Clinical applications

Advances in ECG recognition of acute myocardial ischemia/infarction

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Acute occlusion of a coronary artery leads to the irreversible loss of cardiac muscle and with it, unstable cardiac rhythms, including ventricular fibrillation and sudden death, and impaired contractility resulting in heart failure. The ability to identify and open the occluded vessel and to restore blood flow with thrombolytic drugs, coronary angioplasty or bypass surgery prior to the onset of these irreversible changes will prevent the above-mentioned consequences.

The electrocardiogram (ECG) is the one and only test currently available that can be recorded virtually anywhere an electrocardiograph is present. It provides an immediate result that can be quickly interpreted by trained personnel and/or by an automated, computerized electrocardiograph with interpretive algorithms, provided these automated algorithms are accurate and dependable. The ability to open acutely occluded coronary arteries before myocardial cell necrosis occurs is one of the most dramatic advances in the care of patients with coronary artery disease, but this ability is time-dependent. For this reason, the more rapidly the diagnosis of acute ischemia/infarction is made, the more likely the chance of successful intervention. Similarly, the more able an automated computerized ECG system is able to accurately detect an acute ischemic event and to provide the physician with information that will aid him/her in the choice of diagnostic and therapeutic options, the more useful and potentially life saving it becomes.

Recently, the ECG and Arrhythmia Committee of the American Heart Association (AHA), in concert with the American College of Cardiology (ACC) and the Heart Rhythm Society (HRS) published a series of Scientific Statements concerning recommendations for the standardization and interpretation of the ECG [1-6]. These recommendations recognized and took into consideration the changes in technology, the recently recognized ECG manifestations of both cardiac and non-cardiac diseases that affect the electrical activity of the heart, and the correlative information obtained from newly developed imaging modalities such as echocardiography, magnetic resonance imaging, and a variety of nuclear techniques that have been developed within the last 25 years. These recommendations considered the Technology (Part I), Nomenclature (Part II), Intraventricular Conduction Disturbances (Part III), Repolarization and the QT Interval (Part IV), Chamber Enlargement (Part V) and Acute Ischemia/Infarct (Part VI).

The purpose of this article is to discuss the recent changes in our understanding and interpretation of the electrocardiographic manifestations of acute myocardial ischemia and infarction that are reflected in the recommendations in Part VI of the standards documents, and to relate the new features contained in the Philips DXL diagnostic ECG algorithm [7] to these recommendations. The changes in our appreciation of the electrocardiographic changes of acute ischemia/infarction are important because they impact on our ability to diagnose more promptly and accurately acute myocardial ischemia and infarction, and because they provide clues as to the precise location of the lesion responsible for the ischemic event. As such, they carry with them the opportunity to affect therapeutic decisions that are capable of altering the natural history of this debilitating and potentially lethal disease.

The recommendations contained within the AHA/ACC/HRS Scientific Statement considering acute ischemia/infarction (Part VI) [6] include the following:

1. That labeling specific leads as anterior/inferior/lateral be avoided. Rather leads should be labeled according to their original nomenclature, i.e. I, II, III etc.
2. That the electrocardiograph be equipped with switching systems that allow the limb leads to be displayed in their anatomically contiguous sequence, i.e. aVL, I - aVR, II, aVL, III if so desired by the user/institution
3. That threshold values for abnormal J-point elevation or depression be adjusted for age and gender
4. That software capable of displaying the ST segment spatial vector in the frontal and transverse planes be employed
5. That algorithms be employed to suggest, whenever possible, the occluded artery and the site of the occlusion within that artery
6. That ECG machines be programmed to suggest recording of the right-sided chest leads V3R and V4R in the appropriate setting; that they be able to label these leads; and that algorithms be developed to describe and interpret abnormalities that may occur in these leads
7. That use of the term “posterior” be retained, at least for the present
8. That algorithms suggesting ischemia/infarction in the presence of left bundle branch block that meet recently described criteria be employed
9. That algorithms capable of determining the “Selvester Score” be made available for optional use by the reader.

We will briefly summarize the rationale for these recommendations which are considered more completely in the original articles [1-6].

The first recommendation recognizes that all leads are actually bipolar (the negative pole of the chest leads being Wilson’s central terminal, comprised of the leads I, II and III) and that the various components of the ECG waveform, i.e. the QRS complex, ST segment, T and U waves, may be negative as well as positive. As such they not only reflect electrical events that are directed towards the positive electrode, which in the case of the chest leads is the recording electrode, but also those occurring 180° away from the positive electrode. For instance, a negative QRS complex in V1 reflects a QRS spatial vector directed away from this lead, i.e. posteriorly and to the left, as anticipated by the greater mass of the left ventricle which is located posteriorly and to the left. Similarly, depression of the ST segment in V1 reflects an ST segment spatial vector that is directed away from this lead as occurs in acute ischemia/infarction of the posterior wall. Thus, the leads provide information from the entire heart and not just from the area under the respective positive lead.

The second recommendation recognizes that the current display of the frontal plane leads in groups of three (I, II, III and aVR, aVL, and aVF) are traditional and does not present the leads in their anatomically contiguous sequence. This is accomplished by the Cabrera format of aVL, I, -aVR, II, aVF, III. This format was recommended in the 2000 European Society of Cardiology/ American College of Cardiology guidelines [8]. It is the current standard and commonly used in Sweden and Spain.

The third recommendation recognizes that the junction of the beginning of the ST segment with the end of the QRS complex, the J point, is normally slightly elevated, particularly in the chest (V) leads, and that the amount of this normal ST elevation is age-, gender- and lead-dependent. In general, the J point is highest in leads V2 and V3 and is greater in men than in women. For these reasons thresholds that vary from 0.05 to 0.2 mV (0.5 to 2 mm at standard calibration), depending on the factors identified above, are recommended for these leads.

Recommendations 4, 5 and 6 are interrelated and are based on the recognition that the coronary artery housing the culprit lesion and the location of the lesion within that vessel (i.e. proximal or distal) can often be predicted from analysis of the leads with ST segment depression as well as ST segment elevation, and that this ability might influence the decisions of those having initial contact with the patient, such as Emergency Medical technicians, Emergency Department nurses and Emergency Department physicians.

Analysis of the leads with depression as well as elevation of the ST segment allows creation of the ST segment spatial vector. This permits identification of the region of the heart affected by the acute ischemia/infarction and, by inference, the site of the culprit lesion. For instance, occlusion of the left anterior descending coronary artery (LAD) causes ischemia and infarction of the anterior/lateral wall of the left ventricle and, depending on the length of the vessel, on the cardiac apex. This results in an injury current that will be directed to the left, towards the positive poles of leads V2-V6, resulting in elevation of the ST segment in some or all of these leads. If the lesion is in the proximal portion of the LAD, the basal portion of the left ventricular wall will also be involved and the spatial vector of the ST segment will also be directed superiorly, towards the positive poles of leads I and aVL and away from the positive poles of leads III and aVF. This will be reflected by elevation of the ST segment in leads aVL and I, and depression of the ST segment in leads III and aVF. If the lesion is in the mid- or distal portion of the LAD, the basal region of the left ventricle will not be affected and the ST segment changes in leads aVL, I and III, and aVF will not occur.
Occlusion of the posterior descending coronary artery, regardless of whether it arises from the right or left circumflex coronary artery, will cause acute ischemia/infarction of the posterior wall of the left ventricle. The injury current and, therefore, the spatial vector of the ST segment will be directed posteriorly, away from the positive poles of leads V1 and V2, which are located anteriorly. This will result in depression of the ST segment in these leads.

Since there are no chest leads routinely placed over the posterior wall of the left ventricle (in the V7, V8, and V9 positions), there will be no ST segment elevation recorded in any of the routinely recorded chest leads. If, as usually occurs, the inferior surface of the left ventricle is also involved, elevation of the ST segment will be present in leads II, III and aVF.

If the culprit lesion is in the proximal portion of the right coronary artery, the right ventricle will also be affected and an injury current will be directed to the right and anteriorly as well as inferiorly, i.e. towards the positive pole of lead III and away from the positive pole of aVL. As a result the ST elevation will be greater in lead III than in lead II and ST depression will be present in aVL. In this situation, recording from leads with the positive pole placed over the right ventricle in positions referred to as V4R and V3R will reveal ST elevation.

If both the right ventricle and posterior wall of the left ventricle are involved, the injury current directed anteriorly and to the right may be cancelled by the injury current that is directed posterior and to the left, with the result that ST depression in leads V1 and 2 may not occur and the ST elevation in leads V4R and V3R will be attenuated. However, the ST segment spatial vector will still be directed inferiorly and to the right; the elevation of the ST segment will still be greater in lead III than in lead II and ST depression will still be present in lead aVL.

Thus, by considering the leads with depression as well as elevation of the ST segment, the spatial vector of the ST segment can be generated and from that, the location of the culprit lesion can be predicted. This is facilitated by the ability to record, label and interpret leads V3R, V4R, V7, V8 and V9 as well as the standard V leads.

Recommendation 7 is included because of recent information obtained from magnetic resonance imaging studies which suggests that the myocardial region referred to as “Posterior” on the basis of autopsy studies is actually lateral, and some have suggested that ECG nomenclature should be changed to recognize this fact [9]. However, it was decided that while this may become the consensus in the near future, the current terminology should be retained for the present.

Recommendation 8 recognizes that criteria for diagnosing infarction in the presence of left bundle branch block have been published [10] and, although there is some controversy regarding the sensitivity and specificity of these criteria, it is recommended that algorithms employing these criteria be developed to suggest the possibility of acute/ischemia in the setting of left bundle branch block.

Recommendation 9 is self-explanatory. The Selvester score is a QRS scoring system used to quantitate infarct size [11]. It correlates well with infarct size measured by other techniques, and although not in widespread clinical use at the present time, is likely to become more popular in the future.

The new Philips DXL diagnostic ECG algorithm contains several features that pertain to the recommendations discussed above [7]. These include the following:

• Appropriate lead labels using original nomenclature
• Availability of anatomically contiguous lead sequence in aVL, I, -aVR, II, aVL, III
• Age-, gender-, and lead-specific differences in thresholds for ST segment elevation
• Capability of recording, labeling and interpreting leads V3R, V4R, V5R, V7, V8 and V9
• When an acute inferior wall infarct is detected and right chest leads are not connected, the algorithm suggests recording of right chest leads to check for right ventricular involvement
• Visualization of ST segment vector “ST-Map”
• Identification of culprit lesion
• Recognition of ECG changes indicative of left-, main- or multi-vessel occlusion.

In addition, a new “Critical Value” feature in the Philips DXL algorithm helps identification of ECG changes associated with life-threatening situations requiring immediate medical attention.

Examples of tracings and the associated automated interpretations produced by the DXL algorithm are shown in Figures 1, 2, and 3. The tracings are from three patients with symptoms suggesting an acute coronary event.

In Figure 1, the changes are those associated with an acute inferior wall infarction with posterior wall involvement, and these are recognized by the DXL algorithm. In this patient, leads V3R,
V4R (the leads placed on the right side of the sternum) and leads V8 and V9 (the chest leads positioned on the back, i.e. the posterior leads), in addition to the routine 12 leads, are recorded and considered in the interpretation. Note that the interpretation also identifies the culprit lesion as being in the Right Coronary Artery (RCA). Had the lesion been in the circumflex coronary artery, the changes indicating an infero-posterior infarction would still have been present and the injury current would have still have been directed inferiorly but the ST segment would not have been more elevated in lead III than in lead II (indeed, it may have been greater in lead II than in lead III) and there would not have been ST segment depression in lead aVL. This identifies an injury current directed slightly to the right as well as inferiorly. This spatial orientation of the ST segment is illustrated in the ST-Map derived from the limb leads, i.e. the frontal plane ST vector.

The diagnosis of the posterior infarction results from the ST segment depression in leads V2 and V3 and the ST segment elevation in lead V9. These ST segment changes identify the posteriorly directed injury current which is shown in the ST-Map that is derived from the V leads, i.e. the horizontal plane ST vector. In this patient, the right ventricle might also have been infarcted as the result of the right coronary artery occlusion, but the characteristic ST elevation in the right-sided chest leads V1, V3R, and V4R indicative of the anteriorly and rightward directed injury current associated with the right ventricular infarction is cancelled by the posteriorly and leftward directed injury current associated with the posterior infarction.

Figure 2 shows the changes associated with an acute infarction of the left ventricular anterior and lateral walls. Note the ST segment elevation in leads I, II and aVL and in leads V2-V4. Note also the ST depression in lead III. In this example the ST segment vectors in the frontal plane (derived from the limb leads) and the horizontal plane (derived from the V leads) are shown. In the frontal plane, the ST vector is oriented to the left and slightly superiorly, reflecting the ST elevation in I and aVL and depression in lead III. In the horizontal plane, it is oriented to the left, anteriorly and laterally. The left and anterior orientation of the vector suggests that the anterior and lateral aspects of the left ventricular wall are involved, while the left and slightly superior orientation of the frontal plane vector suggests that the basal aspect of the left ventricle is also involved. It is this combination of findings that prompts the diagnosis of an occlusion of the left anterior descending coronary artery (LAD) which is included in the computerized reading. Indeed, the involvement of the basal portion of the left ventricle, as indicated by the ST segment changes in leads aVL and III, indicate that the culprit lesion is in the proximal portion of the LAD.
Figure 3 shows marked ST segment depression in leads I, II, aVF and leads V2-V6. There is ST segment elevation only in lead aVR. There is also atrial fibrillation and the possibility of combined ventricular hypertrophy. It is possible that the diffuse ST segment depression could be caused by ventricular hypertrophy and perhaps by digitalis, if the drug was being administered. However, in a patient with symptoms suggesting an acute coronary event, these ST segment changes are highly suggestive of a subtotal occlusion of the left main coronary artery or severe diffuse three-vessel coronary artery disease. The ST segment vector is directed away from all the body surface leads, with the exception of lead aVR, indicating that it is directed inwardly from the epicardium towards the endocardium and the right shoulder. This is a most important electrocardiographic finding because it warns of the presence of a life-threatening event demanding immediate medical attention. The critical value printed on the report “Acute Ischemia” serves this purpose.

These tracings exemplify many of the features of the DXL ECG algorithm and satisfy recommendations 1-7 listed above. The threshold values for J-point elevation and depression of the ST segment that are appropriate for the age and sex of the patients have been applied (Recommendation 3); leads V4R, V3R, V8 and V9 are recorded, labeled and interpreted automatically when appropriate (Recommendation 7); the ST vectors in the frontal and horizontal planes are displayed utilizing information from all leads (Recommendation 4) and this information is then processed to facilitate identification of the culprit lesion (Recommendation 5). The DXL algorithm is available with Philips electrocardiograph PageWriter TC series in 12-lead, 15-lead or 16-lead configurations and other user specific lead configurations, as shown in Figure 4 (12). The DXL algorithm is also available with Philips defibrillator/monitor HeartStart MRx in 12-lead configuration, as shown in Figure 5 [13].

These tracings and the other advances in the DXL ECG algorithm referred to above also illustrate the dynamic nature of the electrocardiogram, and its ability to meld advances in the understanding of the electrical activity of the heart with the recognition of new diseases having an electrocardiographic...
signature such as Arrhythmic Right Ventricular Dysplasia/Cardiomyopathy. They also demonstrate the improved ability to visualize the heart in vivo utilizing new and improved imaging techniques, and the advances in computer technology to provide more comprehensive and accurate diagnostic statements that impact directly on patient care.

It is reasonable to anticipate that, in the future, ECG nomenclature will change as correlations to the newer imaging techniques become more robust and that interpretative statements will evolve to reflect the increased informational content of the electrocardiogram.

**References**


