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A New Electrocardiographic Algorithm to Localize the Accessory Pathway in Patients with Wolff-Parkinson-White Syndrome and Prospective Study of Three Electrocardiographic Algorithms Proposed for the Same Purpose

Uz. Dr. Alpay SEZER, Prof. Dr. Kâmil ADALET, Doç. Dr. Fehmi MERCANOĞLU, Doç. Dr. Ercüment YILMAZ, Doç. Dr. Zehra BUĞRA, Prof. Dr. Kemalettin BÜYÜKÖZTÜRK, Prof. Dr. Güngör ERTEM

İstanbul Üniversitesi, İstanbul Tıp Fakültesi, Kardiyoloji Anabilim Dalı, İstanbul

ÖZET

WOLFF-PARKINSON-WHITE SENDROMLU HASTALARDA AKSESUAR YOLUN EKG İLE LOKALİZASYONUNU SAĞLAYAN YENİ BİR AKIM ŞEMASININ OLUŞTURULMASI VE AYNI AMAÇLA ÖNERİLMİŞ OLAN ÜÇ AKIM ŞEMASININ SINANMASI

Çalışmamızın amacı, Wolff-Parkinson-White (WPW) sendromlu hastalarda aksesuar yolun (AY) sinus ritmindeki yüzeyel EKG ile lokalizasyonunu sağlayacak yeni bir akım şemasını radyofrekans kateter ablasyonu (RFA) kılavuzluğunda oluşturmak ve aynı amaçla önerilmiş olan diğer akım şemalarının başarısını sınamaktır. Çalışmaya tek atriyoventriküler AY'u olan ve yüzeyel EKG'de "manifest" ya da "intermittent" preeksitasyon gösteren WPW sendromlu 65 hasta alındı. EKG'de yetersiz preeksitasyon (QRS genişliği ≤100 ms) saptanan ve RFA işlemi başarısız olan hastalar çalışma dışı bırakıldı. AY mitral ve triküspid annuluslar etrafında belirlenen 8 anatomik bölgeden birine lokalize edildi. EKG'ler QRS kompleksi polaritesi, delta dalgası polaritesi ve QRS kompleksi amplitüdü açısından incelendi ve AY bölgeleri arasında ayrım sağlayan kriterler belirlendi. En yüksek başarıyı sağlayan kriterler bir araya getirilerek bir akım şeması oluşturuldu. Yeni akım şeması ile AY hastaların %92'sinde 7 farklı bölgeden birine doğru olarak lokalize edildi. Ancak sağ ve sol posteroseptal yolları EKG ile birbirlerinden ayırmak mümkün olmadı. Başka araştırmacılar tarafından önerilmiş olan üç farklı akım şemasının başarısı aynı hastaların EKG'leri ile sınandı. Bu akım şemaları ile AY'ların sırasıyla %87, %91 ve %93'ünün doğru lokalize edildiği bildirilmiş olmasına karşın, serimizde doğru lokalizasyon oranları sırasıyla %72, %74 ve %62 düzeylerinde kaldı. Sonuç olarak, oluşturduğumuz yeni EKG akım şemasının RFA işlemine kılavuzluk edebilecek bir noninvazif yöntem olduğu, fakat prospektif bir seride sınanarak yüksek başarı oranının teyit edilmesi gerektiği kanısına varıldı. Diğer üç akım şeması ile elde ettiğimiz sonuçlara benzer şekilde, bizim akım şemamızın da farklı bir hasta grubunda daha düşük başarı göstermesi beklenebilir.

Anahtar kelimeler: *Wolff-Parkinson-White sendromu, yüzeyel EKG, akım şeması, radyofrekans kateter ablasyonu*

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Yazışma adresi: Prof. Dr. Kamil Adalet Eski Londra Asfaltı, İpek Sok., Emlak Konut Sitesi, B4 Blok, D: 5, Bahçelievler 34591, İstanbul
Tel.: (0 212) 531 13 56 Faks: (0 212) 296 86 98

Currently, radiofrequency catheter ablation (RFA) is the first choice for curative treatment of patients with Wolff-Parkinson-White (WPW) syndrome (1-4). The success of this procedure depends on precise location of the accessory pathway (AP). Evaluation of the surface electrocardiogram (ECG) can be the first step to determine the AP location. After application of the RFA as a treatment modality for the patients with WPW syndrome, some electrocardiographic algorithms were proposed to localize the AP to one of eight or nine anatomical zones around the mitral and tricuspid annuli [5-7]. The data obtained from the surface ECG can be helpful in planning and shortening the RFA procedure. The aims of this study were to form a new algorithm under the guidance of RFA to localize the AP in patients with WPW syndrome using the surface ECG during sinus rhythm, and to determine the prospective accuracy of three different electrocardiographic algorithms proposed by Fitzpatrick et al [5], D'Avila et al [6] and Chiang et al [7] for the same purpose.

METHODS

Patients: Sixty-five consecutive patients (23 females, 42 males; mean age 37±12 years) with WPW syndrome, who have only one atrioventricular AP and manifest (56 patients) or intermittent (9 patients) preexcitation on the sur-

face ECG were included in the study. The exclusion criteria were inadequate preexcitation (QRS duration ≤100 ms) and an ultimately unsuccessful RFA procedure. None of the patients had previous myocardial infarction. There were 2 patients with hypertrophic obstructive cardiomyopathy and 2 patients with Ebstein's anomaly. Other patients were free of structural heart disease. A verbal or written informed consent was obtained from all patients. The study protocol was approved by the local ethics committee of our institution.

Electrocardiographic data: After a wash-out period of at least 5 half-lives for all antiarrhythmic drugs, 3-channel simultaneous ECG recordings (paper and speed 25 mm/s, calibration 1 cm/1 mV) were obtained in all patients during sinus rhythm before electrophysiologic study. The maximal QRS duration of each ECG was measured. If more than one ECG of a particular patient was present, the more preexcited one (the ECG with greater QRS duration) was chosen for the analysis. Also, the most preexcited QRS complex at each lead was analyzed. The analyzed ECG parameters were QRS complex polarity, delta wave polarity and QRS complex amplitude. QRS complex polarity was classified as positive, negative and isobiphasic. A QRS complex was defined as positive, when the deflections above the baseline were larger than the deflections under the baseline. It was considered as a negative complex when the contrary occurred. Equal positive and negative amplitudes was the criterion for an isobiphasic complex. QRS complex amplitude was defined as the difference between the positive and negative amplitudes in milivolts. Delta wave polarity was classified as positive, negative, biphasic or isoelectric [7]. Examples for this definition are shown in Figure 1.

Electrophysiologic study and radiofrequency catheter ablation: All patients underwent electrophysiologic study and successful RFA after giving informed consent. Techniques of these procedures in patients with WPW syndrome have been described previously [8]. Transvenous atrial approach through the femoral vein was used for the ablation of right-sided pathways. If successful ablation could not be performed through this route, basilic or subclavian veins were used to reach the right atrium. The ablation of left-sided pathways including left posteroseptal pathways was performed with retrograde arterial approach. In case of failure with this technique, the AP was ablated using antegrade transseptal approach. The radiofrequency current was not delivered in the coronary sinus. A local electrogram showing the AP potential or continuous activity or an A-V interval shorter than 40 ms with V wave at least 5 ms earlier than the delta wave indicated a good site for energy delivery.

Location of the accessory pathway: The position of the ablation catheter at the successful ablation site was recorded in posteroanterior, 30 degrees right anterior oblique and 45 degrees left anterior oblique projections. The successful ablation sites, which show the locations of the APs, were grouped into eight anatomical zones around the mitral and tricuspid annuli (Figure 2): Anteroseptal, midseptal, right posteroseptal, left posteroseptal, left anterolateral, left posterolateral, right anterolateral and right posterolateral. Five of these AP sites including anteroseptal and midseptal regions are right-sided and three of them are left-sided. Anteroseptal and midseptal pathways were defined as right-sided because they were ablated on the right side of the heart.

Formation of the algorithm: Our goal was to form an ECG algorithm depending mainly on QRS complex polarity as the ECG parameter. Delta wave polarity and QRS complex amplitude were considered as assisting ECG parameters. Therefore, a three step ECG analysis was performed. At the first step, all 12 leads of the ECGs were reviewed to find out different QRS complex polarity patterns able to distinguish between the eight predetermined anatomical locations of the APs. The most reliable and powerful criteria were used to form an algorithm (Algorithm 1). At the second step, the same analysis was performed for delta waves and the algorithm was revised with delta wave polarity criteria to increase its success rate (Algorithm 2). The third step was planned as a limited ECG analysis, which depends on the results obtained with Algorithm 2. If Algorithm 2 was found to be inadequate for discriminating between some AP locations, the related ECGs were analyzed for QRS complex amplitude criteria, which could be integrated into the algorithm.

Prospective study: Three different electrocardiographic algorithms proposed by Fitzpatrick [5], D'Avila [6] and Chiang [7] to localize the AP in patients with WPW syndrome, were tested prospectively with the same 65 ECGs. These three algorithms rely on different ECG parameters and the anatomical positions of the APs were also defined differently in each algorithm. In D'Avila's algorithm (6), QRS complex polarity in four leads and QRS morphology in one lead should be analyzed to differentiate between 8 AP sites (anteroseptal, midseptal, posteroseptal, left lateral, left posterior, left parasental, right lateral and right parasseptal). Chiang's algorithm [7] involves R/S ratio in two leads and delta wave polarity in three leads as the ECG parameters and discriminates between 9 AP zones (right anteroseptal/anterior, midseptal, right posteroseptal, left posteroseptal, left lateral/anterolateral, left posterior/posterolateral, right anterolateral, right lateral and right posterior/posterolateral). Many different ECG parameters are included in Fitzpatrick's algorithm [5] to distinguish between 18 AP sites: the QRS transition zone in chest leads, the sum of the polarities of the delta waves in leads II, III and

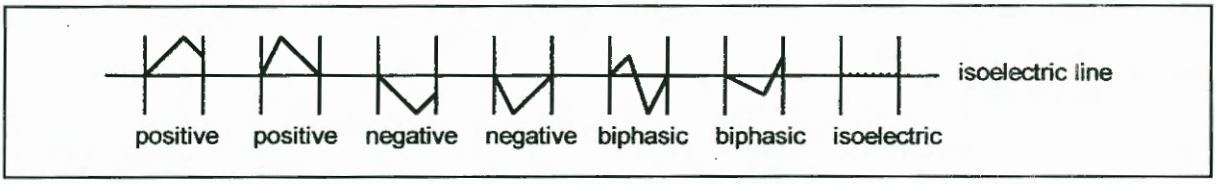
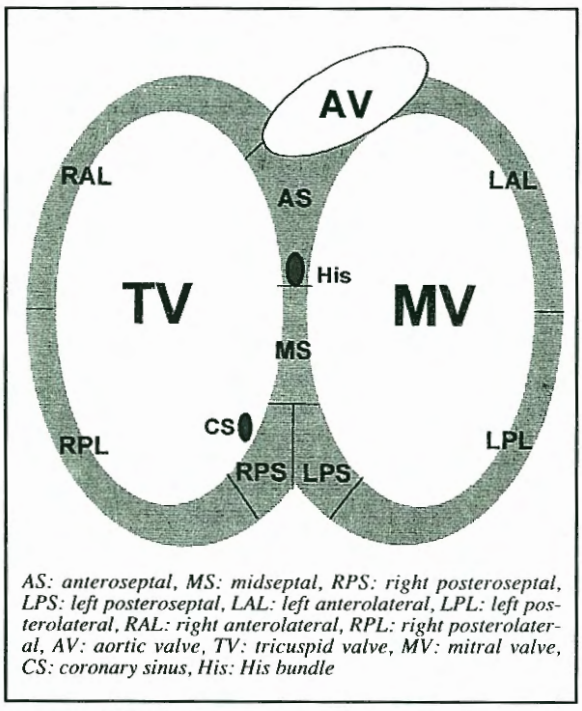


Figure 1. Classification of delta wave polarity. The vertical lines show the beginning of the delta wave and the end of the delta wave defined as the onset of rapid depolarization; but they do not indicate a fixed period.



AS: anteroseptal, MS: midseptal, RPS: right posteroseptal, LPS: left posteroseptal, LAL: left anterolateral, LPL: left posterolateral, RAL: right anterolateral, RPL: right posterolateral, AV: aortic valve, TV: tricuspid valve, MV: mitral valve, CS: coronary sinus, His: His bundle

Figure 2. Anatomical localizations of the accessory pathways

aVF, delta wave frontal plane axis, relative amplitude of the R versus S wave in leads aVL and I, R wave amplitude in lead III and delta wave amplitude in lead II. The anatomical positions of the AP sites were the same as in our study (Figure 2); but anteroseptal and midseptal regions were named as right anteroseptal and right midseptal in this algorithm [5].

Statistical analysis: Results are expressed as mean ± SD. The sensitivity, specificity and diagnostic efficiency of each ECG criterion for differentiation between AP sites were calculated. Also, the sensitivity, specificity, positive predictive value and diagnostic efficiency of the new algorithm for each AP location were determined. The accuracy of the prospectively tested algorithms in our serial and their sensitivity for each AP location were calculated. The effect of the degree of preexcitation on the accuracy of the algorithms were analyzed by two different methods: First, Student t-test and Mann-Whitney U test were used to compare the QRS duration of the mislocated pathways with the correctly located pathways. Second, chi-square test was used to compare the success of the algorithms in patients with different degree of preexcitation; that is patients with a QRS duration ≤110 ms versus >110 ms, ≤115 ms versus >115 ms, ≤120 ms versus >120 ms, ≤130 ms versus > 130 ms and ≤140 ms versus >140 ms. A p value <0.05 was considered as statistically significant.

RESULTS

QRS durations and pathway locations: The mean QRS duration of the 65 ECGs was 127±15 ms. There were 36 right-sided and 29 left-sided pathways (QRS duration 130±15 ms and 123±14 ms, respectively). Of the 36 right-sided pathways, 8 (12%) were anteroseptal (QRS duration 132±19 ms), 2 (3%) were midseptal (QRS duration 115±7 ms), 12 (18%) were right posteroseptal (QRS duration 124±9 ms), 3 (4%) were right anterolateral (QRS duration 126±11 ms) and 11 (17%) were right posterolateral (QRS duration 138±17 ms). Of the 29 left-sided pathways, 4 (6%) were left posteroseptal (QRS duration 137±15 ms), 16 (%25%) were left anterolateral (QRS duration 120±12 ms) and 9 (14%) were left posterolateral (QRS duration 122±14 ms).

Electrocardiographic analysis and formation of the algorithm:

QRS complex polarity: Reliable and powerful QRS complex polarity criteria which can differentiate between AP locations or location groups are shown in Table 1. Of these criteria, the most accurate ones were used to establish Algorithm 1 (Figure 3). Lead V_1, which can be used to differentiate left free wall pathways from right free wall and septal pathways, was placed at the beginning of the algorithm. A positive or isobiphasic QRS complex in lead V_1 was present in 88% of left free wall pathways; but among right free wall and septal pathways, only one left posteroseptal pathway showed a positive QRS complex in lead V_1 (specificity 97.5%). QRS complex polarity in lead III was used to distinguish between left anterolateral and left posterolateral pathways. All left anterolateral pathways demonstrated positive QRS complex polarity and 8 of left posterolateral pathways showed negative (7 pathways) or isobiphasic (1 pathway) QRS complex polarity in this lead.

The right arm of the algorithm was more complicated (Figure 3). It included left free wall pathways with a negative QRS complex in lead V_1 (2 left anterolateral and 1 left posterolateral), right free wall and septal pathways. Lead III was used to discriminate left anterolateral and anteroseptal pathways from the other pathways. A positive QRS complex in lead III was present in all left anterolateral pathways and in 7 of 8 anteroseptal pathways. One anteroseptal pathway showed a isobiphasic QRS complex and all midseptal, posteroseptal and right free wall pathways had a negative QRS complex in lead III. Lead

Table 1. Accurate QRS complex polarity criteria of the surface ECG which can be used to discriminate between accessory pathway locations or location groups.

Accessory pathway location	ECG criteria*	Sensitivity (%)	Specificity	Diagnostic efficiency (%)
LFW vs septum and RFW	V1(+/+)	88	97.5	93.8
AS and LAL vs other APs	III (+)	95.8	97.6	69.9
LAL vs other APs	aVL(-/+)	87.5	93.9	92.3
PS vs RFW	II(-)	75	85.7	80
PS vs RFW	V_2(+)	100	71.4	86.7
AS vs MS and PS	III(+/+)	100	100	100
PS vs As and MS	II(-)	75	100	84.6
PS vs AS and MS	aVF(-)	100	100	100
PS vs AS and MS	V_2(+)	100	80	92.3
LAL vs AS	aVL(-/+)	87.5	62.5	79.2
LAL vs AS	V_2(+)	100	87.5	95.8
LAL vs LPL	III(+)	100	88.9	96
LAL vs LPL	aVF(+)	100	66.7	88
RAL vs RPL	aVF(+)	100	90.9	92.9

LFM: left free wall, RFW: right free wall, AP: accessory pathway, PS: posteroseptal, /: or, (+): positive QRS complex, (±): isobiphasic QRS complex, (-): negative QRS complex, vs: versus, other abbreviation as in Figure 2.
**The polarity of the QRS complex shown in parentheses reflects the criterion which locates the AP to the former anatomical region(s) indicated in that row.*

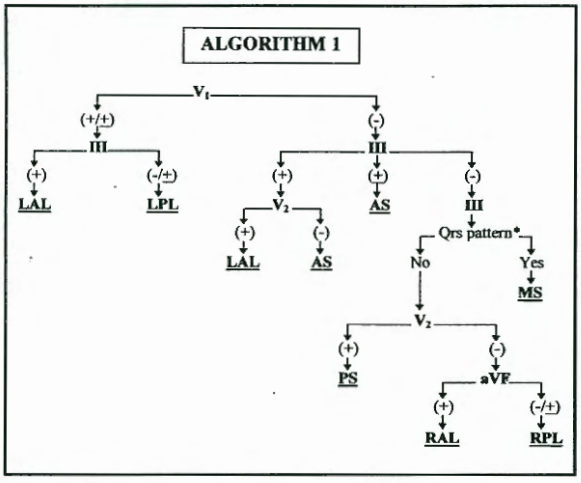


Figure 3. A new algorithm to localize the accessory pathway in patients with WPW syndrome by analyzing QRS complex polarity in only four leads and QRS morphology in one lead on the surface ECG during sinus rhythm. (*Qrs pattern was originally described by D'Avila et al (6); abbreviations as in Figure 2 and Table 1).

V_2 was used to differentiate left anterolateral pathways from anteroseptal pathways because all left anterolateral pathways demonstrated a positive QRS complex and all anteroseptal pathways except one had a negative QRS complex in lead V_2.

A QRS complex polarity criterion which was able to differentiate midseptal pathways from posteroseptal and right free wall pathways could not be found. But the "Qrs pattern" (a deep "Q" wave followed by a "r" wave and a "s" wave) in lead III, which was originally described by D'Avila et al [6] in midseptal pathways, was present on the ECGs of our two patients with midseptal pathways. Therefore, this criterion was integrated into our algorithm. Lead V_2 was used to discriminate between posteroseptal and right free wall pathways. All posteroseptal pathways showed positive QRS complex polarity and 10 of 14 right free wall pathways demonstrated negative QRS complex polarity in this lead.

Four right posterolateral pathways, which were located in the paraseptal region of the right free wall, had a positive QRS complex in lead V_2. At the final step, the differentiation between right anterolateral and right posterolateral pathways was made using lead aVF. All right anterolateral pathways had a positive QRS complex and 10 of 11 right posterolateral pathways showed a negative (9 pathways) or isobiphasic (1 pathway) QRS complex in this lead. A QRS complex polarity criterion which can differentiate between left posteroseptal and right posteroseptal pathways was not present.

Fifty-seven (87.7%) of the 65 APs were located correctly with Algorithm 1. The eight mistakes included

Table 2. Sensitivity, specificity, positive predictive value and diagnostic efficiency of Algorithm 1 for each AP location.

Accessory pathway location	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Diagnostic efficiency (%)
Anteroseptal	88	100	100	98
Midseptal	100	100	100	100
Posteroseptal	94	92	79	92
Left anterolateral	100	96	89	97
Left posterolateral	89	98	89	97
Right anterolateral	100	98	75	98
Right posteroleteral	55	100	100	92

Table 3. Delta wave polarity criteria of the surface ECG which can be used to discriminate between accessory pathway locations or location groups.

Accessory pathway location	ECG criteria*	Sensitivity (%)	Specificity	Diagnostic efficiency (%)
LFW vs septum and RFW	I(-/+)	97.5	64	86.2
LFW vs septum and RFW	aVL/-/+)	72	90	83.1
AS and LAL vs other APs	III(+)	91.7	87.8	89.2
AS vs MS and PS	III (+)	100	100	100
PS vs AS and MS	aVF(-/bf)	81.3	100	88.5
RPS vs LPS	II(+/±)	66.7	75	68.8
RPS vs LPS	V1 (-)	50	100	62.5
LAL vs AS	aVL(-)	81.3	87.5	83.3
LAL vs LPL	III (+)	87.5	66.7	80
LAL vs LPL	aVL(-)	81.3	88.9	84
LAL vs LPL	aVF(+)	87.5	66.7	80
RAL vs RPL	aVF(+)	100	90.9	92.9

(+): positive delta wave, (±): isoelectric delta wave, (-): negative delta wave, bf: biphasic delta wave, other abbreviations as in Figure 2 and Table 1.
**The polarity of the delta wave shown in parentheses reflects the criterion which locates the AP to the former anatomical region(s) indicated in that row.*

1 anteroseptal pathway located to the left anterolateral region, 1 left posteroseptal pathway located to the left posterolateral region, 1 left posterolateral pathway judged to be a left anterolateral pathway, 4 right posterolateral pathways misdiagnosed as posteroseptal pathways and 1 right posterolateral pathway located to the right anterolateral region. Seven of these 8 mislocations were in the neighbouring AP sites. The sensitivity, specificity, positive predictive value and diagnostic efficiency of Algorithm 1 for each AP location are shown in Table 2. The sensitivity for right posterolateral pathways was relatively low.

Delta wave polarity: Delta wave polarity criteria which can discriminate between AP locations or location groups are shown in Table 3. A reliable and powerful delta wave polarity criterion to distinguish between right and left posteroseptal pathways could not be found. In addition, none of these criteria were more accurate than related QRS complex polarity criteria (Table 1). The statistical power of delta wave polarity and QRS complex polarity criteria was similar for differentiation of anteroseptal pathways from midseptal and posteroseptal pathways, and right anterolateral pathways from right posterolateral pathways (Table 1 and Table 3). All right anterolateral pathways had a positive delta wave and 10 of 11 right posterolateral pathways showed a negative or biphasic delta wave in lead aVF. The integration of this lead aVF criterion in the algorithm formed Algorithm 2 (Figure 4). The combined use of QRS complex polarity and delta wave polarity criteria in lead aVF prevented incorrect location of one right posterolateral pathway to right anterolateral region and increased the success rate of the algorithm to 89.2%.

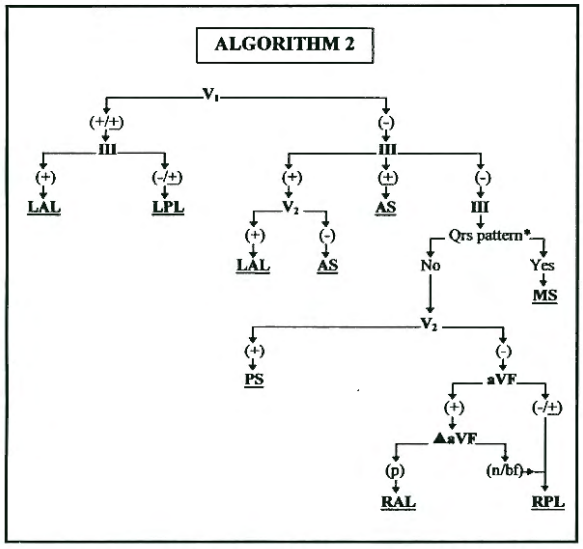


Figure 4. The new algorithm after integration of the delta wave polarity criterion in lead aVF. (*Qrs pattern was originally described by D'Avila et al (6): aVF: delta wave in lead aVF, '(p): positive delta wave, (n): negative delta wave, (bf): biphasic delta wave, other abbreviations as in Figure 2 and Table 1.)

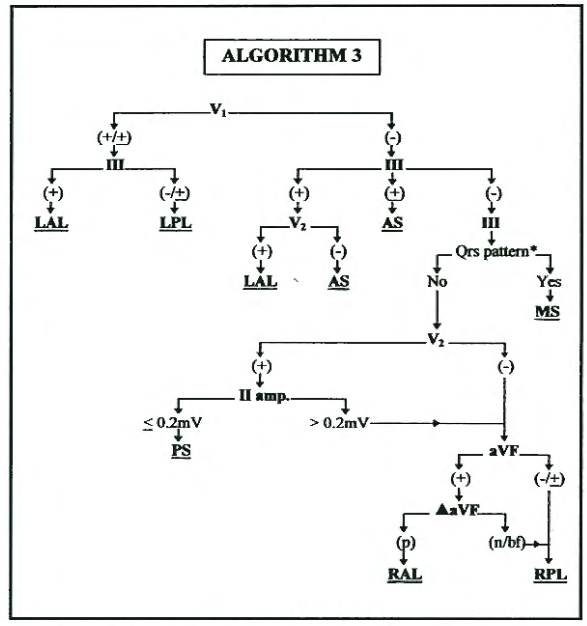


Figure 5. The new algorithm after integration of the QRS complex amplitude criterion in lead II. (*Qrs pattern was originally described by D'Avila et al (6); II amp.: QRS complex amplitude in lead II, mV: milivolt, other abbreviations as in Figure 2, Table 1 and Figure 4.)

QRS complex amplitude: QRS complex amplitude analysis was carried out in patients with right anterolateral, right posterolateral, right posteroseptal and left posteroseptal pathways. The aims of this analysis were to find criteria which can differentiate between right and left posteroseptal pathways, and between right free wall and posteroseptal pathways. The former could not be achieved, but the latter was accomplished using QRS complex amplitude in lead II. The QRS complex amplitude in lead II was ≤0.2 mV in 15 of 16 posteroseptal pathways and >0.2 mV in 11 of 14 right free wall pathways. When this criterion was used together with QRS complex polarity in lead V_2, 1 instead of 4 right posterolateral pathway was misdiagnosed as a posteroseptal pathway; however a new error appeared: A right posteroseptal pathway was mislocated to right posterolateral region. Nevertheless, this last revision in the algorithm decreased the number of mislocations to five and increased the sensitivity of the algorithm to 92.3%. Four of the 5 mislocations were in the neighbouring AP sites. The exception was the anteroseptal pathway of a patient with Ebstein's anomaly located to left anterolateral region. The pathways of the other three patients with structural heart disease were located correctly with the new algorithm.

The revised algorithm (Algorithm 3) is shown in Figure 5. The sensitivity, specificity, positive predictive value and diagnostic efficiency of Algorithm 3 for each AP location are summarized in Table 4. The success of Algorithm 3 was similar for patients with differents degrees of preexcitation. In addition, a significant difference between the QRS duration of the misdiagnosed pathways and the remaining pathways was not present.

Prospective study: Although the reported success rates of the algorithms of Fitzpatrick (5), D'Avila (6) and Chiang (7) were 87%, 92% and 93%, respectively, these algorithms demonstrated lower success rates in our study group (72%, 74% and 62%, respectively).

Fitzpatrick's algorithm: Fourty-seven (72.3%) of 65 APs were located correctly with this algorithm. Eleven (61%) of the 18 mislocations were in the neighbouring AP sites. One right-sided pathway was misdiagnosed as a left-sided pathway and 3 left-sided pathways were judged to be right-sided. The APs of three patients with structural heart disease could not be located correctly. The reported and prospectively determined sensitivities of this algorithm for each AP site are summarized in Table 5. The algorithm showed a lower sensitivity for midseptal, left posteroseptal, left posterolateral and right posterolat-

Table 4. Sensitivity, specificity, positive predictive value and diagnostic efficiency of Algorithm 3 for each AP location.

Accessory pathway location	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Diagnostic efficiency (%)
Anteroseptal	88	100	100	98
Midseptal	100	100	100	100
Posteroseptal	88	98	93	95
Left anterolateral	100	96	89	97
Left posterolateral	89	98	89	97
Right anterolateral	100	100	100	100
Right posterolateral	91	98	91	97

Table 5. The reported and prospectively determined sensitivities of Fitzpatrick's algorithm (5) for each accessory pathway site.

Accessory pathway location	Number of patients	Reported sensitivity (%)	Sensitivity in our series (%)
Right anteroseptal	8	91	88
Right midseptal	2	71	50
Right posteroseptal	12	76	75
Left posteroseptal	4	80	25
Left anterolateral	16	100	94
Left posterolateral	9	85	67
Right anterolateral	3	83	100
Right posterolateral	11	100	45

eral pathways in our study group. The results were similar for the remaining AP sites. Fitzpatrick's algorithm [5] demonstrated similar success in patients with different degrees of preexcitation. A significant difference between the QRS duration of the misdiagnosed pathways and the remaining pathways was not present.

D'Avila's algorithm: Fourty-eight (73.8%) of 65 APs were located correctly with this algorithm. The location of one anteroseptal pathway could not be determined between anteroseptal and left anterolateral regions because the QRS complex in lead aVL was isobiphasic and this possibility was not covered in the algorithm. Thirteen (81%) of the 16 mislocations were in the neighbouring AP sites. Two right-sided pathways were misdiagnosed as left-sided pathways and 1 left-sided pathway was judged to be right-sided. The AP of only one patient with structural heart disease was mislocated. The reported and prospectively determined sensitivities of this algorithm for each AP site are summarized in Table 6. The algorithm showed a lower sensitivity for anteroseptal, posteroseptal, left posterior and right paraseptal pathways in our patients. The results were similar for the remaining AP sites. D'Avila's algorithm [6] showed similar success in patients with different degrees of preexcitation. A significant difference between the QRS duration of the misdiagnosed pathways and the remaining pathways was not present.

Chiang's algorithm: Fourty (61.5%) of 65 APs were located correctly with this algorithm. Seventeen (68%) of the 25 mislocations were in the neighbouring AP sites. Eleven right-sided pathways was misdiagnosed as left-sided pathways and 2 left-sided pathways were judged to be right-sided. The APs of two patients with structural heart disease could not be located correctly. The reported and prospectively determined sensitivities of this algorithm for each AP site are summarized in Table 7. The results were similar for left lateral/anterolateral and right anterolateral pathways, but the success of the algorithm was considerably lower for the other AP sites. A statistically significant difference between the QRS duration of the misdiagnosed pathways and the remaining pathways was not present. However, the success of this algorithm was significantly lower in patients with limited preexcitation: It was 33% in 12 patients with a QRS duration of ≤110 ms and 68% in the remaining patients ($p<0.03$).

Table 6. The reported and prospectively determined sensitivities of D'Avila's algorithm (6) for each accessory pathway site.

Accessory pathway location	Number of patients	Reported sensitivity (%)	Sensitivity in our series (%)
Anteroseptal	8	92	63
Midseptal	2	50	100
Posteroseptal	16	87	69
Left lateral	16	98	100
Left posterior	8	100	13
Left paraseptal	1	82	100
Right lateral	9	100	100
Right paraseptal	5	93	60

Table 7. The reported and prospectively determined sensitivities of Chiang's algorithm (7) for each accessory pathway site.

Accessory pathway location	Number of patients	Reported sensitivity (%)	Sensitivity in our series (%)
Right anteroseptal/anterior	8	91	38
midseptal	2	83	50
Right posteroseptal	12	80	58
Left posteroseptal	4	87	25
Left lateral/anterolateral	16	98	88
Left posterior/posterolateral	9	96	67
Right anterolateral	1	90	100
Right lateral	7	90	71
Right posterior/posterolateral	6	94	17

DISCUSSION

The new algorithm: We were able to design a new ECG algorithm localizing the AP to one of seven sites around the mitral and tricuspid annuli with a success rate of 92%. This was accomplished through a three step ECG analysis, which favors the use of QRS complex polarity criteria to form the skeleton of the algorithm. Therefore, our final algorithm depends mainly on QRS complex polarity in four leads and QRS morphology in one lead; but one delta wave polarity and one QRS complex amplitude criterion were included in the algorithm to increase its success rate. Nevertheless, the integration of these delta wave polarity and QRS complex amplitude criteria increased the accuracy of our algorithm only by 4%. None of the delta wave polarity criteria was found to be more accurate than the related QRS complex polarity criteria, delta wave polarity was classified according to the more detailed definition of Chiang et al [7]. In our study, we modified this definition by finding the beginning and the end of each delta wave, instead of describing delta wave polarity as the polarity of a fixed initial part of the QRS complex. Chiang et al [7] proposed that the polarity of the initial 40 ms segment of the most preexcited QRS complex in each of the extremity leads, and the polarity of the initial 60 ms segment of the most preexcited QRS complex in each of the precordial leads represented the polarity of the delta wave in the respective leads. However, the length of the delta wave is influenced by the degree of preexcitation (9,10), and this rule may not be valid, when limited preexcitation is present. In our study group, the QRS complex polarity criteria were still superior to delta wave polarity criteria, when the original definition of Chiang et al [7] was applied or the classic definition of Gallagher [11] for delta waves was used. QRS complex polarity is easier to determine and it seems to be a more reliable ECG parameter than delta wave polarity for localization of APs.

The new algorithm was very successful in distinguishing between right-sided and left-sided pathways. The only exception was the patient with Ebstein's anomaly. The other four mislocations were in

the neighbouring AP sites. Such a mistake will not influence the plan of the RFA procedure, and therefore it is clinically insignificant. On the other hand, differentiation between right and left posteroseptal pathways is important for clinical purposes because retrograde arterial approach through the femoral artery is preferred for the ablation of the latter instead of delivering energy in the coronary sinus by using transvenous atrial approach. A major limitation of our algorithm is its incapacity for this differentiation. Under the limits of our analysis, we could not find any reliable ECG criterion fulfilling this purpose. D'Avila et al [6] had also not reported a QRS complex polarity criterion discriminating right and left posteroseptal pathways. Duckeck et al [12] suggested that delta wave polarity in lead V_1 is a good ECG parameter for this purpose and Chiang et al [7] also integrated this criterion into their algorithm. However, the diagnostic efficiency of this criterion was only 62% in our series. The complex anatomy of the posteroseptal space and the close location of right and left posteroseptal pathways to each other seem to prevent electrocardiographic discrimination of these pathways.

An important limitation of our study is the presence of only 2 (3%) patients with midseptal pathways. This small sample size precluded the determination of reliable ECG criteria for the diagnosis of midseptal pathways. The ECGs of our patients with midseptal pathways showed the "Qrs pattern" in lead III, which was originally defined by D'Avila et al [6] as a spesific finding for midseptal pathways. Thus, we integrated this criterion into our algorithm and obtained a sensitivity of 100% for the diagnosis of midseptal pathways. However, this value is misleading because in the serial of D'Avila et al [6], "Qrs pattern" was present in only 50% of the patients with midseptal pathways. Moreover, this pattern is also not spesific for midseptal pathways: We noticed it on the ECG of a patient with a left posteroseptal pathway. This left posteroseptal pathway was not mislocated to the midseptal region with our algorithm, but it was misdiagnosed as left posterolateral pathway because QRS complex polarity in lead V_1 was positive. Left posteroseptal pathways may have a positive QRS complex in lead V_1 on the surface ECG [6,13]. This possibility is not covered in our algorithm because only one such example was present in our serial and the ECG features of this left posteroseptal pathway was very similar to left posterolateral pathways. For these reasons, the overall success rate of our algorithm will probably be lower in a patient population with more midseptal and left posteroseptal pathways. Nevertheless, a substantial change should not be expected because usually less than 15% of the patients have midseptal and left posteroseptal pathways [5,7].

Prospective study: The first independent prospective evaluation of the algorithms proposed by Fitzpatrick [5], D'Avila [6] and Chiang [7] was performed in our study. These algorithms demonstrated much lower success rates in our study group compared to their reported accuracy. The sensitivity of Fitzpatrick's [5] and D'Avila's [6] algorithms was relatively lower in four of the eight AP sites (Table 5 and 6), which caused a decrease in the overall success rate of their algorithms. The reported and prospectively determined sensitivities of their algorithms were similar in the remaining AP locations. On the contrary, Chiang's [7] algorithm was less accurate in all AP sites except left lateral/anterolateral and right anterolateral regions (Table 7). The presence of few patients with midseptal, right anterolateral and left paraseptal pathways prevented a reliable interpretation of the accuracy of the algorithms for these AP sites. Beyond this limitation, the results of the prospective study can be explained in several ways:

All algorithms were based on the analysis of several ECG parameters of a patient population. The most powerful ECG criteria obtained through this analysis were put together to form the most successful algorithm. Therefore, every algorithm reflects the ECG features of that study population. However, the ECG may show great variation in patients with WPW syndrome depending on the degree of preexcitation [10,13,14]. Different degrees of preexcitation for similar AP zones in different study groups may influence the success of the algorithm. Only Fitzpatrick et al [5] reported the mean QRS duration of the ECGs for each AP site. Generally, preexcitation was more pronounced in their study group and lower sensitivity of their algorithm in right posterolateral and left posterolateral pathways may be due to the less preexcited ECGs of our patients (QRS duration 150±17 ms versus 139±18 ms for right posterolateral pathways,

133±16 ms versus 122±14 ms for left posterolateral pathways). The ECGs analyzed in Chiang's study [7] also seem to have more pronounced preexcitation compared to our study. Minimal preexcitation pattern (a term applied by Teo et al [9] to describe a 12-lead ECG, in which the maximal delta wave duration in any lead was <40 ms) was present in only 6% of the patients in Chiang's [7] study group, whereas 15% of our patients had minimal preexcitation on their ECGs.

Different interpretations when evaluating the ECG and localizing the AP with RFA are other factors which may influence the results of the prospective study. Criteria involving delta waves may be difficult to evaluate, especially in case of limited preexcitation (QRS duration ≤110 ms). Chiang's algorithm [7], which includes mainly delta wave polarity criteria, was the least successful algorithm in our series. On the other hand, D'Avila's algorithm [6], which involves only QRS complex polarity criteria except the "Qrs pattern", was the most accurate algorithm. In other words, the results of our prospective study also supports the superiority of QRS complex polarity criteria over delta wave polarity criteria. Another possible explanation for errors is the determination of AP location under fluoroscopic guidance. Real anatomical borders do not exist between AP zones, and pathways located near the borders of these regions may be the source of some misinterpretations. However, the high proportion of pathways mislocated to the neighbouring AP zones should not be taken as a proof for the high frequency of such misinterpretations because closely located APs, which lie at the opposite sides of an arbitrary border, may show similar preexcitation patterns on the 12-lead ECG, thus their electrocardiographic differentiation is also difficult. In our study, this fact was observed in the 4 right posterolateral pathways misdiagnosed as posteroseptal with Algorithm 1 due to the positive QRS complex in lead V_2. All of these right posterolateral pathways were located in the right paraseptal region and their preexcitation pattern was very similar to posteroseptal pathways.

Finally, each algorithm may involve criteria which are inadequate to discriminate between some AP locations. Three of the 4 left posteroseptal pathways were misclassified as right-sided with Fitzpatrick's algorithm [5]. The precordial QRS transition was between the leads V_1 and V_2 in these three patients. The criterion proposed for discrimination of right and left-sided pathways showing this precordial QRS transition pattern (the difference of the amplitudes of R-wave and S-wave in lead I) failed in our patients with left posteroseptal pathways. On the other hand, it was successful in the 16 of 17 other pathways (1 midseptal, 12 right posteroseptal, 2 left anterolateral, 1 left posterolateral) exhibiting the same QRS transition pattern. The only exception was the anteroseptal pathway of the patient with Ebstein's anomaly mislocated to the left anterolateral region.

Six of the 8 left posterior pathways were considered as left paraseptal pathways with D'Avila's algorithm [6] because QRS complex polarity in lead III was insufficient to differentiate between these locations. In this algorithm, a positive or isobiphasic QRS complex in lead V_1 locates the AP to the left free wall and a positive, isobiphasic or negative QRS complex in lead III discriminates the location of the AP between left lateral, left posterior and left paraseptal regions, respectively. In other words, D'Avila et al [6] halved the left posterolateral region in left posterior and left paraseptal zones and they limited the diagnosis of a left posterior pathway with the presence of equal negative and positive deflections in lead III. Such an approach does not seem to be reasonable when using a diagnostic tool which shows substantial variability due to the degree of preexcitation and the orientation of the heart within the chest (10,13,14). Chiang et al [7] reported that they could distinguish between three AP sites on the right free wall by analyzing only the delta wave polarity in lead aVF. The sensitivity of this criterion was 71% in our patients with right free wall pathways. We believe that surface ECG is not sensitive enough to define three different AP sites on the right and left free walls of the heart. Moreover, such detailed information is also not necessary to guide the RFA procedure.

Chiang's algorithm [7] was found to be significantly less accurate in patients with limited preexcitation (QRS duration ≤110 ms). Such a significant difference was not observed in the algorithms of Fitzpatrick [5] and D'Avila [6]. Limited preexcitation was

present in 12 (18%) of our patients, 6 of them had septal or right free wall pathways. In this subgroup of patients, a correct diagnosis was achieved in 4 (67%) of the 6 left free wall pathways with Chiang's algorithm, but none of the septal and right free wall pathways were located correctly. Chiang et al [7] defined delta wave polarity as the polarity of the first 40 ms of the QRS complex in extremity leads and the polarity of the first 60 ms of the QRS complex in precordial leads. Our findings indicate that this definition may be erroneous in patients with limited preexcitation. Delta waves may be hardly discernible in these patients and their duration may be shorter than 40 ms in extremity leads and shorter than 60 ms in precordial leads. Therefore, an initial fixed interval of the QRS complex may not always reflect the polarity of the delta wave. Chiang et al [7] reported that their algorithm predicted the pathways of all patients with minimal preexcitation pattern correctly, but all of these patients had left free wall pathways. Our serial included 10 patients with minimal preexcitation pattern, 4 of them had septal or right free fall pathways. In this subgroup, only 3 left free wall pathways could be diagnosed correctly with Chiang's algorithm and all of the septal and right free wall pathways were mislocated. On the other hand, the success rates of the algorithms of Fitzpatrick and D'Avila in these patients were very close to their overall accuracy: Both algorithms located 7 (70%) of these 10 pathways correctly. These data demonstrate that the value of Chiang's algorithm is questionable in patients with limited or minimal preexcitation, especially if they have a septal or right free wall pathway.

Limitations: Inadequate preexcitation, structural heart disease, skeletal abnormalities, the orientation of the heart within the chest and the position of chest electrodes are factors which can interfere with the use of the surface ECG to localize the AP (13,14). Our algorithm and the other algorithms are designed to localize only one atrioventricular pathway during sinus rhythm. They can not be used in variants of WPW syndrome and their value in patients with multipl APs and during atrial fibrillation or atrial pacing remains to be tested.

Conclusions: We concluded that our new ECG algorithm is a useful noninvasive tool to guide the RFA procedure; but a prospective study is needed to verify its high success rate. A drop in the accuracy of our algorithm should be expected in a different group of patients,as we have shown for the other algorithms. Much lower success rates of the other algorithms in our series may be due to different degrees of preexcitation for similar AP zones, different interpretations when evaluating the ECG or localizing the AP under fluoroscopic guidance, and finally the presence of some inadequate ECG criteria in each algorithm.

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