ORIGINAL ARTICLES

Reappraisal of the Traditional Wenckebach Phenomenon with a Modified Ladder Diagram

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Understanding of the traditional Wenckebach phenomenon is enhanced by using a modified ladder diagram where AV conduction in any cycle is represented by a slanted line in the AV bar together with similar AV conduction lines of all the preceding cycles. The diagram facilitates calculation of the duration of RR intervals (equal to the basic PP or sinus interval minus the PR or AV increment applied to this particular cycle) and the duration of the pause (equal to $2 \times$ PP or sinus interval minus the sum of all the increments applied to the AV delay). The modified Wenckebach diagram should help students understand the mysterious clustering of QRS complexes or “paradoxical” increase of the ventricular rate that occurs during a Wenckebach sequence.

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DEFINITIONS

Type I second-degree AV block is traditionally defined as the occurrence of a single nonconducted sinus P wave associated with progressive prolongation of the PR intervals before and after the blocked impulse provided there are at least two consecutive conducted P waves (i.e., 3:2 AV block) to determine the behavior of the PR interval.^{1–3} The criteria for type I second-degree AV block have not changed from Wenckebach's original observations.⁴ The PR interval after the blocked impulse is always the shortest in the sequence if the P wave is conducted to the ventricle but it is not necessarily short. The RR intervals shorten gradually as the PR intervals increase. More than 50% of type I sequences are atypical and do not conform to the traditional teaching about the mathematical behavior of the various atrial, AV and ventricular intervals.^{5–8}

The classic pattern of type I block virtually never occurs when the conduction ratio reaches and extends beyond 6:5 block.⁹ In all forms of typical and

atypical type I structures the postblock PR interval is shorter and the cornerstone of diagnosis. Atypical type I sequences may differ in one or more features attributed to the traditional form. In atypical type I block a PR interval may shorten (negative increment), or show no discernible or measurable change anywhere in a type I sequence. Indeed, atypical type I sequences in their terminal portion can exhibit a number of consecutive PR intervals showing no discernible change before the single blocked beat an arrangement that may be mistaken for type II block (pseudo-type II block).^{7,10} The second PR interval in an atypical type I sequence may not exhibit the largest PR interval increment (as in traditional type I block), and the last PR increment may sometimes be the largest. Changes in the sinus rate may influence the PR interval. The duration of some of the RR intervals may decrease or remain unchanged. The occurrence of longer RR intervals may be linked to changes in the preceding PP interval but slowing or an increase of the sinus rate generally does not interfere with the diagnosis of type I block. In contrast, slowing of the

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sinus rate interferes with the diagnosis of type II second-degree AV block.¹⁰ Occasionally, the incremental changes in conduction are too small to be measured at the usual ECG speed of 25 mm/s. This form of type I block seen in Holter recordings is easily mistaken for Mobitz type II block. Such potentially misleading sequences are almost always associated with obvious typical or atypical type I structures at other times of the day. The occurrence of both type I and type II block in the same recording is so rare especially with a narrow QRS that what appears to be a type II block can confidently be labeled an atypical type I block.¹⁰ The high prevalence of atypical type I makes the term "progressive" inappropriate to describe the prolongation of the PR intervals in the definition of type I block. The behavior of the PR intervals should be replaced by "inconstant changes" of the AV or PR intervals to reflect the variability of the PR intervals of conducted beats.

All the publications describing classic type I block mention that the greatest increment of the PR interval occurs in the second beat. A relatively large number of publications also emphasize that as the PR interval lengthens, the RR intervals shorten gradually. However, only a few publications explain the mechanism of ventricular acceleration and how to calculate the changing RR intervals during the progression. This lack of details makes it difficult for the beginner to understand the reason for the increasing ventricular rate. Although the presence of a pause is universally stated, its precise duration is often ignored. When the duration of the pause is mentioned it is often imprecise and assigned a value less than double the duration of a variety of atrial or ventricular intervals. The feasibility of calculating the actual duration of the pause based on the mathematical relationship of the various electrocardiographic intervals rarely appears as a feature of Wenckebach second-degree AV block.

MODIFIED WENCKEBACH DIAGRAM

The modified Wenckebach diagram may be considered to be an enhanced ladder diagram with several additions: (1) AV conduction in any cycle is represented by the slanted line in the AV bar together with AV conduction of all the preceding cycles. This representation is unique to the modified ladder diagram.¹¹ Figure 1 shows that all the

different AV delays preceding a given AV interval are easily identifiable within the AV bar by slanted lines of varying inclination. (2) The AV delays are represented by AVn where n = 1 to 4 and AV1 is the first or opening AV delay of the Wenckebach periodicity where there is obviously no increment of the AV interval. This is followed by AV2, AV3, and AV4. The increments are depicted as $\Delta 1$, $\Delta 2$, and $\Delta 3$ accompanying AV2, AV3, and AV4, respectively. Because the first AV delay has no increment, numbering of the Δ s or increments must be one step behind that of the AV delays. Thus, increment $\Delta 2$ forms part of the third AV delay (AV3). Each AV delay is shown to consist of the sum of the preceding AV delay and the Δ (increment) for that particular cycle. For example $AV4 = AV3 + \Delta 3$ where AV3 is the duration of the previous AV delay residing in the second ventricular interval (RR2).

CHARACTERIZATION OF PAUSES

The following lists outline the various descriptions of the pause in type I block. The data were obtained from the literature, books, and the Internet.

A. RR intervals

1. The longest RR interval is less than twice the shortest RR interval.
2. The pause is less than the preceding two RR intervals.
3. The pause is shorter than the sum of any two consecutive conducted beats (RR intervals).
4. The RR interval that contains the dropped beat is less than two of the shortest RR intervals seen on the ECG.
5. The pause containing the dropped beat is less than the summed cycles of any two previous cycles.
6. The RR interval that includes the nonconducted P wave is usually less than the sum of two RR intervals of the underlying rhythm.

B. PP intervals

1. The pause is twice the cycle length of the proximal or distal area. The pause is less than twice the PP interval or any of the RR intervals.
2. The pause is less than the sum of two PP intervals.

Figure 1. Modified Wenckebach diagram. Note the progressive decrease of the PR increment ($\Delta 1 > \Delta 2 > \Delta 3$), progressive decrease of the RR intervals, and the reverse relation between PR and RP interval. When the PR interval increases ($AV1 < AV2 < AV3 < AV4$), the RP interval decreases ($V1-A1 > V2-A3 > V3-A4$). The equation for the RR cycle length = PP interval + Δ for the cycle where the RR interval is being calculated. This can be simply derived mathematically taking the first cycle as an example: $RR2 = PP - AV2 + AV3 = PP - AV2 + (AV2 + \Delta 2) = PP + \Delta 2$. Δ = increment. See text for details.

3. The RR interval encompassing the nonconducted P wave is twice the PP interval *minus* the total increment in the PR intervals of the Wenckebach period.
4. The duration of the pause between two QRS complexes, which is produced by the blocked P wave, equals twice the normal PP interval minus the difference between the PR interval before the block and the PR interval after the block. Thus, the pause will be less than twice the normal PP interval.

DURATION OF THE PAUSE AND THE WENCKEBACH DIAGRAM

All the above statements are actually correct. Because there is always an increment in the PR interval in traditional type I block, the long interval (the one containing the blocked P wave) will always be shorter than any two short intervals either atrial or ventricular even any atrial interval + any short ventricular interval in the absence of slowing of sinus activity. Traditionally, the duration of the pause is often compared to twice the duration of the last and shortest ventricular cycle

probably because that is the way Wenckebach originally described it.⁴

The rules concerning the duration of the pause also apply during an atypical type I sequence associated with a stable sinus rhythm even if the greatest PR increment is in the last cycle before the blocked beat. We believe that the measurement of the pause should be standardized by using the PP intervals rather than other intervals. The pause is less than two PP intervals. This statement in juxtaposition with the duration of the pause in type II block facilitates the memorization and understanding that the pause is equal to two PP intervals in type II block but not in type I block.¹⁰

The duration of the pause may not follow the rules in atypical type I block and in vagally mediated AV block.^{10,12,13} Vagally mediated second-degree AV block is considered to be a type I variant in which there is the simultaneous occurrence of abrupt sinus slowing and AV block. Obvious slowing of the sinus rhythm before and during the pause may lengthen the last RR cycle and the pause to values longer than the accepted criteria applicable to traditional type I block. Hence it is important to always look for sinus slowing in atypical Wenckebach periodicity.

The modified Wenckebach diagram that assumes a stable sinus rhythm helps to understand why the pause is equal to two PP intervals minus the sum of all the increments. Looking at cycle RR3 in Figure 1, it is easy to see that the elimination of all three increments creates a slanted AV line parallel to the one associated with the first AV delay. Then going forward and subtracting the three separate Δ s yields the duration of the pause which is therefore equal to two PP intervals minus the sum of all the AV increments. $\text{Pause} = 2 \text{ PP} \text{ minus } (\Delta 1 + \Delta 2 + \Delta 3)$.³

DURATION OF THE VENTRICULAR INTERVALS AND THE WENCKEBACH DIAGRAM

Looking at Figure 1 showing 5:4 type I block, it becomes obvious that the first ventricular interval V1-V2 (or RR1) = PP + $\Delta 1$ (where $\Delta 1$ is the increment for the first ventricular cycle). Then V2-V3 (or RR2) = P-P + $\Delta 2$ (where $\Delta 2$ is the increment for the second ventricular cycle). This is followed by V3-V4 (or RR3) = PP + $\Delta 3$ (where $\Delta 3$ is the increment for the third ventricular cycle). Thus the duration of an RR interval is equal to the basic PP interval plus the PR or AV increment for this particular cycle.

ADVANTAGES OF THE MODIFIED DIAGRAM

Marriott's *Practical Electrocardiography* book states that "the pattern of progressively decreasing RR intervals preceding a pause in AV conduction that lasts for less than twice the duration of the shortest RR interval is of only academic interest in the case of AV nodal block, but a similar pattern of PP intervals may provide the only clue to the presence of sinus-nodal exit block."¹⁴ It is certainly true that the Wenckebach phenomenon is recognized by its footprints. Traditional type I AV block is the paradigm for the Wenckebach phenomenon and a thorough knowledge of its features facilitates its recognition from other sites in the heart.¹⁵ We do not agree that the presence of decreasing RR intervals and the duration of the pause is of academic interest in AV Wenckebach periodicity. Understanding the modified diagram and the Wenckebach phenomenon is an exer-

cise in logic that provides the satisfaction of really appreciating the details of traditional AV Wenckebach block. In that respect, the depiction of all the preceding and current AV delays within each cycle provides a unique way to understand the impact of the increments in AV conduction. The modified Wenckebach diagram should help students understand the mysterious clustering of QRS complexes or "paradoxical" increase of the ventricular rate and facilitate its explanation by clinical teachers. More precise knowledge of pause duration in terms of PP intervals highlights the fundamental difference between type I and type II AV block.¹⁰ Finally, the diagnosis of unusual forms of atypical type I block can only be made with a thorough knowledge of the traditional form of type I block and its limitations.

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