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GUIDELINES

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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 1: Nomenclature for diagnosis and abnormal findings

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1 | INTRODUCTION

Electrocardiographic examination is widely used in cardiovascular medicine and other clinical fields including preoperative examinations and health checks for the general population. The results of automatic diagnosis obtained by a computer equipped electrocardiograph have been widely applied in clinical medicine as well as in preventive medicine. Due to the wide range of utility and application, the results of automatic diagnosis of electrocardiogram (ECG) are shared and utilized for medical practice in various situations by cardiologists and specialized medical staff and also practitioners in other fields and paramedical personnel.

Therefore, automatic diagnosis of ECG requires high accuracy, but there are in fact many problems and issues that require clarification.[1]

Measures to improve the diagnostic accuracy of automatic diagnosis of ECG and to further enhance its clinical utility are of high importance.[2]

2 | CURRENT STATUS AND PROBLEMS IN AUTOMATIC DIAGNOSIS OF ELECTROCARDIOGRAM

Since the automated diagnosis of ECG requires a particularly high diagnostic accuracy, the most important criteria are not to mislead

clinically significant abnormal findings that require immediate medical care. To this end, electrocardiographic manufacturers have developed programs with an emphasis on eliminating false negative results, the so called "overlook" automatic diagnosis of ECG. Consequently, diagnostic algorithms tend to be constructed with a range of numerical values or comments that have a wider interpretation than the diagnostic criteria, as it is believed that a certain extent of over-diagnosis is justified.

In contrast, there is an algorithm that a notation "pacemaker electrocardiogram" at the time of detecting the pacing spike results in termination of subsequent further analysis. This may conversely result in many potential overlooks.

Automatic interpretation of ECG using a computer was first reported by Pipberger et al[3] in 1960, followed by Okajima et al,[4] Kimura et al,[5] and Matsuo et al[6] with new automated diagnosis systems announced one after another from Japan. Thus, practical use of computer-aided automated diagnosis of ECG progressed rapidly. Although the diagnostic accuracy has been improving for over half a century, it is by no means satisfactory to the expert electrocardiologist.[7–9] In parallel, from the non-expert point of view, automatic diagnosis is complicated by excessive comments or various detailed electrocardiographic findings and diagnoses are displayed automatically every time when indicative findings are recorded.[1]

In addition, it is often difficult for non-experts to determine if these detailed findings and diagnoses are clinically important or minor findings not requiring medical attention. Even though the findings or diagnoses have only minor clinical significance, patients are sometimes asked to consult a specialist for further diagnosis and treatment. Thus, the current automatic diagnosis of ECG impacts proper and effective medical care, and highlights the urgent need for further improvement of the accuracy and utility of automated diagnosis from the perspective of medical economics and the safe and efficient development of novel drugs.[10,11]

The major factors contributing to the current situation and problems may be due to the different nomenclature of diagnosis and/or findings based on ECG waveforms that are used by different manufacturers. Ideally, it should be described in accordance with the glossary of the Japanese Circulation Society or the Japanese Heart Rhythm Society, with reference to the recommendations by academic societies in the United States and Europe.[12] Thus, it is difficult and confusing for non-experts to understand the notations.

3 | A PANEL FOR THE STUDY OF AUTOMATIC DIAGNOSIS OF THE ELECTROCARDIOGRAM IN JAPAN

In order to promote the accuracy, reliability, and clinical usefulness of the automatic diagnosis of ECG, it is essential to accurately grasp and clarify various problems of the current diagnostic system, and to discuss each specific task for improvement from various clinical and technical viewpoints.

Therefore, we established a cross-sectional study group with members including physicians and researchers who have been involved in the development of computer-aided automatic diagnosis of ECG, clinicians with extensive experience in ECG readings, and engineers of electrocardiographic manufacturers.

The group comprised 10 core members from the current and past officers of the Japanese Heart Rhythm Society, 33 physicians with a sub-speciality in electrocardiology and technical managers of ECG manufacturers, and 10 advisors with extensive scientific and academic experience (Table 1).

We have discussed various terms used as a diagnosis or abnormal findings in the automatic ECG machines. The aim of this process was to unify various terminology, technical terms, and diagnostic comments to be as simple and understandable as possible even for non-specialized doctors and medical staff for ECG readings. We propose that the notation is acceptable and valuable as a terminology for automatic diagnosis of ECG.

4 | CONSIDERATIONS ON TERMINOLOGIES USE AS DIAGNOSIS AND ABNORMAL FINDINGS OF ECG IN AUTOMATIC DIAGNOSIS OF WIDELY USED ELECTROCARDIOGRAPH IN JAPAN

We first reviewed the terms that have been used as a diagnosis or abnormal finding in the automatic diagnosis, which was considered urgent from various viewpoints. Even in the 2007 recommendations for standardization and interpretation of the ECG from the USA, the terms of diagnosis and abnormal findings of ECG were listed jumbled, possibly creating confusion. The following five points were used as the pillars for the present study. The equivalent Minnesota code, which is widely used in conventional medicine globally, are

TABLE 1 Members for the study of automatic diagnosis of the electrocardiogram in Japan (in no particular order)

[Core Members]
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described in the table as much as possible to prevent unnecessary confusion.[13]

1. For similar conditions, terms describing an ECG finding and those describing a pathological diagnosis should be clearly distinguished.
   "This is really important to evaluate clinical significance including underlying pathological conditions in each patient. It is better to distinguish terms for diagnosis and those for ECG findings."
   Example 1: "PR prolongation" is a simple ECG finding, while "first degree atrio-ventricular (AV) block" is a diagnosis.
   Example 2: "marked left axis deviation" is an ECG finding, while "left anterior hemiblock (fascicular block)" is a diagnosis.
   Example 3: "abnormal Q wave" is an ECG finding, while "suspected previous myocardial infarction" is a diagnosis.
2. Unify terminologies used in different electrocardiograph models as much as possible.
   "Technical terms should be simple and universal to avoid unnecessary confusion."
   Example 1: PR interval (mainly used in USA), PQ interval (mainly used in Japan), PR time, and PQ time should be unified to "PR interval."
   Example 2: Second-degree AV block (Wenckebach type) (mainly used in Japan), Second-degree AV block, Mobitz type I (Wenckebach) (mainly used in USA), Second-degree type 1 AV block, etc, should be unified to "Second-degree AV block (Wenckebach type)."
   Example 3: Brugada syndrome suspected, Brugada type electrocardiogram, coved type ST elevation, saddleback type ST elevation, etc, should be unified to "Brugada type ST-T abnormality (coved type) and Brugada type ST-T abnormality (saddleback type)," although detailed diagnostic criteria of their ECG abnormalities have not been firmly established.
3. New terminologies that have often been used in clinical practice should be introduced in the automatic diagnosis of ECG system.
   "This is also important to enhance clinical utility of the automated diagnosis system, because some of these terms are not yet listed in Japan or the USA."
   Examples: Early repolarization, J-wave, accelerated idioventricular rhythm, Second degree (advanced) AV block, etc
4. Terms for a diagnosis or abnormal finding where the definition is unclear or the clinical significance is low should be avoided as much as possible.
   "To avoid unnecessary consultations with expert cardiologists, terms where their definition are unclear or the clinical significance is low should be avoided."
   Examples: Clockwise rotation, counter-clockwise rotation, classification of type A or B or C of WPW syndrome, short run of ventricular premature contractions or supra-ventricular premature contractions, etc
5. For terms that may be difficult for non-experts, there should be a separate brief explanation.
   "The clinical significance of some technical terms may be difficult for non-expert physicians or medical staff to understand."
   Examples: Left anterior hemiblock (fascicular block), left posterior hemiblock (fascicular block), AV junctional escape rhythm, Brugada type ST-T abnormality, etc

4.1 | Terms that should be recommended for automated diagnosis of ECG

To date, the terms for diagnosis or abnormal findings of ECG have not been unified between different electrocardiograph manufacturers. A variation of the same term appears on the electrocardiograph of each company. As these terms should accurately represent the abnormal findings and conditions as much as possible, we propose to unify these terms into terminologies that are not confusing and easy to understand for everyone. We selected 24 terms for abnormal ECG findings such as abnormal Q wave, right axis deviation, left axis deviation, etc (Table 2), and 97 terms for diagnosis such as AV block, premature contractions, atrial fibrillation, etc (Table 3).

4.1.1 | Terms recommended for abnormal ECG findings

In the reading and evaluation of the conventional ECG, information on various waveform and measures of wave intervals have been described as ECG findings. However, for example, with regard to the PR interval, which is an indicator of AV conduction, the notation such as PQ interval, PQ time, PR time, etc is different depending on the reader even if it is the same index. Furthermore, the numerical value used as a diagnostic criterion is not necessarily unified. In addition, when the PR interval was extended, terms such as PR prolongation, Prolonged PR interval, PQ prolongation or first-degree AV block,

TABLE 2 Terms recommended for use as abnormal findings of ECG (24 items)

[Axis] right axis deviation, marked right axis deviation, left axis deviation, marked left axis deviation, indeterminate axis
[Q wave/R wave] abnormal Q wave, left ventricular high voltage, poor R wave progression
[PR/QT interval] short PR interval, prolonged QT interval, short QT interval
[ST-T] Brugada type ST-T abnormality (coved type), Brugada type ST-T abnormality (saddleback type), ST elevation, ST elevation (moderate), ST depression, ST depression (moderate), early repolarization, J wave, T wave abnormality (high amplitude), T wave abnormality (low amplitude), T wave abnormality (inversion)
[U wave] prominent U wave, inverted U wave
(See Table S1 in details)

TABLE 3 Diagnostic terms recommended for use from ECG (97 items)

[Sinus abnormality] sinus arrhythmia, sinus tachycardia, sinus bradycardia, Sino-atrial block, sinus arrest
[Ectopic rhythm] ectopic atrial rhythm, AV junctional rhythm, accelerated AV junctional rhythm, idioventricular rhythm, accelerated idioventricular rhythm
[Escape rhythm] AV dissociation, AV junctional escape beat, ventricular escape beat, AV junctional escape rhythm, ventricular escape rhythm
[Intraventricular conduction disturbances] complete right bundle branch block, incomplete right bundle branch block, left bundle branch block, intraventricular conduction disturbance, left anterior hemiblock (fascicular block), left posterior hemiblock (fascicular block), bifascicular block, trifascicular block
[AV block] first-degree AV block (PR prolongation), second-degree AV block (Wenckebach type), second-degree AV block (Mobitz type II), second-degree AV block (2:1 conduction), second-degree AV block (advanced), third-degree AV block (complete AV block), paroxysmal AV block
[WPW syndrome] WPW syndrome
[Pacemaker rhythm] artificial pacemaker rhythm, artificial pacemaker beat
[Supraventricular arrhythmias] supraventricular premature contraction, supraventricular premature contraction (frequent), AV junctional premature contraction, AV junctional premature contraction (frequent), supraventricular tachycardia, atrial tachycardia, atrial fibrillation, tachycardic atrial fibrillation, bradycardic atrial fibrillation, atrial flutter, tachycardic atrial flutter, bradycardic atrial flutter, atrial standstill
[Ventricular arrhythmias] ventricular premature contraction, ventricular premature contraction (couplet), ventricular premature contraction (bigeminy), ventricular premature contraction (trigeminy), ventricular premature contraction (frequent), ventricular premature contraction (multiform), ventricular premature contraction (R on T), non-sustained ventricular tachycardia, sustained ventricular tachycardia
[Cardiac overload / Chamber hypertrophy] left atrial overload (enlargement), right atrial overload (enlargement), left ventricular hypertrophy, right ventricular hypertrophy, biventricular hypertrophy
[Myocardial infarction] anterior myocardial infarction (acute), anterior myocardial infarction (acute, possible), anterior myocardial infarction (indeterminate age), anterior myocardial infarction (indeterminate age, possible), anterior myocardial infarction (old), anterior myocardial infarction (old, possible), anteroseptal myocardial infarction (acute), anteroseptal myocardial infarction (acute, possible), anteroseptal myocardial infarction (indeterminate age), anteroseptal myocardial infarction (indeterminate age, possible), anteroseptal myocardial infarction (old), anteroseptal myocardial infarction (old, possible), lateral myocardial infarction (acute), lateral myocardial infarction (acute, possible), lateral myocardial infarction (indeterminate age), lateral myocardial infarction (indeterminate age, possible), lateral myocardial infarction (old), lateral myocardial infarction (old, possible), inferior myocardial infarction (acute), inferior myocardial infarction (acute, possible), inferior myocardial infarction (indeterminate age), inferior myocardial infarction (indeterminate age, possible), inferior myocardial infarction (old), inferior myocardial infarction (old, possible), pure posterior myocardial infarction (acute), pure posterior myocardial infarction (acute, possible), high lateral myocardial infarction (acute), high lateral myocardial infarction (acute, possible), right ventricular myocardial infarction (acute), right ventricular myocardial infarction (acute, possible)
[ST-T abnormalities] myocardial ischemia (possible), nonspecific ST-T changes, pericarditis (possible), hyperpotassemia (possible), hypopotassemia (possible)
[Others] dextrocardia/situs inversus (possible), low voltage (limb lead)
(See Table S2 in details)

Abbreviations: AV, atrio-ventricular.

have been used as the ECG findings. Since these terms are often interchanged as terms of ECG findings or pathological diagnosis, it is very confusing for non-ECG expert users (Table 2).

Currently, there is no consensus on the critical value criteria to determine whether these findings are truly present. In a 2007 statement from the USA, it was pointed out that many different criteria for ECG diagnosis have been used. Therefore, we hereby described the value that is relatively widely used as a "typical reference value," however, it is important to note that some of them are still controversial.

Electrocardiographic surveys related to Brugada syndrome, which has attracted attention for its association with sudden death in young subjects, have also been recently introduced as automatic diagnosis of ECG. However, various expressions such as "Brugada syndrome suspected," "Brugada type ECG," "coved type ST elevation," "saddleback type ST elevation," etc have been used for the ECG findings. However, the diagnosis of Brugada syndrome should be made based on both characteristic ECG abnormalities as well as past history of syncope and/or family history of sudden cardiac death. Thus we recommend keeping it as an abnormal ECG finding termed as "Brugada type ST-T abnormality (coved type)" or "Brugada type ST-T abnormality (saddleback type)," even their precise ECG criteria are still controversial.

In contrast, when these abnormal findings of ECG are identified, the follow-up action is critically important, and especially for non-cardiologists who may hesitate on the right course of action. Therefore, in this statement, in addition to the typical numerical values (reference values) for the criteria of each observation, the clinical significance and specific medical treatment or follow-up policy recommended on these findings are described in Table S1.

4.1.2 | Terms recommended for diagnosis

ECG diagnostic terms that are considered abnormal based on some pathological changes are listed in Table 3.

Similarly these terms are not unified among ECG automatic diagnosis system. For example, in the diagnosis of second-degree AV block

TABLE 4 Terms not recommended to be used at automatic diagnostics of ECG

Terms not recommended	Explanation
S1S2S3 pattern	A relationship with the right ventricular hypertrophy has been considered, but it has no significant clinical evidence.
S1Q3T3 pattern	A relationship with the right ventricular overload due to pulmonary infarction has been considered, but the specificity and clinical significance are not high.
RSR' pattern	It is thought to represent right ventricular conduction delay, but the difference with incomplete right bundle branch block or Brugada type ECG abnormalities is not clear.
Clockwise rotation	It does not represent a particular disease or condition, and has poor clinical significance.
Counter-clockwise rotation	It does not represent a particular disease or condition, and has poor clinical significance.
Low voltage (chest lead only)	This abnormal finding is recognized in obesity, etc Low voltage both in limb and chest leads may indicate cardiac or extra-cardiac diseases.
Supraventricular premature contractions (couplet, bigeminy, trigeminy)	Clinical significance is not clear.
Supraventricular premature contractions (short run)	This diagnostic statement is included in non-sustained atrial tachycardia or supraventricular tachycardia
Ventricular premature contractions (short run)	This diagnostic statement is included in non-sustained ventricular tachycardia

showing the so-called Wenckebach period, the terms "Wenckebach type second-degree AV block," "Mobitz type I second degree AV block," "second-degree AV block (Wenckebach period)," etc have been used. Although "Mobitz type I" was a possibility as "Wenckebach" represents a specific cycle, the terms "Mobitz type I" and "Mobitz type II" are a possibly confusing. As the term "Wenckebach type" is already widely used in the clinical practice, we decided to adopt "second-degree AV block (Wenckebach type)" as a recommended diagnostic term in the automatic diagnosis of ECG in Japan.

For automatic diagnosis of myocardial infarction in ECG, information on the site of infarction and time of onset is critical in clinical practice. However, it is sometimes difficult to make accurate judgments on these with only one ECG recording, even with a specialist. If the time of infarct onset in unclear based on the ECG, we recommend the term "indeterminate age." In addition, if each result is not definitive, we have added the term "possible." While site of myocardial infarction are clearly stated in the 2007 recommendation statement from the USA, the phase of the infarction process is absent. Consequently, terms or classifications of myocardial infarction are absent in the Minnesota code, except for descriptions on ST-T changes or Q waves.

For the diagnostic terms, we kept in mind the expressions that are easy to understand and as widely used as possible. However, some of them represent confusing expressions and complex conditions, and we have therefore provided Table S2 to explain these terms as accurately as possible.

4.2 | Terms to be avoided for use in automatic diagnosis of ECG

The terms shown in Table 4 include those that have been often used in ECG evaluation in general practice. However, many panel members indicated that these terms should be avoided in automatic diagnosis of ECG, because relation to the pathological condition is unclear and the clinical significance is consequently low. Furthermore, the definition for some terms is ambiguous and the critical findings for evaluation are not established. Therefore, these terms were deemed not suitable for use in automatic diagnosis of ECG. The reasons for avoidance has been described as much as possible, and include terms for example, bigeminy, trigeminy, and couplets that have appeared in the 2007 recommendation from the USA.

4.3 | Implementation to new electrocardiograph models

Sudden changes or modifications in terminology may cause severe confusion in the clinical field, since it contains many widely used terms. In order to prevent this confusion, we are not requiring each ECG manufacturer to use them on a new model or to unify between manufacturers. This is a recommendation as a direction or guideline for future changes or improvements based on the results of this study.

5 | CONCLUSION

As there are many problems that require immediate attention in the current automated diagnosis of ECG, we established a panel to study automated diagnosis of the electrocardiogram in Japan. The study group comprised physicians and researchers specializing in electrocardiology, and engineers of electrocardiograph manufacturers as core members. For the past several years, we have started on activities to further enhance the clinical utility of the automated

diagnosis of ECG by objectively analyzing these problems and addressing them.

As an initial step, we have extracted and organized the variety of problems related to current automated diagnosis of ECG. Subsequently, we considered measures for improvement. Here, we have proposed the possibility of the standardization of terms used for automated diagnosis of ECG as an expert consensus statement.

The key aim of this study group is to further improve the utility of the automated ECG diagnosis system and improvement of the actual accuracy of automated diagnosis is mandatory. In our next step, we are planning to create a large database of ECG associated with problematic automated diagnosis from our members. We hope that the results of these activities will lead to increases in clinical utility of automated diagnosis of ECG, which is widely used globally.

CONFLICT OF INTEREST

All authors declare no conflict of interest to this article.

APPENDIX

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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