograde concealment and the ΔERP after retrograde concealment. As shown in figure 7, there was a good correlation between LRR − SRR and the ΔERP (r = .89, p < .001), supporting the hypothesis that variability of R-R intervals in atrial fibrillation is related to concealed anterograde conduction into the accessory pathway. By contrast, LRR − SRR was not related to ΔERP (r = −.41). Although SRR correlated well with ERP (figure 7), the ARR correlated better with ΔERP (r = .8, p < .01) than with ERP (r = .6, p = NS), again supporting the role of concealed anterograde conduction in influencing the ventricular response. The SRR was not related to ΔERP (r = −.15, p = NS). Similarly, the ARR interval was not related to ΔERP (r = .28, p = NS).

When patients with demonstrable anterograde concealment by the extrastimulus technique were compared with those in whom it could not be demonstrated, patients with concealment had longer ARR (429 ± 54 vs 371 ± 61 msec; p < .05) and greater LRR − SRR values (443 ± 105 vs 364 ± 85 msec; p < .05), but did not have different SRRs (276 ± 37 vs 244 ± 44 msec; NS). There was no change in these latter

**FIGURE 4.** Demonstration of retrograde concealment into the accessory pathway. A. The last cycle of an atrial drive (S₁) is followed by an atrial extrastimulus (S₂) that blocks in the accessory pathway and conducts with a normalized QRS. A second atrial extrastimulus (S₃) also blocks in the accessory pathway. B. S₂ is omitted and S₃ now conducts with preexcitation even though the S₁S₃ interval remains unchanged (790 msec). C. The S₁S₂ interval remains at 310 msec (as in A), but S₂ now conducts with preexcitation. In this patient there was slight overlap at the effective refractory period of the accessory pathway (310 msec) so that S₂ at this coupling interval was sometimes preexcited. S₃ now conducts with preexcitation; repeated trials demonstrated that block in the accessory pathway after S₁ depended on normalization after S₂. This is best explained by concealed retrograde conduction in the accessory pathway by an aborted echo after the normalized S₂ (A), which results in block in the accessory pathway after S₁. Alternatively, it may be possible that A₃ conducts with preexcitation in panel C as a result of shortening of refractoriness by the preexcited QRS following A₂. This is unlikely since the A₃A₃ interval (480 msec) well exceeds the ERP in this case and one need not postulate that preexcitation following A₃ requires preexcitation following A₂.

**FIGURE 5.** Comparison of ERP, ERP, and ERP. Left. The effective refractory period (ERP) of the accessory pathway in a given patient is compared with the ERP. Right. ERP is compared with the ERP. For any given patient, ERP, ERP, and ERP are calculated at the same drive cycle length (generally 600 msec; table 1).
FIGURE 6. Pattern of preexcited and normal QRS during atrial fibrillation. In this representative record, runs of preexcited QRS alternate with a run of normal QRS complexes (random alternation of single normal and preexcited QRS complexes is not observed). A relatively long pause (870 msec) during unchanged atrial activity is also observed. The latter phenomena are best explained by repetitive concealed conduction into the accessory pathway during runs of normal QRS and, conversely, repetitive retrograde concealment into the atrioventricular node during runs of preexcited QRS.

parameters when patients with demonstrable retrograde concealment were compared with those without it (table 1).

Prolongation of conduction over an accessory pathway. Patient 20 had a single right anteroseptal accessory pathway capable of bidirectional conduction (table 1). The ventriculoatrial interval representing conduction time over the accessory pathway remained constant during incremental ventricular pacing and ventricular extrastimulus testing. However, introduction of a ventricular extrastimulus (V₃) after a ventricular extrastimulus (V₂) that failed to conduct to the atrium resulted in marked prolongation of the ventriculoatrial conduction time (figure 8). Omission of V₂ allowed V₃
FIGURE 8. Prolongation of retrograde accessory pathway conduction after concealment. The last cycle of a ventricular drive ($S_1$) is followed by a ventricular extrastimulus ($S_2$) that fails to conduct to the atrium. A second ventricular extrastimulus ($S_3$) conducts to the atrium over the accessory pathway but with prolongation of the ventriculoatrial interval (55 to 85 msec measured at the His bundle atrial electrogram). An echo beat with a normalized QRS follows $V_3$, proving that retrograde atrial activation after $V_3$ occurred via the accessory pathway (anteroseptal in location).

to conduct over the accessory pathway with its normal ventriculoatrial time.

Observations during reciprocating tachycardia. Patient 25 had two accessory atrioventricular pathways with a right anteroseptal pathway capable of bidirectional conduction and a left lateral pathway capable of retrograde conduction only. During reciprocating tachycardia (figure 9), retrograde atrial activation occurred over both pathways or over the left lateral pathway only. Notably, anterograde preexcitation via the right anteroseptal pathway was not present during reciprocating tachycardia using only the left lateral pathway in the retrograde direction, even though the rate of tachycardia was considerably slower than the maximum

FIGURE 9. Reciprocating tachycardia using one or two accessory pathways. Reciprocating tachycardia (orthodromic) at cycle length 390 msec is shown. The first four cycles show retrograde atrial fusion resulting from a lateral and right anteroseptal accessory pathway (RA and CSd atrial electrograms both early). The fifth and following cycles show retrograde atrial activation exclusively over the left-sided pathway after retrograde block in the right accessory pathway. Anterograde (bystander) conduction over the right-sided pathway is not evident even though the cycle length of tachycardia exceeds the anterograde refractory period of this pathway (290 msec).
atrial pacing rate sustaining conduction over the right anteroseptal pathway.

The latter could be explained by concealed retrograde conduction into the right anteroseptal pathway, and this was supported by the demonstration (by the extrastimulus technique) of retrograde concealment into the accessory pathway in this patient. Similar observations were made in a second patient (patient 23) with two accessory pathways.

**Discussion**

Concealed conduction has been described in most cardiac tissues and has been postulated as an explanation for certain manifestations of arrhythmias in patients with WPW syndrome. We have shown that concealed conduction can be demonstrated with the extrastimulus technique in the majority of a referred population of patients with WPW syndrome. The measurement ΔERP_{av} appears to be a meaningful measure of the effective refractory period of the accessory pathway following an impulse that has concealed in the atrioventricular pathway.

Two observations were made during atrial fibrillation in our patients. First, when both preexcited and normal complexes were present, normal and preexcited QRS complexes were not randomly interspersed but rather runs of consecutive preexcited QRS complexes alternated with runs of consecutive normal QRS complexes.\(^3\)\(^4\) This phenomenon was universally observed in patients demonstrating both normal and preexcited QRS complexes and is best explained by repetitive retrograde concealment into the accessory pathway after establishment of normalization and, conversely, repetitive retrograde concealment into the normal atrioventricular conduction system after preexcitation is established. Second, the ventricular response during preexcited QRS complexes was markedly irregular, with long R-R intervals considerably greater than the average being a universal observation. If conduction over accessory pathways is "all or none," the latter can only be explained by the irregularity and inhomogeneity of atrial wavefronts approaching the accessory pathway.\(^3\)\(^4\) However, the demonstration of partial conduction over the accessory pathway supports the role of concealed conduction in explaining the irregularity of the ventricular response during atrial fibrillation.\(^3\)\(^4\)

To test the latter hypothesis, we compared LRR - SRR (a measure of variability of R-R intervals over the accessory pathway during atrial fibrillation) with ΔERP_{av} (our derived measure of anterograde concealment reflecting apparent prolonged refractoriness after concealment into the accessory pathway). The excellent and highly significant correlation between the two suggests that the LRRs observed during atrial fibrillation are indeed related to anterograde concealment into the accessory pathway. In agreement with previous reports,\(^3\)\(^4\) we found a good correlation between the SRR between preexcited beats and the ERP_{av}. However, the ARR correlated significantly with ΔERP_{av} but not with effective refractory period, further supporting the contribution of concealed conduction to the net ventricular response during atrial fibrillation. It is apparent that the average ventricular response during atrial fibrillation is an important determinant of the clinical expression of arrhythmia and that the latter is greatly influenced by concealed conduction. It is possible that a measure of concealment may be a useful predictor of prognosis in patients with WPW in the event of atrial fibrillation. Although the SRR between preexcited beats has been felt to be an important determinant of possible mortality in patients with WPW syndrome,\(^4\) some patients manifest infrequent SRRs between preexcited beats with a generally slow average ventricular response. The average rate may be limited by concealed conduction into the accessory pathway in these patients and they may be at decreased risk for ventricular fibrillation.

Repetitive concealed conduction into an accessory pathway has been postulated as an explanation for the absence of "bystander" accessory pathway participation in patients with tachycardia mechanisms not involving their accessory pathways.\(^8\) This phenomenon was observed in two of our patients with multiple accessory pathways in which the accessory pathway not involved in the orthodromic tachycardia mechanism was not apparent during the tachycardia in spite of the fact that the refractory period of the accessory pathway should have permitted bystander participation. Retrograde concealment by the extrastimulus technique could be readily demonstrated in both of these patients and this fact supports the role of concealed conduction in bystander phenomena. This has potentially important implications for the surgical ablation of accessory pathways,\(^15\) when a second unsuspected accessory pathway may become "apparent" after ablation of the first.

Concealed conduction into the accessory pathway may be a determinant of the type of echo zone observed during atrial extrastimulus testing.\(^16\)\(^17\) Pritchett et al.\(^17\) observed that the upper limit of the echo zone during atrial extrastimulus testing may begin concurrently with loss of preexcitation (type 2 echo zone) or that the upper limit of the echo zone may only begin at coupling intervals shorter than the effective refractory
period of the accessory pathway (type 3 echo zone). They suggested that the minimum echo time had to be greater than the functional refractory period of the atrium near the accessory pathway and, when this was not the case, echoes only appeared at shorter coupling intervals after greater atrioventricular nodal delay had been attained (that is, the type 3 echo zone). However, in some patients, the atrial functional refractory period was sufficiently short to permit return of the echo after block was observed in the accessory pathway and still return of the echo was not observed. Concealed anterograde conduction in the accessory pathway was postulated in these instances. A type 3 echo zone was observed in 11 of our 26 patients, and in 10 of these, concealed conduction into the accessory pathway could be demonstrated by the extrastimulus technique, lending support to the hypothesis that concealed conduction into the accessory pathway may be a determinant of the upper limit of the echo zone during atrial extrastimulus testing.

Although conduction over accessory pathways is generally considered to be all or none, rate-dependent or "decremental" conduction over accessory pathways has been described.11 18 It has been suggested that this behavior may reflect a different morphologic substrate than commonly encountered in most WPW patients. In one patient we were able to demonstrate prolongation of conduction time over the accessory pathway only after concealment of a nontransmitted impulse. At all other times during the study, this patient demonstrated a constant ventriculoatrial conduction time, the pathway conducting in an all-or-none fashion. It is thus possible that concealed conduction may result in rate-dependent conduction in tissue that otherwise shows no evidence of "decremental" conduction.

Although we have shown that both anterograde and retrograde concealment into accessory pathways can be demonstrated, our study has several limitations. First, it may be impossible to demonstrate concealment due to technical factors such as the occurrence of atrial or ventricular refractoriness before block in the accessory pathway and the occurrence of repetitive responses and echo beats. Second, it is difficult to quantify concealment in a meaningful way to enable comparisons between patients. The ERP₄₈ is only an independent reflection of accessory pathway concealment if block after the atrial extrastimulus (A₂) occurs over the accessory pathway at shorter coupling intervals than block in the atrioventricular node. The ERP₄₈ is dependent on conduction of the atrial extrastimulus (A₂) over the normal atrioventricular conduction system as well as retrograde concealment into the accessory pathway. Indeed, a contribution of anterograde concealment to ERP₄₈ cannot be ruled out.

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References
Concealed conduction in accessory atrioventricular pathways: an important determinant of the expression of arrhythmias in patients with Wolff-Parkinson-White syndrome.

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