5 Supraventricular Tachycardias: How to Diagnose the Mechanism

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5.1 Case 1

F.R., a 62-year-old woman, went to the emergency department for tachycardia sudden onset. She was symptomatic for prolonged palpitations. Medical history and cardiovascular risk factors were negative, but she referred in the past years several episodes of palpitation without any recorded ECG. This time a 12-lead ECG was recorded (Fig. 5.1).

5.1.1 ECG Analysis

A narrow QRS tachycardia with regular R-R interval is present. R-R interval is 420 ms (heart rate 143 bpm). A P wave is visible and is flat in lead I, negative in inferior leads, and positive in leads aVR and aVL; P-wave axis is therefore −90°, and its duration is 40 ms. QRS complexes are 80 ms in length with a normally orientated axis in the frontal plane (+30°). PR interval is 80 ms. The P/QRS ratio is 1:1. ST segment is normal, and QTc is also normal (370 ms).

This is a clear case of supraventricular tachycardia. The differential diagnosis could be the following:

- *Sinus tachycardia*: this hypothesis can be immediately excluded because the P-wave axis (−90°) is different from that of a normal sinus P (range 0–75°).
- *Atrial tachycardia*: heart rate is compatible, but, if this hypothesis is correct, this atrial tachycardia should come from a lower part of the atrium near the interatrial septum; P waves have a concentric activation morphology (upper axis and short duration). The atrioventricular (AV) conduction is 1:1 with short PR duration (80 ms) that is not typical for this tachycardia type.
- *Atrioventricular node reentrant tachycardia (AVNRT)*: it could be an atypical AVNRT with anterograde conduction through the fast pathway and the retrograde conduction through the slow pathway (fast-slow type). This kind of circuit could well explain the RP duration longer than PR. Concentric atrial activation is also typical of AVNRT.
- *Permanent junctional reciprocating tachycardia (PJRT—Coumel tachycardia)*: this type of tachycardia is characterized by a macro-reentry circuit with anterograde conduction through the AV node and His-Purkinje system and a retrograde conduction through a slow-conductive (decremental conduction) concealed accessory pathway. Usually it has a posteroseptal localization. These ECG features (retrograde concentric P wave, P/QRS ratio 1:1, and RP greater than PR) are compatible with a PJRT.

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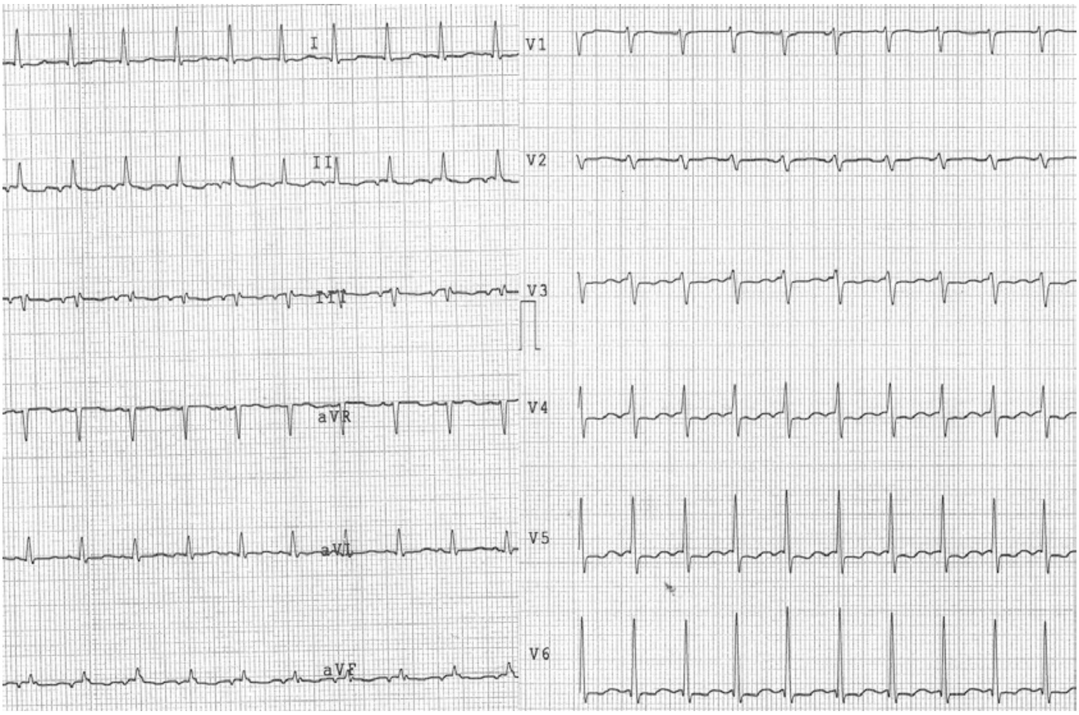

Fig. 5.1 Case 1: 12-lead ECG

Vagal maneuvers or adenosine administration may help to make a correct diagnosis during a SVT.

In this case, a carotid sinus massage was performed, and the tachycardia ended up abruptly with a QRS complex not followed by a P wave. At this point, the atrial tachycardia hypothesis could be excluded; in fact, typical response to vagal maneuvers is a transient high-grade AV block (P/QRS ratio from 1:1 to 2:1, 3:1, etc.) with contemporary persistence of the tachycardia. Only in rare cases atrial tachycardias end up with a vagal maneuver. Both atypical AVNRT and PJRT may stop during vagal maneuvers because of a block occurring within the slow pathway or in the decremental conduction accessory pathway. Therefore both of them may end with a QRS complex not followed by a P.

PJRT is a rare form of supraventricular tachycardia and is more common at a young age. Atypical AVNRT is the most valuable hypothesis in this case. However it is not possible to distinguish between these two forms only at this surface ECG. The right diagnosis was reached by an intracavitary electrophysiological study [1–3]. The atypical AVNRT (fast-slow pattern) was confirmed. The patient was treated by catheter ablation of the slow pathway.

5.2 Case 2

C. D. is a 50-year-old man with several cardiovascular risk factors (hypertension, hyperlipidemia, obesity, family history of cardiovascular disease) and was admitted to the emergency department for palpitations. A 12-lead ECG was recorded.

5.2.1 ECG Analysis

It is a narrow QRS tachycardia with regular R-R interval of 300 ms (heart rate is 200 bpm). It is possible to recognize a P wave that follows each QRS complex, more visible in leads II, III, and aVR. P wave is negative in lead I and aVL. Its length is 40 ms, and the RP interval is 100 ms (RP >70 ms). RP interval is shorter than PR interval. The P/QRS ratio is 1:1. QRS complex is narrow (80 ms) with a normally orientated axis in the frontal plane (+60°). QTc interval is 430 ms.

This is a case of supraventricular tachycardia with RP < PR. The differential diagnosis may include:

- *Sinus tachycardia*: unlikely because P-wave axis is not within 0° and 90°. Furthermore heart rate is not compatible with a simple sinus tachycardia at rest [6].
- *Atrial tachycardia*: if this hypothesis was correct, it should be possible to see more than three ectopic P waves, with regular PP intervals [7]. Any kind of P morphologies could identify an atrial tachycardia. The atrial activation is often eccentric (depending on the origin of the focus in the atria). In particular a P axis positive in the inferior leads is typical of an atrial origin of the tachycardia (with the exception of an AVRT with an anteroseptal accessory pathway). In case of appearance during the recording of a second-degree AV block, a diagnosis of atrial tachycardia (a reentrant tachycardia always conduct with a P/QRS ratio 1:1) could be more likely. In this ECG, a P wave negative in leads I and aVL makes this diagnosis unlikely.
- *Atrioventricular node reentrant tachycardia—typical (AVNRT)*: in the typical form (slow-fast), retrograde P waves are constantly related to the preceding QRS (RP<PR) and in the majority of cases are very close to the QRS complex (RP <70 ms). Indeed, P waves can be masked within the QRS or seen as a small terminal P wave that can simulate a right bundle branch block particularly in V1. In this ECG, P waves are well visible and distant from QRS; therefore the diagnosis of AVNRT is unlikely.
- *Atrioventricular reentrant tachycardia (AVRT)*: this kind of tachycardia is characterized by the presence of a P wave following a narrow QRS complex, with a RP interval longer than 70 ms. The atrial activation normally starts from the origin of the accessory pathway, which connects atria and ventricles, in a retrograde activation; P-wave morphology and axis during tachycardia depend on the circuit localization. In our ECG, it is possible to recognize all the features aforementioned. Moreover, the presence of QRS alternans (regular voltage variation >1 mm, at least 10 s after initiation of supraventricular tachycardia) is highly indicative of a retrograde accessory AV pathway included in the tachycardia circuit (Fig. 5.2) [8]. The arrhythmia was effectively interrupted by verapamil and adenosine.

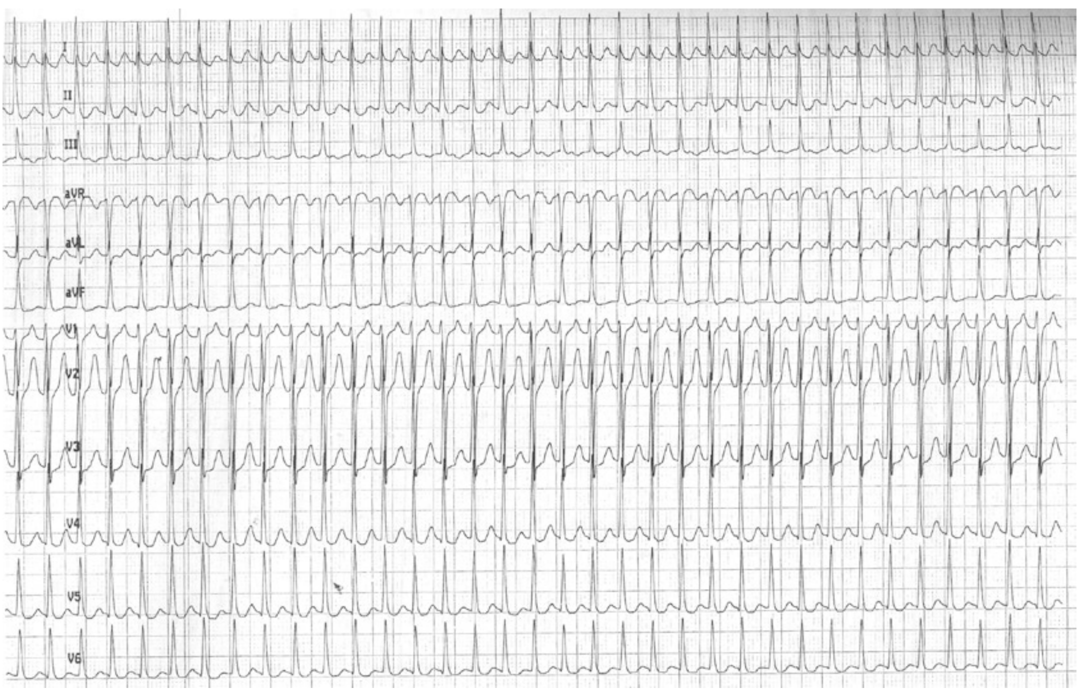

Fig. 5.2 Case 2: 12-lead ECG

An intracavitary electrophysiological study (EPS) was performed that confirmed inducibility of an orthodromic atrio-ventricular tachycardia. The localization of the accessory pathway was left lateral, as we could argue from the P-wave axis negative in lead I and aVL and positive in V1 [9].

The patient was successfully treated by radiofrequency catheter ablation of the accessory pathway.

5.3 Case 3

A 74-year-old female patient, with a history of palpitations, was admitted to ER for dyspnea at rest and palpitations. A 12-lead ECG was recorded (Fig. 5.3).

5.3.1 ECG Analysis

The ECG shows a narrow complex tachycardia with slight heart rate irregularity and a mean rate of 100 bpm. There is a regular-irregular rhythm. QRS axis is −30°. There are positive P waves in inferior leads (II, III, and aVF), in lead I, and from V3 to V6, while negative P are in aVR and V1. P-wave axis is therefore leftward and posteriorly directed. In some beats, P waves clearly precede the QRS complexes with a PR interval of 200 ms (1st, 4th, 8th, and 11th beats), while in other beats, they are inserted in the T wave of the previous ventricular complexes, either at the apex (as in the 2nd, 5th, 9th, 12th) or in the ascending part (3rd, 6th, 10th, 13th beats), with longer PR interval (of 300 and of 400 ms, respectively).

T waves of these beats have a different morphology, with sharp and nearly biphasic aspects. Looking carefully at the QRS complex of the 3rd, the 6th, the 10th, and the 13th beats, we observe a RSr' morphology that is different shape compared to the other QRS complexes. The r' is actually a deflection of QRS determined by the fusion of a P wave with the preceding QRS. Therefore PR and RP intervals are irregular, with some P waves clearly not conducted to ventricles.

PP intervals have an average duration of 460 ms with slight variations. P-wave length is 40 ms. Ventricular repolarization is normal, with a QTc of 410 ms.

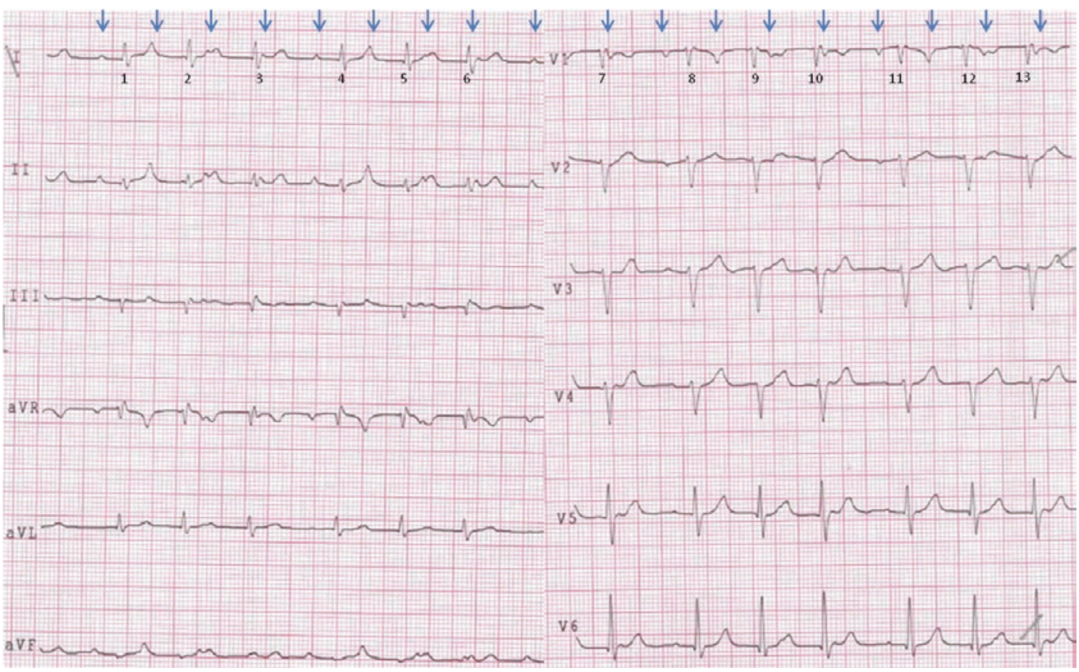

Fig. 5.3 Case 3: 12-lead ECG

This is a case of supraventricular arrhythmia, and the possible differential diagnoses are:

- *Sinus tachycardia with frequent PACs (premature atrial contractions) and PJCs (premature junctional contractions)*: this hypothesis was excluded because of the substantial regularity of PP intervals (there is only a slight variation of their length) and the absence of a real-anticipated QRS complex. R-R irregularity is due to a variable AV conduction rather than to premature beats.
- *Atrial tachycardia (AT)*: we have P waves at a rate of about 140 bpm, with a leftward and posteriorly directed axis. If this hypothesis is correct, this atrial tachycardia origins from the right atrium (negative P wave in V1) at the level of crista terminalis (negative P wave in aVR). There are irregular PR and RP intervals. By looking carefully at the PR intervals, there is a progressive prolongation until the atrioventricular (AV) conduction is blocked, and a P wave is not followed by a QRS complex (Wenckebach phenomenon). This AV relationship can be compatible with an AT.
- *Atrioventricular node reentrant tachycardia (AVNRT)*, *junctional tachycardia (JT)*, *and atrioventricular reciprocating tachycardia (AVRT)*: these hypotheses can be immediately excluded because of the irregularity of the tachycardia and the presence of a Wenckebach phenomenon. Diagnosis of reentrant or reciprocating tachycardia is unlikely.
- *Atrial fibrillation for the irregularity of the tachycardia*: it can be excluded because of presence of clear P waves in this case.

This supraventricular arrhythmia spontaneously terminated after a few minutes. The patients later underwent an electrophysiological study that showed an easy inducibility of a focal atrial tachycardia that showed an earliest depolarization point in left and right part of the interatrial septum and in the superolateral portion of the RA wall.

Focal atrial tachycardias (ATs) are characterized by atrial activations starting rhythmically within a small area (focus) outside the sinus node region, from which they spread out centrifugally. This focal activity can be caused by automaticity, triggered activity, or microreentry.

AT cycle length is usually ≥250 ms, but it can be as short as 200 ms and exhibit important variations over a certain period of observation (minutes to hours). AT ECG pattern shows typically discrete P waves at rates 130–240 bpm [10].

Focal ATs rise mainly from the right atrium (RA), and approximately two thirds of them are distributed along the long axis of the crista terminalis (from the sinus node to the coronary sinus) and the atrioventricular junction (tricuspid annulus). The pulmonary vein (PV) ostia are instead the most common sites of origin of left atrium focal tachycardias [11].

P wave morphologies can be used to localize approximately the site of the origin of the ATs. V1 and I leads are used for discriminating RA from LA origin. Leads II, III, and aVF may help to differentiate superior from inferior left atrial foci, while the P configuration in aVR can differentiate activation arising from crista terminalis from those originating from the tricuspid annulus or right atrium septum (Fig. 2.4) [6, 12, 13]. The final diagnosis is usually made through endocardial mappings.

P waves and QRS relationship depends not only from the tachycardia rate but also from the atrioventricular node conduction properties. If the rate of the tachycardia is faster than the AVN conductive capacity (e.g., in AVN disease or with a slowing conduction therapy), some of the P may be blocked, with a P/QRS ratio higher than 1 or sometimes a clear Wenckebach phenomenon [7]. This is the mechanism of Case 3.

5.4 Case 4

A 49-year-old male, with a history of recurrent paroxysmal supraventricular tachycardias (under Flecainide 100 mg/day), was admitted to our clinic with indication to perform an electrophysiology study. While in the hospital, he suddenly complained of palpitations, and a 12-lead ECG was recorded (Fig. 5.4).

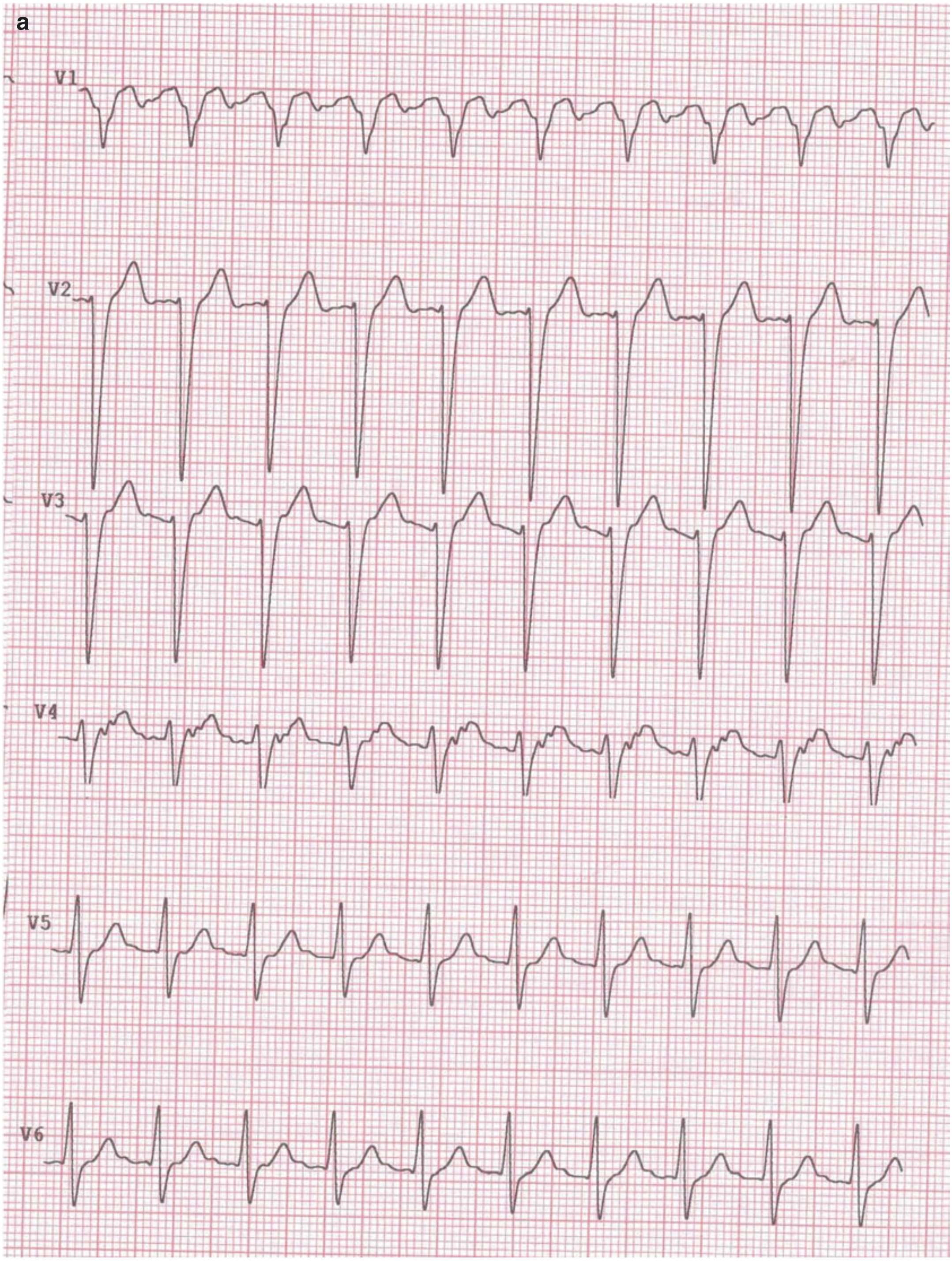

Fig. 5.4 (**a**, **b**) Case 4: 12-lead ECG

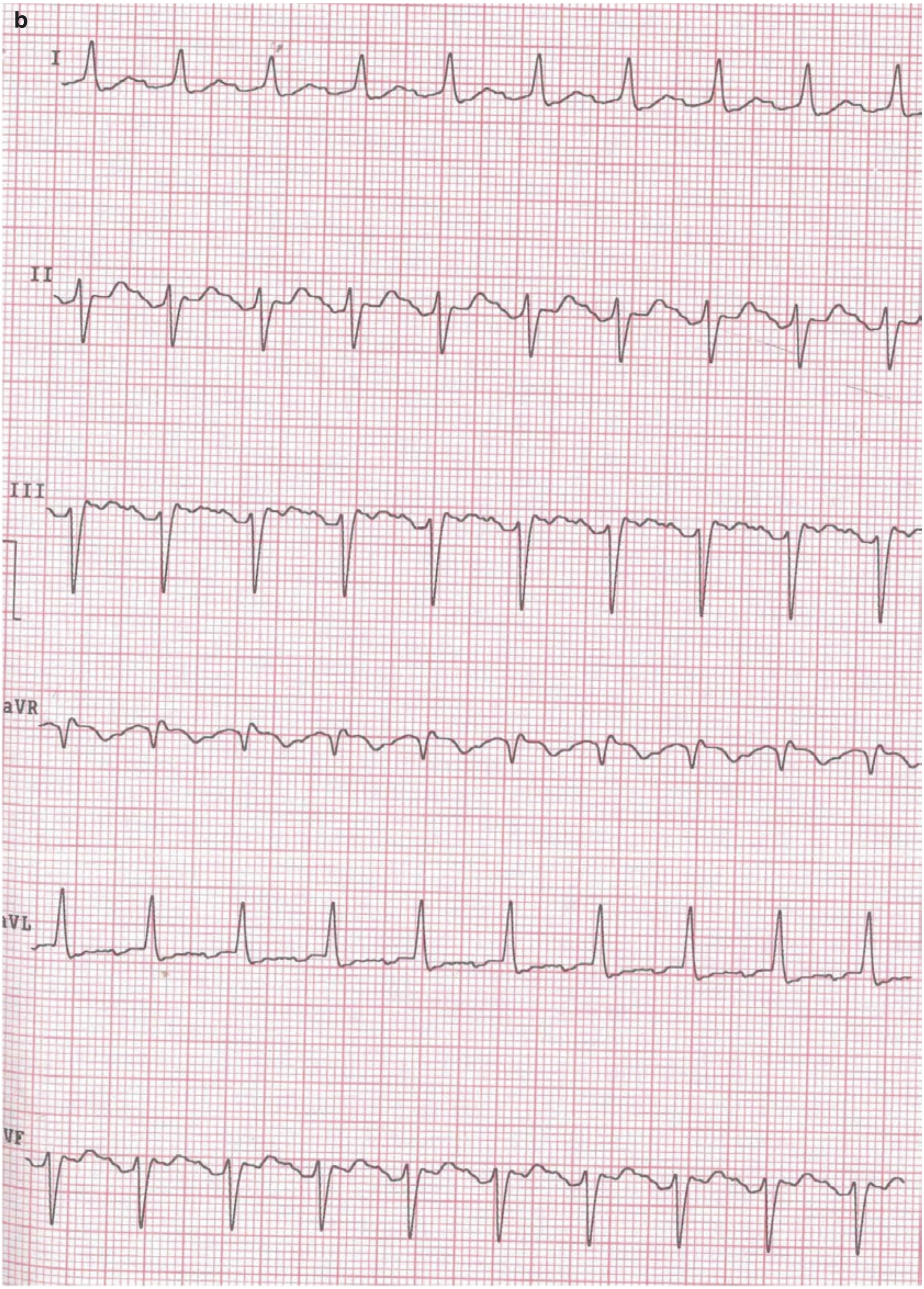

Fig. 5.4 (continued)

5.4.1 ECG Analysis

The ECG shows a narrow complex regular tachycardia with a mean heart rate of 130 bpm (R-R cycle length 450 ms). There are positive atrial waves before every QRS complex in inferior leads (II, III, aVF) and in V1, within the descending T-wave branches. We can also observe a notch within the T waves that can be interpreted as hidden atrial waves (i.e., V4 shows a notch in the ascending branch of T wave). P/QRS ratio is therefore 2:1. QRS length is slightly prolonged (110 ms); there is a left axis deviation (−45° on the frontal plane). The QRS has a qR pattern in aVR and rS in II, III, and aVF, probably secondary to the left anterior fascicular block. Ventricular repolarization is normal, and the QTc is 410 ms.

This is another narrow QRS tachycardia.

Differential diagnosis:

- *Atrial fibrillation (AF)*: it can be excluded because R-R are regular. Furthermore in this ECG, we can clearly identify the atrial activation waves, rarely present in case of AF (the atrial rate is so fast that the P waves are not identifiable, or only coarse fibrillatory waves are usually seen).
- *Sinus tachycardia*, *atrioventricular node reentrant tachycardia (AVNRT)*, *and atrioventricular reentrant tachycardia (AVRT)*: the P/QRS ratio is 2:1; therefore those hypotheses should be rejected.
- *Typical atrial flutter (AFL)*: counterclockwise AFL is characterized by pure negative deflections in the inferior leads. In clockwise (reverse typical) AFL, activation propagates in the opposite direction; therefore this time AFL generally has broad positive deflections in the inferior leads, with characteristic notching [11–15].
- *Atypical atrial flutter and atrial tachycardia*: because of the high-ventricular rate, these arrhythmias cannot be excluded.

In order to slow AV conduction and consequently better recognize the ongoing arrhythmia, adenosine 12 mg was administered. Figure 5.5 shows the ECG recorded during infusion.

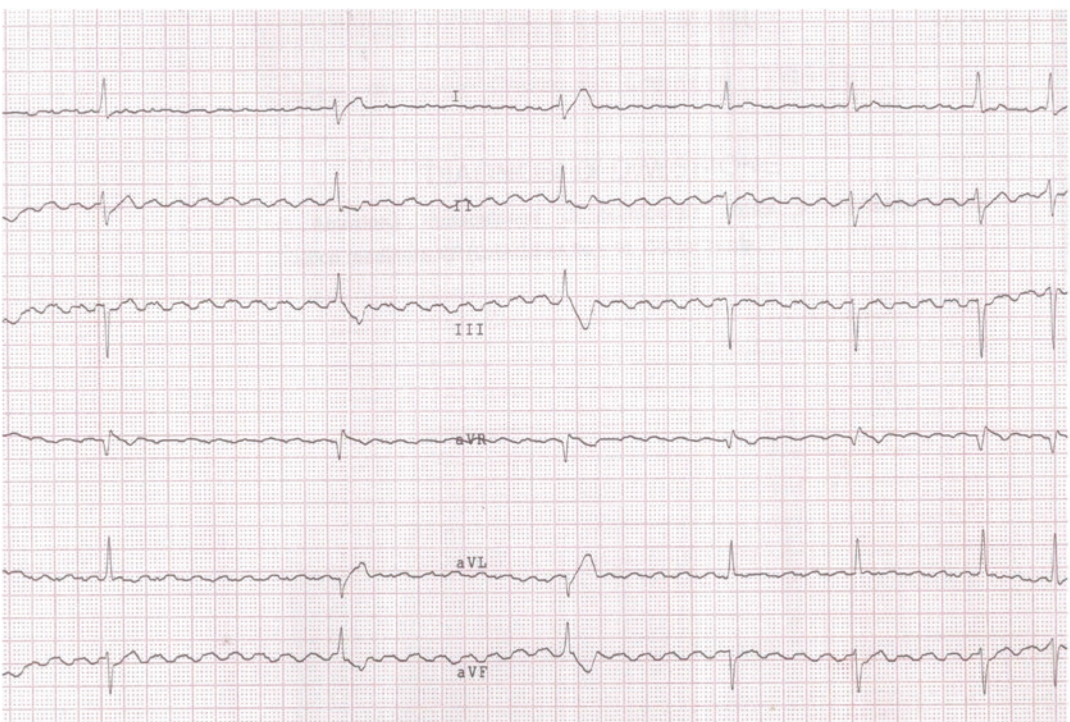

Fig. 5.5 Effect of adenosine on tachycardia

There are regular atrial activations, with a constant cycle length of almost 300 ms. The F-wave axis is positive in inferior leads. Furthermore, F waves show broad positive deflections, with notching in the ascending branch. With adenosine, AV conduction slowed abruptly down to 8:1, with wider QRS appearance and with different axis and morphology (such as ventricular escape beat). Then the arrhythmia speeded up again with a variable AV conduction (5:1, 3:1).

A diagnosis of clockwise typical atrial flutter with 2:1 AV conduction was therefore done. The QRS slight prolongation was considered to be secondary to chronic flecainide therapy.

The patient underwent successful isthmus catheter ablation and reverted to stable sinus rhythm.

5.5 Supraventricular Tachycardias: Systematically Approach to a Differential Diagnosis

In summary, a 12-lead ECG systematic approach could help us to understand the mechanisms and therefore make the correct differential diagnosis (Table 5.1).

The ECG correct analysis starts from R-R intervals, with a primary focus on the presence of regular or irregular R-R intervals. Then we should look for P waves and analyze the P/QRS ratio in order to understand a possible kind of relationship between atrial and ventricular activity. When the ratio is higher than 1:1, a primary atrial arrhythmic circuit is likely. If there is a 1:1 ratio, we can hypothesize a circuit that involves atria and ventricles. Assessing PR and RP intervals and P-wave morphology, it is possible to understand the kind of origin of atrial activation and the type of circuit. This approach is summarized in Table 5.2 [1, 4].

Other ECG features can be useful to understand the type of supraventricular tachycardia [3, 5]:

- *Effect of premature ventricular beat* (*PVB*): in PVB presence, it is important to evaluate its effect on the tachycardia cycle. If the PVB does not alter the tachycardia cycle and does not interrupt the tachycardia, an AVRT can be excluded. In this last case, the ventricle is part of the reentrant circuit, and therefore a PVB should influence at least the tachy-cycle.
- *Tachycardia onset and termination*: reentrant tachycardias have sudden onset and terminations. Instead focal tachycardias can be characterized by warm-up and cold-down phenomena with progressive heart rate increase when tachycardia starts and progressive heart rate decreases before stopping. It is of importance also the last tachycardia beat: if it is a P wave, atrial tachycardia, atrial flutter, atypical AVNRT, and, in the majority of case, PJRT could be excluded.
- *Electric alternans during tachycardia*: this is a rare phenomenon characterized by alternant QRS amplitude changes. It was initially described in orthodromic AVRT. Subsequent authors described it also in AVNRT and in rapid atrial pacing with an abrupt onset. Data suggest that electric alternans during tachycardia is a rate-dependent phenomenon due to sudden heart rate increase and does not have any precise correlation with the mechanism of a specific tachycardia. However reentrant tachycardia (AVRT and AVNRT) is characterized by a sudden onset and a heart rate higher than other supraventricular arrhythmias; that is the main reason why the electric alternans is more likely to appear in these last forms.

Table 5.1 Supraventricular tachycardia types and characteristics

Tachycardia	Mechanism	R-R interval	HR	P wave	P/QRS ratio	PR	QRS	Response to vagal maneuver
Sinus tachycardia	Increase activity of sinus node	Regular	100–180	Normal axis	Generally 1:1	Shorter than RP	Normal or conduction aberrant	Gradual slowing
Atrial tachycardia	Increase activity of ectopic focus (automaticity or microreentry)	Generally regular	75–200	Morphology related to origin	Often >1	Shorter than RP	Normal or conduction aberrant	High grade of AV block
MAT	Multiple atrial ectopic foci	Irregular	120–180	At least 3 types of P-wave morphology	Often >1	Variable	Normal or conduction aberrant	High grade of AV block
Atrial flutter	Macro-reentry in right atrium (typical flutter): counterclockwise or clockwise	Regular if P:QRS ratio is constant	75–175	Sawtooth F wave (typical flutter); no isoelectric line	>1	Generally constant	Normal or conduction aberrant	High grade of AV block
Atrial fibrillation	Chaotic atrial activation	Irregular	100–160	Absent; irregular atrial activation (F wave)	Not evaluable	Not evaluable	Normal or conduction aberrant	High grade of AV block
Typical AVNRT (slow-fast)	Dual AV nodal pathways. Macro-reentry with anterograde conduction by slow pathway and retrograde conduction by fast pathway	Regular	150–250	Hidden in QRS; pseudor' (V1); concentric atrial activation (narrow upper axis P wave)	Generally 1:1	Longer than RP	Normal or conduction aberrant	Terminate or anything
Atypical AVNRT (fast-slow)	Dual AV nodal pathways. Macro-reentry with anterograde conduction by fast pathway and retrograde conduction by slow pathway	Regular	150–250	Concentric atrial activation (narrow upper axis P wave)	Generally 1:1	Shorter than RP	Normal or conduction aberrant	Terminate or anything
Orthodromic AVRT	Macro-reentry with anterograde conduction by AV node-His-Purkinje system and retrograde conduction by AP	Regular	150–250	Eccentric atrial activation (morphology related to AP localization); concentric atrial activation in posteroseptal AP	Mandatory 1:1	Longer than RP	Normal or conduction aberrant	Terminate or anything
PJRT	Macro-reentry with anterograde conduction by AV node-His-Purkinje system and retrograde conduction by decremental slow conduction AP	Regular	120–200	Concentric atrial activation (narrow upper axis P wave)	Mandatory 1:1	Shorter than RP	Normal or conduction aberrant	Terminate or anything

HR heart rate, *MAT* multifocal atrial tachycardia, *AVNRT* atrioventricular node reentrant tachycardia, *AVRT* atrioventricular reentrant tachycardia, *PJRT* permanent junctional reciprocating tachycardia (Coumel tachycardia)

Table 5.2 ECG features to assess

1st: assess RR	R-R regular					R-R irregular		
2nd: assess P wave and P/QRS ratio	P not visible	P:QRS = 1:1			P: QRS>1	No. of P waves	F waves	Different P waves
3rd: assess RP and PR	↓	RP<PR		RP>PR	↓	↓	↓	↓
		RP <70 ms	RP >70 ms					
4th: more probably diagnosis	Typical AVNRT		AVRT; AT	ST; AT; atypical AVNRT; PJRT	Aflu; AT	AF	Aflu with different AV conduction	MAT

AVNRT atrioventricular node reentrant tachycardia, *AVRT* atrioventricular reentrant tachycardia, *AT* atrial tachycardia, *ST* sinus tachycardia, *PJRT* permanent junctional reciprocating tachycardia, *Aflu* atrial flutter, *AF* atrial fibrillation, *MAT* multifocal atrial tachycardia (Table from Contadini D, Menditto A (2015) Supraventricular Reentrant Tachycardias. In: Capucci A. (eds) Clinical Cases in Cardiology. Springer, Cham)

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