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Expert consensus document on automated diagnosis of the electrocardiogram: The task force on automated diagnosis of the electrocardiogram in Japan part 3: Inappropriate internal processing in the automatic diagnosis of electrocardiograms and its problems

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1 | BACKGROUND

In the automatic analysis and diagnosis of electrocardiograms, complicated computer processing is performed in various steps, and electrocardiograph manufacturers have built automatic diagnosis systems based on their own concepts. Such computer diagnosis of electrocardiograms is widely used to provide especially useful information in actual clinical practice and medical checkups. However, as mentioned in the first and second reports of our statement, it is common for users to be confused by the inappropriate or sometimes clearly incorrect diagnosis.[1]

It is often difficult to know how these inappropriate outputs of automatic diagnoses were derived because most diagnostic algorithms are in a black box. It has been thought that an overreading, an overlooking, or measurement errors will be the main causes of these inappropriate diagnoses.[2]

However, we sometimes notice that one or a part of the diagnosis was deleted or skipped intentionally in the diagnostic process,

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TABLE 1 Internal computer processing to improve diagnostic efficiency.

1. If diagnosis A, whether or not correct, appears first in automatic diagnosis, all subsequent branching processes are completely stopped.
2. If diagnosis B appears in the middle of the automatic diagnosis process, the previous diagnosis is retained, and all or part of the subsequent branching process is stopped.
3. If diagnosis C appears in the middle of the automatic diagnosis process, the subsequent branching process proceeds as predetermined, but the result does not display the subsequent diagnosis.
4. Besides, although the details are unknown, obvious abnormal findings dare not be displayed.

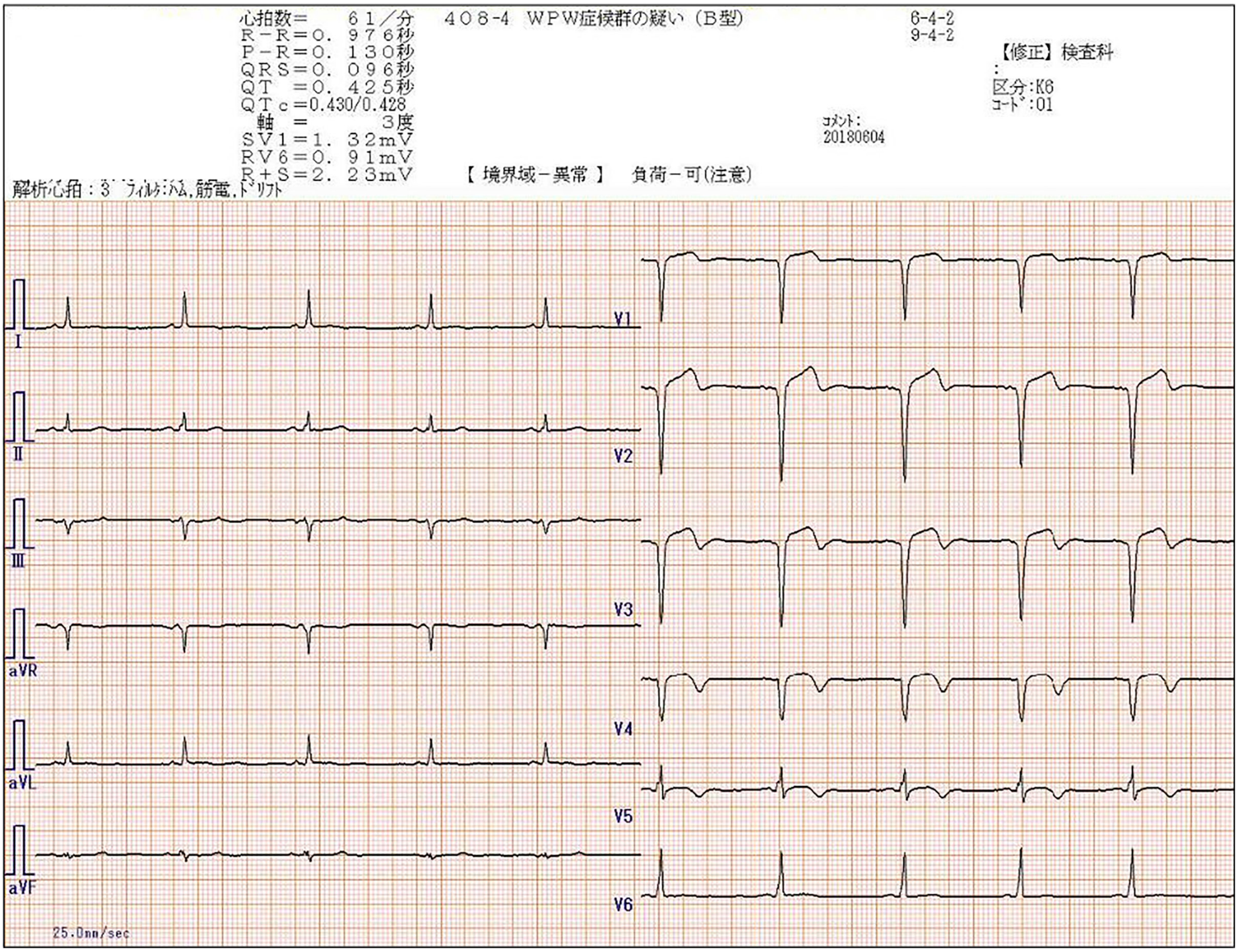

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FIGURE 1 A case of WPW syndrome. Important findings suggestive of myocardial ischemia were completely masked. Clinical backgrounds: A 46-year-old male. A record of a medical examination of the company. About 1 month prior, he developed acute coronary syndrome and has received coronary stenting therapy. WPW syndrome has been pointed out during former medical examinations. This is the case that triggered this study. ECG findings: "Suspected WPW syndrome (type B)" is only displayed as the automatic diagnosis in Japanese, and there is no description of other obvious abnormal findings such as QS pattern in leads V1 to V4, ST elevation in leads V2 to V4, and negative T wave in leads V3 to V5. Discussion: Since delta waves are observed in leads II, V5, V6, etc., the diagnosis of WPW syndrome does not seem to be a mistake, but the above important findings that reflect myocardial infarction or myocardial ischemia associated with acute coronary syndrome are not displayed at all. After the diagnosis of WPW syndrome, the subsequent automatic process for additional diagnosis could have been skipped because of the line break processing, as shown in (1) of Table 1.

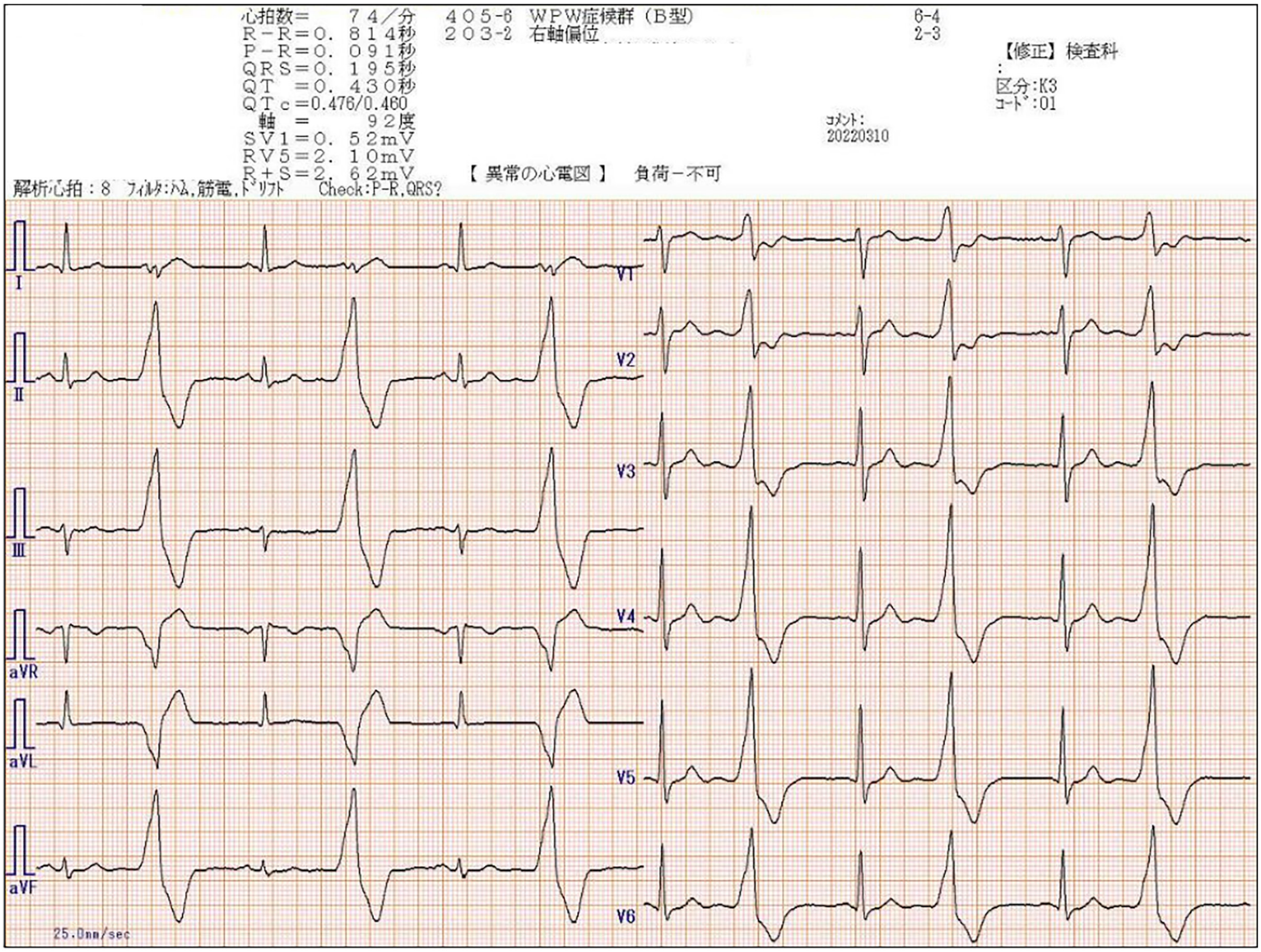

FIGURE 2 A case of premature ventricular contractions (PVC) bigeminy masked after misdiagnosis as WPW syndrome. Clinical backgrounds: A 53-year-old male. A record of when he was aware of palpitations. ECG findings: The automatic diagnosis was displayed as "WPW syndrome (type B) and right axis deviation (RAD)" in Japanese. However, no findings suggested the presence of both accessory pathways and right axis deviation from the morphology of sinus beat. Discussion: Looking at the values of the automatic measurement, the PR interval was 0.091 s, the QRS width was 0.195 s, the average electrical axis was 92°, etc. It is thought that the ventricular premature contractions have been mistakenly measured as sinus beats, resulting in the above misdiagnosis. After the misdiagnosis as WPW syndrome and right axis deviation, the subsequent automatic diagnosis process is stopped by the line break processing as shown in (1) of Table 1, and the "PVC bigeminy" might be completely masked. Since the initial misdiagnosis triggered the subsequent inappropriate diagnosis, improving the accuracy of the automatic diagnosis system itself is considered necessary.

and then the obviously inadequate diagnosis was displayed; this is a rare phenomenon. In such a case, the judgment process based on the branching theory is interrupted by an automatic processing system for diagnostic efficiency, which can be called "line break processing."

Conversely, although many abnormal findings have been displayed, they all may be included in the main diagnosis in some cases. In such cases, fine unnecessary findings are displayed endlessly by the branching process, resulting in the evaluator's perplexity.

In this report, we illustrate some examples of inappropriate automatic diagnoses that the authors have experienced and discuss the actual situation of inappropriate automatic processing and its problems.

2 | TYPES OF INAPPROPRIATE AUTOMATIC DIAGNOSIS

Automatic processing that is considered electrocardiologically or clinically inappropriate can be divided into two types:

Type 1: The branching process is interrupted, and the following processes are skipped. Then, important diagnoses or findings that should be displayed are not displayed.

Type 2: Many unnecessary diagnoses or minor findings that need not be displayed are displayed.

In type 1, there is a risk that hidden important diseases will be missed, and subsequent medical treatment will not be performed appropriately.

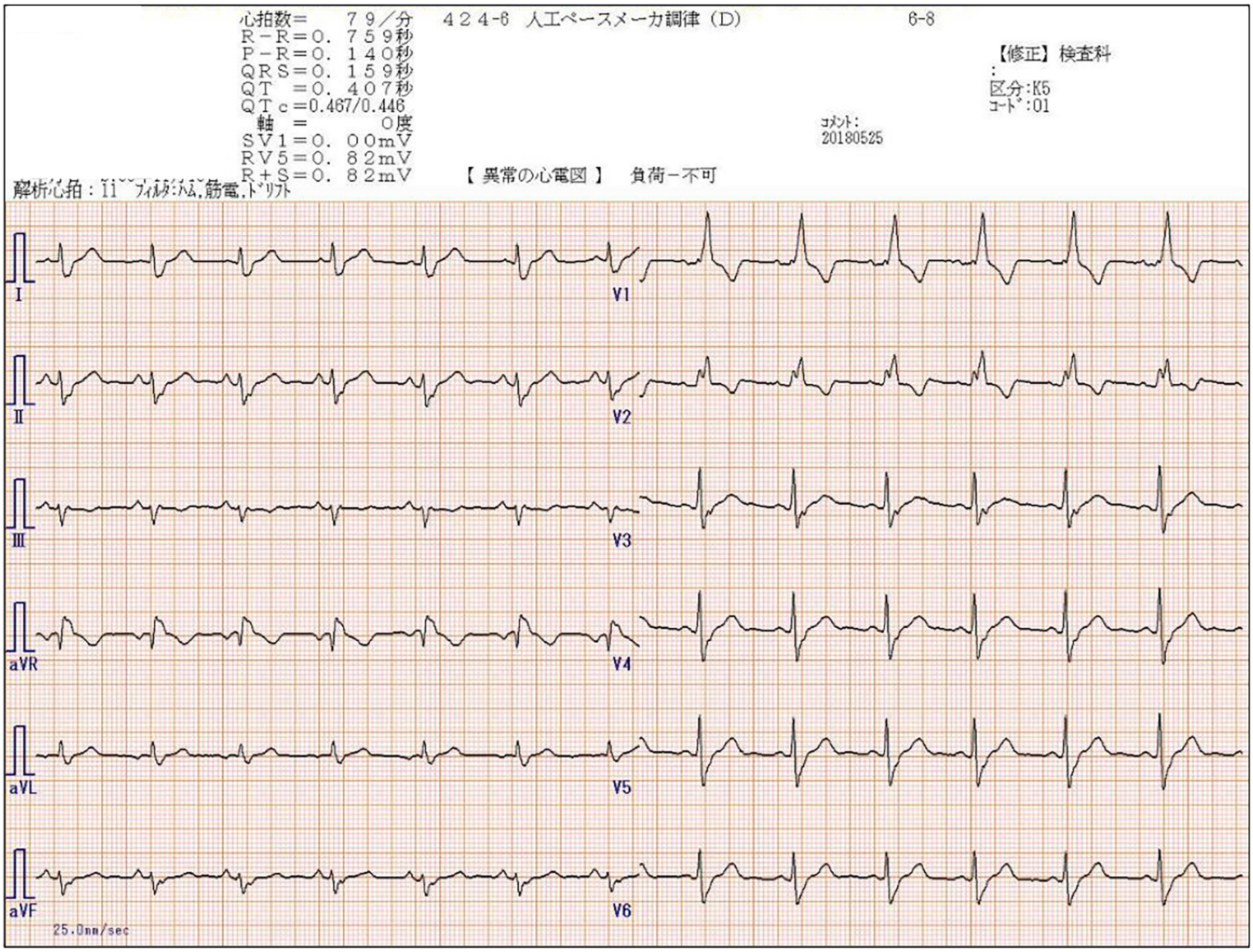

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FIGURE 3 A case of complete right bundle branch block (CRBBB) masked after misdiagnosis as pacemaker rhythm. Clinical backgrounds: A 54-year-old male. A record at an annual medical checkup. A diagnosis of CRBBB had been made every year. However, a diagnosis of "pacemaker rhythm" was made this time. ECG findings: The automatic diagnosis was displayed as "pacemaker rhythm" in Japanese, but there were no signs of a pacing spike. ECG shows a typical CRBBB pattern of rsR' in leads V1, V2, and deep S in leads V5, V6. Discussion: It is thought that the misdiagnosis of pacemaker rhythm has masked the presence of CRBBB due to line break processing, as shown in (1) of Table 1.

In type 2, many minor findings that should be included in the main diagnosis are displayed disorderly and are bothersome in a clinical setting.

3 | LINE BREAK PROCESSING

"Line break processing" is one of the rules in proofreading documents, for example, not to put punctuation, closing parentheses, question marks, or other symbols at the beginning of a line or to prevent a word from being cut off in the middle. This line break processing is widely used in the computer's word processing software to adjust the length of a sentence, interval of letters, or text feedings automatically.

There may be various opinions on whether it is appropriate to use the expression "line break processing" in the automatic diagnosis of electrocardiograms. However, in our group discussion, we found no other suitable expression to explain the results of inappropriate automatic diagnosis, as shown below. Thus, we decided to use "line break processing" as a computer algorithm to improve diagnostic efficiency.

4 | MERITS AND DEMERITS OF THE LINE BREAK PROCESSING

In the automatic diagnosis of electrocardiograms by computer, it is essential to construct a complex diagnostic algorithm based on the branching theory that combines detailed waveform measurements. It sometimes requires an enormous amount of computation to cover all diagnoses of electrocardiograms. To improve the efficiency of this process as much as possible, each electrocardiograph manufacturer

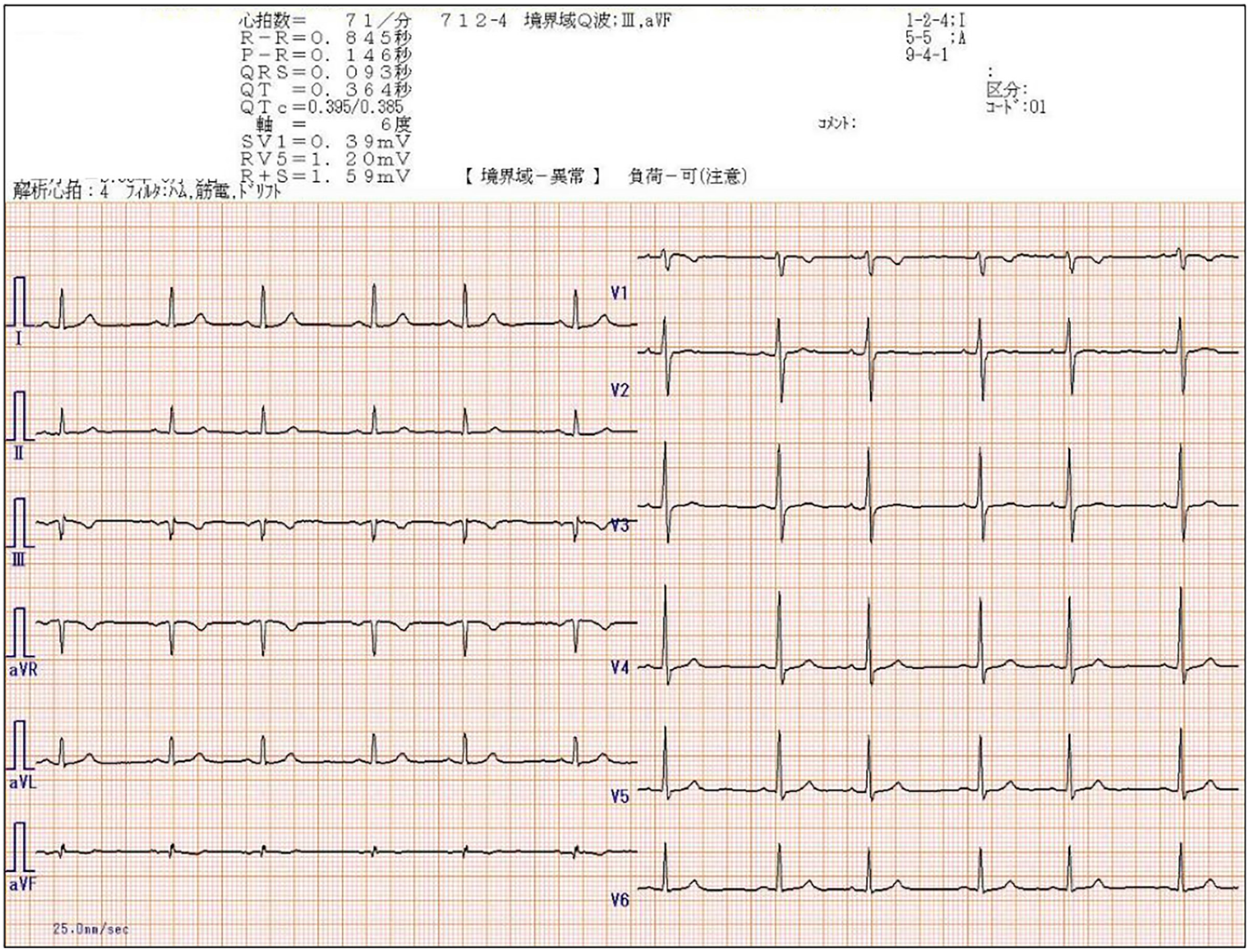

FIGURE 4 A case of premature atrial contractions (PAC) bigeminy masked after misdiagnosis as borderline Q wave. Clinical backgrounds: A 58-year-old female. A record at an annual medical checkup. She has no serious history or family history. ECG findings: The automatic diagnosis was displayed as "borderline Q wave in leads III and aVF" in Japanese. However, we notice a long-short alternating cycle of RR interval showing bigeminy. This arrhythmia will be considered a bigeminy of PAC because every P wave at a short cycle reveals a small amount of transformation. However, the Wenckebach period of the sino-atrial block with three to two conductions may not be denied. Discussion: It is thought that the diagnosis of borderline Q wave has masked the presence of bigeminal arrhythmia due to line break processing, as shown in (1) of Table 1.

may likely perform automatic processing (Table 1), although the detailed contents are not disclosed. It is difficult to identify which of the processes in Table 1 are being performed to improve the efficiency of automatic diagnosis.

We experience two types of demerits due to the line break processing. The most serious problem is that following one correct diagnosis, other important findings have not been displayed anymore. Another serious problem is that the initial result is misdiagnosed, and the correct diagnosis is considered to have been masked.

In contrast, we sometimes encounter cases where minor findings are displayed disorderly, resulting in cumbersome and time-consuming clinical settings. However, all these findings can be included in a main diagnosis. A line break processing can be applied in these cases.

5 | EXAMPLES OF INAPPROPRIATE DIAGNOSES DUE TO LINE BREAK PROCESSING; TYPE 1 INAPPROPRIATENESS

Various cases of inappropriate automatic diagnosis exist due to "line break processing." However, in the authors' experience, many seem related to the "WPW syndrome" and "pacemaker rhythm." In other rare cases, "abnormal Q wave," "right bundle branch block," "left bundle branch block," "ventricular premature complex," etc. are also suspected of being internally processed so that the accompanying abnormal findings are not displayed.

Figure 1 is an example that triggered this study, and Figures 2–5 show actual electrocardiograms with inappropriate automatic diagnosis that seems to have been caused by various line break processing.

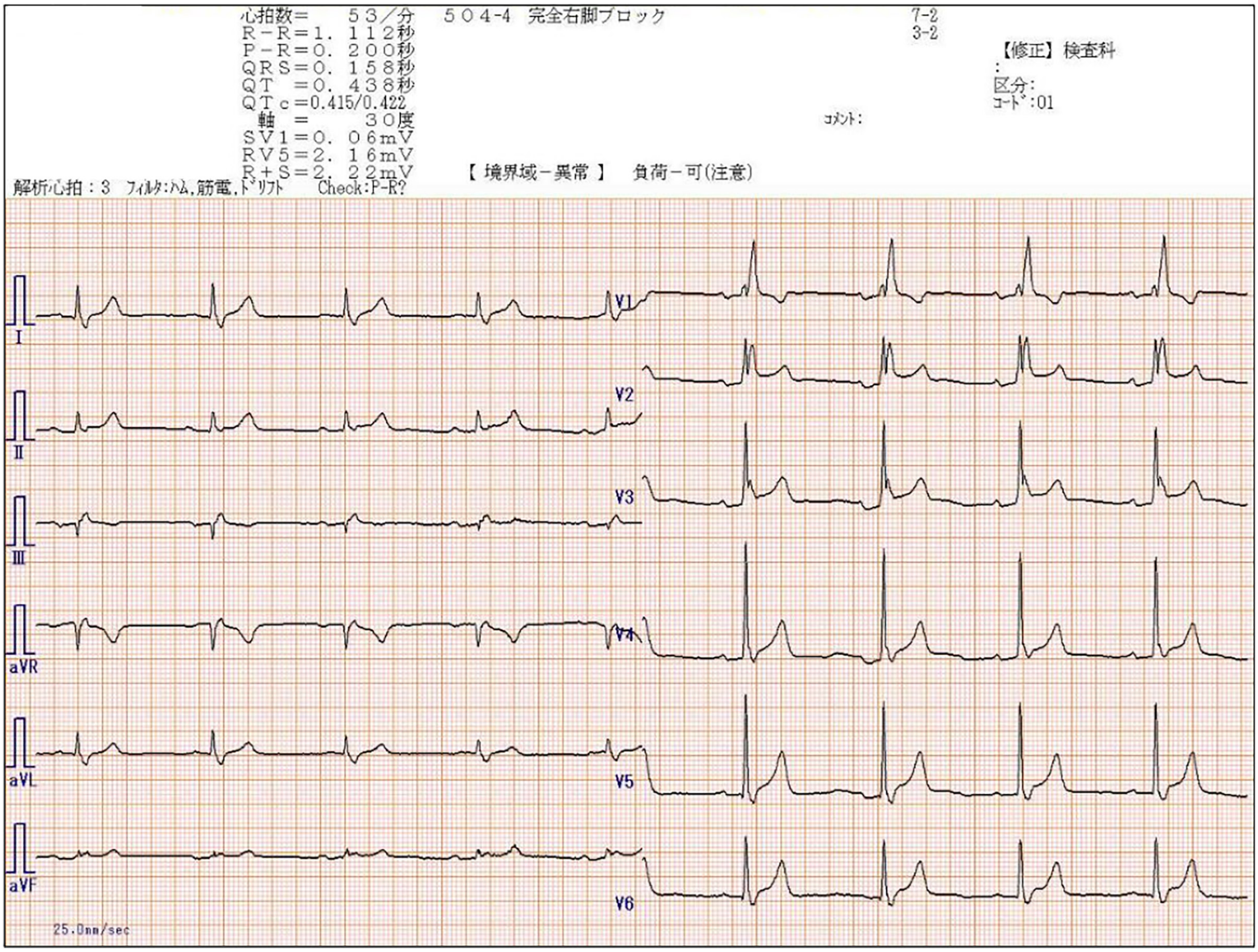

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FIGURE 5 A case of CRBBB. Coexistent ST elevation in the chest leads has been masked. Clinical backgrounds: A 73-year-old male. A record at an annual medical checkup. He has congestive heart failure, and loop diuretics have been prescribed. ECG findings: The automatic diagnosis of CRBBB was made appropriately in Japanese. However, apparent ST elevation in chest leads that may suggest myocardial ischemia has been completely ignored. Discussion: It is thought that the diagnosis of CRBBB has masked the presence of the above important findings due to line break processing as shown in (1) or (4) of Table 1.

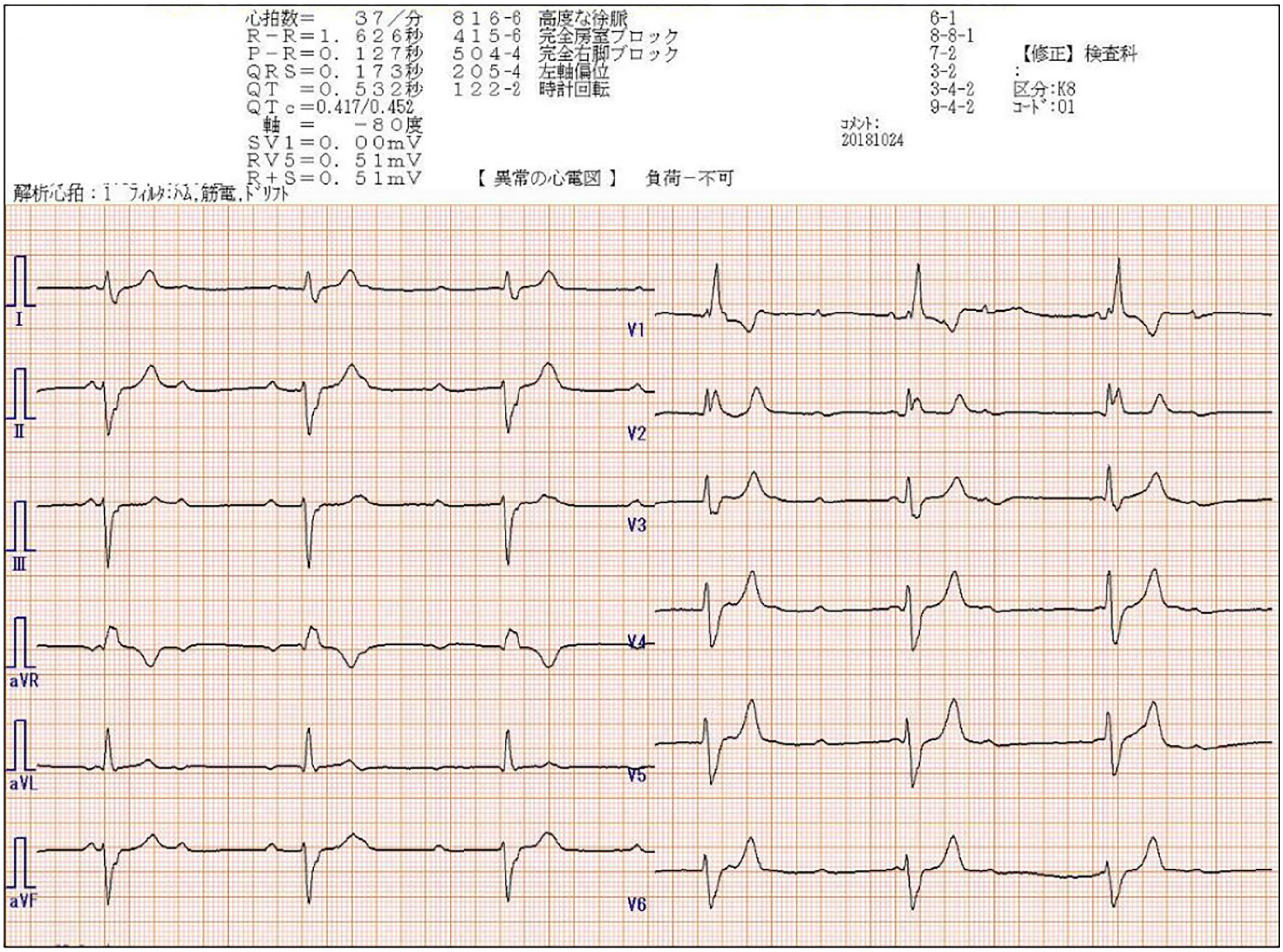
6 | EXAMPLES OF INAPPROPRIATE DIAGNOSES THAT SOME INTERNAL PROCESSING FOR DIAGNOSTIC EFFICIENCY SHOULD BE APPLIED; TYPE 2 INAPPROPRIATENESS

In contrast, we have experienced not a few cases where many minor findings are listed and displayed disorderly. In these cases, some major diagnoses already contain several other minor findings, and displaying them all is often unnecessary. In many cases, it is expected to improve the efficiency of the diagnosis process by actively performing internal processing equivalent to "line break processing" and simplifying the diagnosis, thereby contributing to avoiding unnecessary confusion in clinical settings and reducing the burden on electrocardiogram evaluators.

Figures 6–8 present sample electrocardiograms of inappropriate automatic diagnosis that should have improved the efficiency of diagnosis by some automatic internal processing.

7 | FREQUENCY OF OCCURRENCE OF INAPPROPRIATE AUTOMATIC DIAGNOSIS

It is extremely difficult to state exactly how often cases of inappropriate diagnosis thought to have been caused by internal computer processing are seen in the real world. First, the criterion of inappropriate diagnosis is not unified by each electrocardiogram



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P－R=0. １２７秒  ５０４-4  完全右脚ブロック               7-2      【修正】 検査科
QRS=0. １７３秒  ２０５-4  左軸偏位                     3-2       :
QT  =0. ５３２秒  １２２-2  時計回転                     3-4-2    区分:K8
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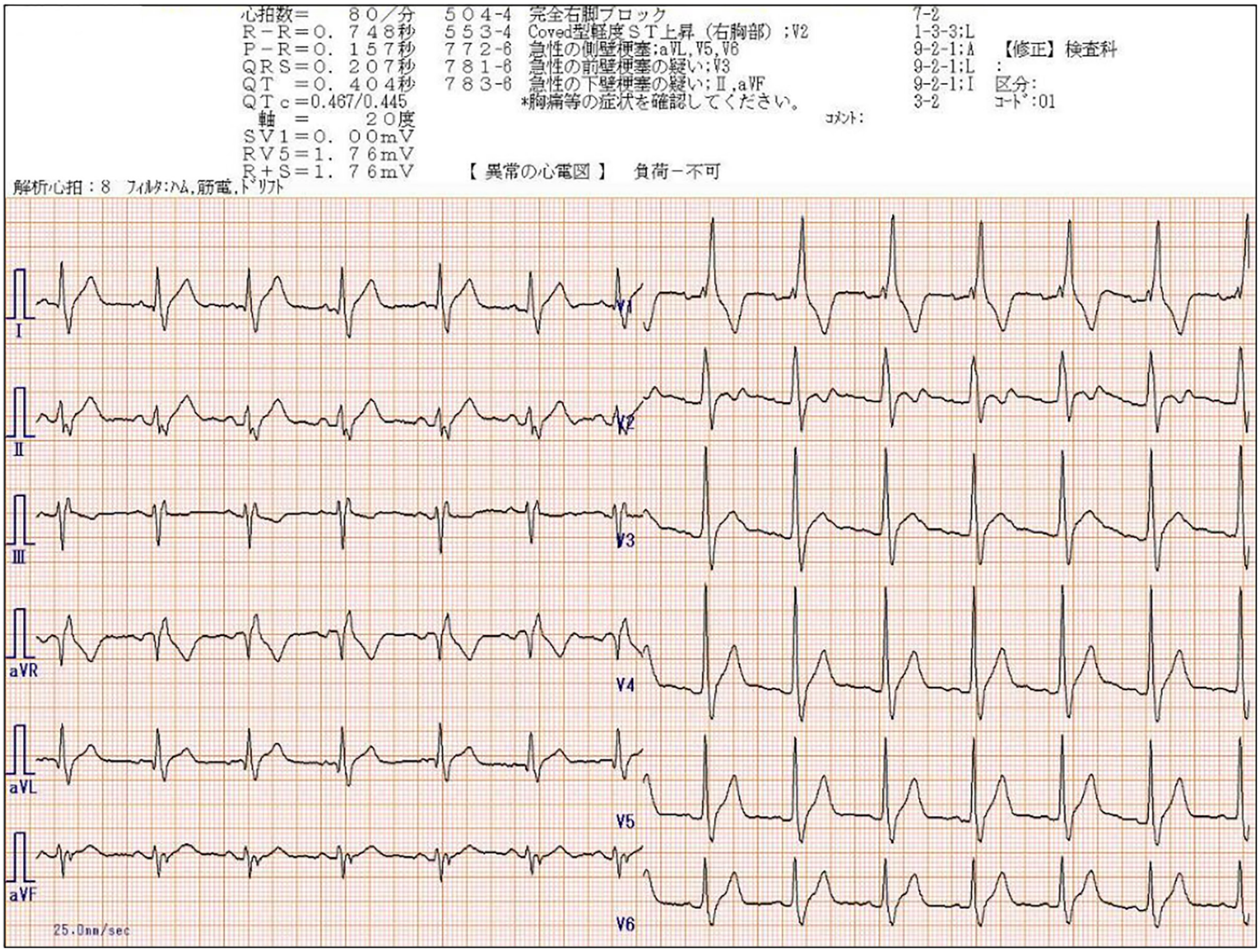
FIGURE 6 A case of complete atrio-ventricular (AV) block. All other findings must be masked because they were included in the main diagnosis. Clinical backgrounds: An 82-year-old male. A record at the outpatient clinic for further evaluation of marked bradycardia. He had recently experienced frequent dizziness. ECG findings: The automatic diagnosis of "high degree bradycardia", "complete AV block," "CRBBB," "left axis deviation (LAD)," and "clockwise rotation" were displayed in Japanese. However, "high degree bradycardia" and the latter three diagnoses will be included in the "complete AV block." "Ventricular escape rhythm with CRBBB+LAD morphology" will be added. Discussion: Above inappropriate description of automatic diagnosis may cause evaluators unnecessary confusion. It is thought that those unnecessary findings must be skipped due to line break processing after the diagnosis of complete AV block was made.

evaluator. Second, the required diagnostic accuracy may depend on the situation regarding the electrocardiogram examination. Of course, each electrocardiograph manufacturer has their unique algorithm for automatic diagnosis in black boxes that were not published in detail.

For the above reasons, the frequency of inappropriate automatic diagnoses is a matter of conjecture. From the authors' experience, it is estimated that only 0.1%–0.2% of those with electrocardiogram records in medical examinations are included, even in minor cases that are not clinically problematic. However, even if there are a small number of cases, the cases shown in this paper certainly exist, and we cannot neglect the utmost care when evaluating electrocardiograms.

8 | COUNTERMEASURES IN CLINICAL SETTINGS

Although the most important thing when overreading and deciphering an electrocardiogram in daily practice is to diagnose it responsibly by the evaluator himself, undoubtedly, the automatic diagnosis results will also help point the way to accurate and appropriate diagnosis. It is important not to take the described automatic diagnosis as they are but first to consider the automatic measurements and the diagnosis based on them with a suspicious eye. There are many things that each evaluator should check, such as whether the described automatic diagnosis is correct, whether there is a possibility of misdiagnosis, whether there are no omissions in the description of abnormal findings, and whether it is organized in an



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QRS＝０．２０７秒　７８１-6　急性の前壁梗塞の疑い;V3　9-2-1;L　:
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FIGURE 7 A case of CRBBB. All other serious findings must be masked because they were overdiagnosed. Clinical backgrounds: A 36-year-old male. A record at an annual medical checkup. He has been healthy and has experienced no chest pain or palpitations. ECG findings: The automatic diagnosis of "CRBBB," followed by "coved type ST elevation," "acute lateral infarction," "acute anterior infarction," and "acute inferior infarction" were displayed in Japanese. Evaluators who do not specialize in ECG will be surprised. However, the latter four pretentious diagnoses will be apparent overdiagnoses. Discussion: Above inappropriate description of automatic diagnosis may bring serious confusion in the clinical practice. Those inappropriate findings must be skipped due to internal processing for diagnostic efficiency.

appropriate form that is easily understood. In particular, concerning omissions in important findings that may have been due to inadequate line break processing, deep insight is essential to the evaluation, and much time will be spent on detailed consideration and appropriate corrections.

9 | CONCLUSIONS

As the task force on automated diagnosis of the electrocardiogram in Japan, we have issued statements in the first and second reports to objectively evaluate the accuracy of automatic diagnosis of electrocardiograms and improve its usefulness in clinical settings. In this paper, as the third report, we focused on so-called "line break processing" among the various internal computer processing for the automatic diagnosis of electrocardiograms. The advantages and disadvantages of interrupting the branching theory for improving the efficiency of diagnosis are discussed, and the actual situation and problems are described.

10 | LIMITATION

Since a number of representatives of ECG manufacturers in Japan including Fukuda Denshi, Nihon Koden, and Suzuken Companies have joined as members of our committee, all of them have already recognized the problems about line break processing. However, the algorithms of computer analysis including the line break processing vary from company to company and some of them have not been published as so-called black box. Thus, we cannot apply the above way of thinking uniformly for each manufacturer. Unfortunately, we could not understand the real-world situation yet.

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CONFLICT OF INTEREST STATEMENT

All authors declare no conflict of interest in this article.

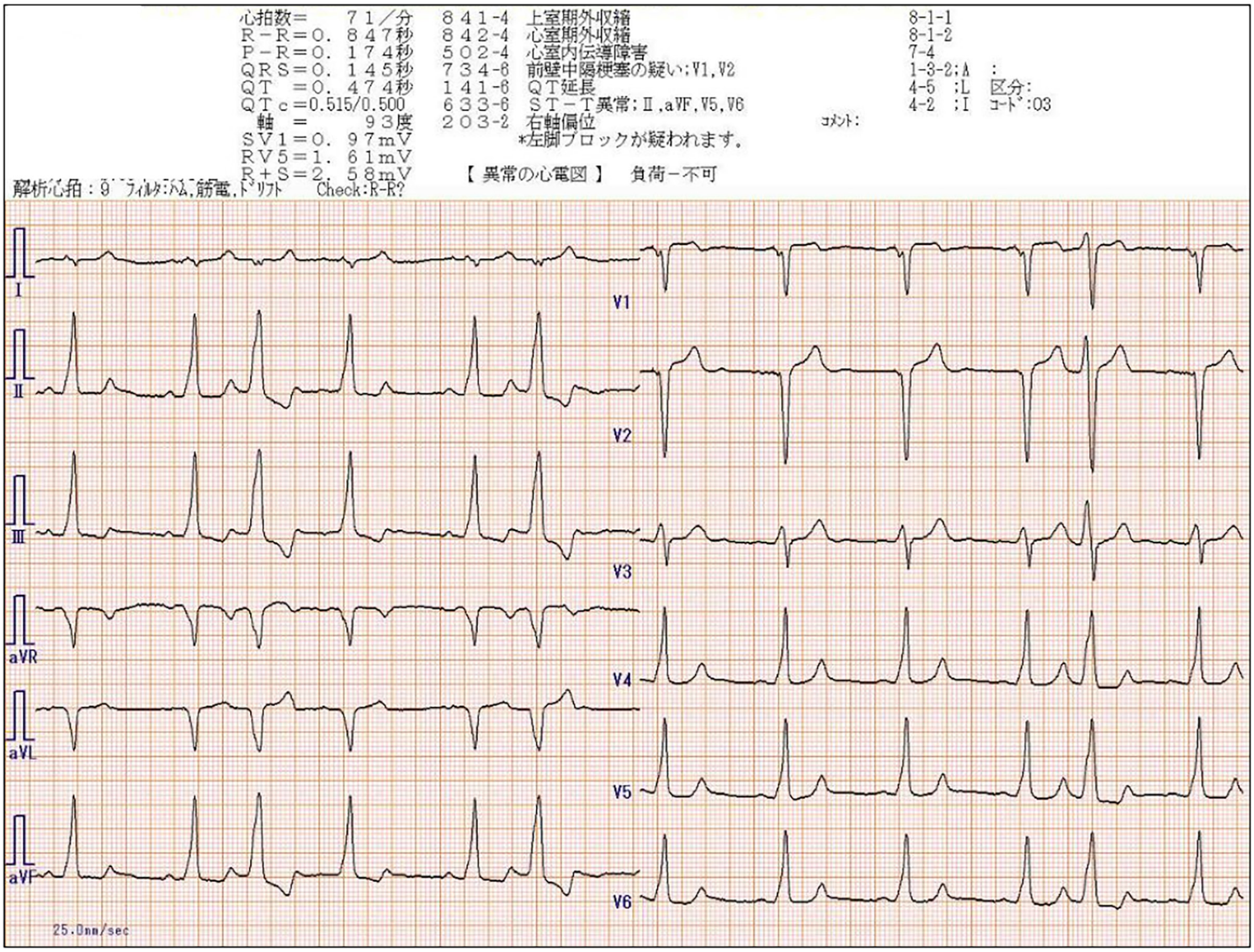

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FIGURE 8 A case of WPW syndrome. Overlooking the accurate diagnosis caused many inappropriate findings. Clinical backgrounds: A 44-year-old female. A record of when she felt palpitation. ECG findings: In the automatic diagnosis, many bothersome diagnoses and findings, for example, PAC, PVC, intra-ventricular conduction disturbance (IVCD), anteroseptal old myocardial infarction (OMI), QT prolongation, ST-T abnormalities, RAD, and suspected left bundle branch block (LBBB), are randomly displayed. The diagnosis of WPW syndrome was overlooked at first. Nevertheless, it is not so difficult in the presence of the delta wave. Discussion: If a diagnosis of WPW syndrome can be made, almost all other findings must be included in the diagnosis. Many inappropriate findings, except WPW syndrome and PAC, must be masked due to internal processing.

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