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Special Article

Abnormalities of the S-T Segment—Part II

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Primary S-T Segment Abnormalities (S-T Not Locked to T)

Myocardial Infarction

There are three abnormalities associated with many, but not all, acute myocardial infarctions (Fig. 5). The myocardial *dead* zone is larger in the endocardial than in the epicardial portion of a segment of the myocardium. The area of *injury* surrounding the dead zone is usually larger in the epicardial area than in the endocardial area. The area of *ischemia* surrounding the area of injury is larger in the epicardial area than in the endocardial area of the myocardium.

The dead area alters the initial portion of the QRS complex. The mean initial 0.02–0.04 s vector is directed away from the segment of endocardium where the dead area is located. The mean S-T segment vector is directed toward the area of segmental epicardial injury that surrounds the dead area. The mean T vector is directed away from the area of segmental epicardial ischemia.

Most infarcts are located in the left ventricle and septum, but involvement of the right ventricle is currently being recognized more often than it was in the past. The diagram shown in Figure 5 illustrates the anatomic orientation and shape of the left ventricle. One can predict the electrocardiographic (ECG) patterns that would be produced when one imagines an infarct located in several different segments of the left ventricular myocardium. Note that the S-T segment and T-wave vectors tend to be relatively opposite each other in most instances. It should be pointed out also that the direction of the S-T segment vector is more likely to identify the location of the infarction than the mean T-wave vector or mean initial 0.04 s vector. This is because the S-T segment displacement is more often a new electrical force, whereas an initial 0.04 s vector and a T-wave vector were present before the infarct. They may have been normal or abnormal before the infarct. The new tracing will show the vector sum of the new electrical forces plus the old electrical forces, whereas the S-T segment vector is more likely to represent a single new abnormality.

The prognosis of a patient with myocardial infarction is better, with or without thrombolytic therapy, when the S-T segment displacement disappears in 3 to 4 h than it is when the S-T segment displacement lasts for a longer period of time.[9, 10]

The mean S-T segment vector is directed anteriorly and slightly to the left when there is an anterior infarction, at 0° to +60° in the frontal plane and anteriorly when there is an anterolateral infarction, inferiorly and slightly posteriorly when there is an inferior myocardial infarction, posteriorly when there is a true posterior infarction, and to the right and anteriorly when there is a right ventricular-inferior myocardial infarction.

There are three types of primary S-T segment displacement that deserve emphasis in patients with myocardial infarction.

Right ventricular infarction: This type of infarction occasionally accompanies an inferior infarction. The S-T segment vector is directed inferiorly, to the right, and anteriorly (Fig. 6A) and is caused by predominant epicardial injury. The farther the S-T segment vector is directed to the right and anteriorly, the more likely there is to be infarction of the body of the right ventricle as well as infarction of the inferior portion of the left ventricle. This is usually due to acute obstruction of the proximal portion of the right coronary artery.

Apical infarction: This uncommon infarction may not produce an abnormal initial 0.04 s vector because there is no myocardium opposite the cardiac apex. Ordinarily, the abnormal Q wave that results from the abnormally directed initial 0.04 s vector is produced by the intact endocardium that is opposite the infarction. Hence, with apical infarction there may be no abnormal Q wave because the aortic valve is opposite the apex. The diagnostic problem produced by an apical infarction is that it produces an S-T vector due to acute epicardial injury that is directed toward the cardiac apex (Fig. 6B). The direc-

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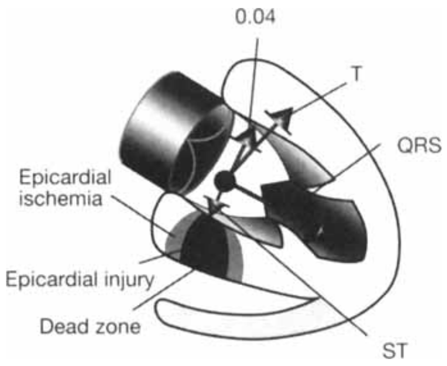


FIG. 5 Electrocardiographic abnormalities associated with myocardial infarction. The dead area in this example is located inferiorly. It is largest in the endocardial area and smallest in the epicardial area. The zone of injury surrounds the dead zone and is largest in the epicardial area. The area of ischemia surrounds the area of injury and is largest in the epicardial area. The arrow representing the mean initial 0.03–0.04 s QRS vector is directed away from the dead zone. The arrow representing the mean S-T vector points toward an area of epicardial injury. The arrow representing the mean T vector points away from the area of epicardial ischemia. Reproduced from Ref. 3, p. 362, with permission.

tion of the mean T vector may not be altered significantly early in the process of apical infarction; perhaps the apical epicardial injury dominates initially. During the early stage of this infarction, the mean S-T vector is directed parallel with the mean T vector. The S-T segment abnormality is a primary S-T segment change because the area of injury, which produces the S-T segment, has not, at that early stage of infarction, changed to an area of ischemia that produces the abnormal T waves. This type of S-T segment displacement simulates the S-T vector of early generalized pericarditis (see later discussion).

Endocardial infarction: Endocardial injury from intense myocardial ischemia of the left ventricle is usually generalized and is recognized by studying the S-T segment of the ECG (Fig. 6C). It commonly occurs in patients with left ventricular hypertrophy, obstructive coronary artery disease, and hypotension from a cardiac or noncardiac cause.

The QRS complex may be normal. The Q-T interval is either normal or prolonged. The S-T segment vector is directed away from the centroid of generalized endocardial injury. Accordingly, it is directed away from the presumed location of the cardiac apex and a normally directed T vector.

The T waves may be normal in size and normally directed, or they may be larger than normal but normally directed because of generalized endocardial ischemia.

Endocardial infarction should be diagnosed when a new S-T vector (as described above) appears and lasts for several hours. The entire endocardium of the left ventricle may be infarcted in such patients. More commonly, the signs of prolonged endocardial injury give way to the more common ECG signs of infarction.

The most common abnormalities that must be differentiated from subendocardial injury are the abnormalities seen in the ECG of patients who are taking digitalis. The Q-T interval is usually shorter than normal when digitalis is causing the abnormality. In addition, the terminal T wave is small when digitalis is responsible for the S-T segment abnormality. The S-T vector is directed relatively opposite to the direction of the mean QRS vector and the small mean terminal T vector. As discussed earlier, the S-T segment displacement produced by digitalis is actually due to very early repolarization. When the S-T segment displacement is due to digitalis and the S-T vector is opposite the mean terminal T vector, it is in reality a secondary S-T segment abnormality because it is part of the T wave. The direction of the S-T segment vector represents an exception to the rule that an S-T segment vector that is not directed relatively parallel to the mean T vector is a primary S-T segment abnormality.

Pericarditis

Pericarditis is usually generalized but may be localized.

Acute early generalized pericarditis: Acute early generalized pericarditis, as it occurs in viral infections, produces acute generalized epicardial damage. The epicardial portion of the myocardium becomes involved to a varying degree. The myocardial damage causes ECG abnormalities. The S-T segment vector that represents the S-T segment displacement in the ECG is directed toward the centroid of the generalized epicardial injury (Fig. 6D). The mean S-T vector is directed to the left, inferiorly, and is parallel with the frontal plane or slightly anterior to it. The T waves may change very little initially.

Years ago it was customary to refer to the S-T segment displacement of generalized pericarditis as being concordant; that is, the S-T segment was elevated in the three bipolar extremity leads. Later, when the unipolar extremity leads were added, it was necessary to add an exception because the S-T segment was displaced downward in lead aVR. These descriptive terms are not needed when one uses the vector concept and uses an arrow to indicate the direction of the mean S-T vector. To state the S-T segments are concordant, as they are in generalized pericarditis, or discordant, as they are in myocardial infarction or localized pericarditis, is simply a cumbersome way of describing the direction of the mean S-T vector.

As hours and days pass, the S-T segment displacement of generalized pericarditis diminishes and an abnormal mean T vector appears. The latter is commonly directed opposite to the cardiac apex and is usually directed opposite to the original direction of the mean T vector. It is commonly directed opposite to the mean QRS vector. Still later, the S-T segment displacement may return to the base line of the ECG, and the T vector, which is directed opposite to its original direction, may become more prominent. Finally, the abnormal T-wave vector may return to normal or a residual T-wave abnormality may persist.

The S-T segment displacement of generalized pericarditis must be differentiated from the S-T segment displacement of apical myocardial injury related to infarction. The S-T segment displacement is usually larger in patients with infarction than it is in patients with pericarditis. This difference, regrettably, is not always sufficiently apparent to be consistently diagnostic. Unfortunately there is no way to separate these two

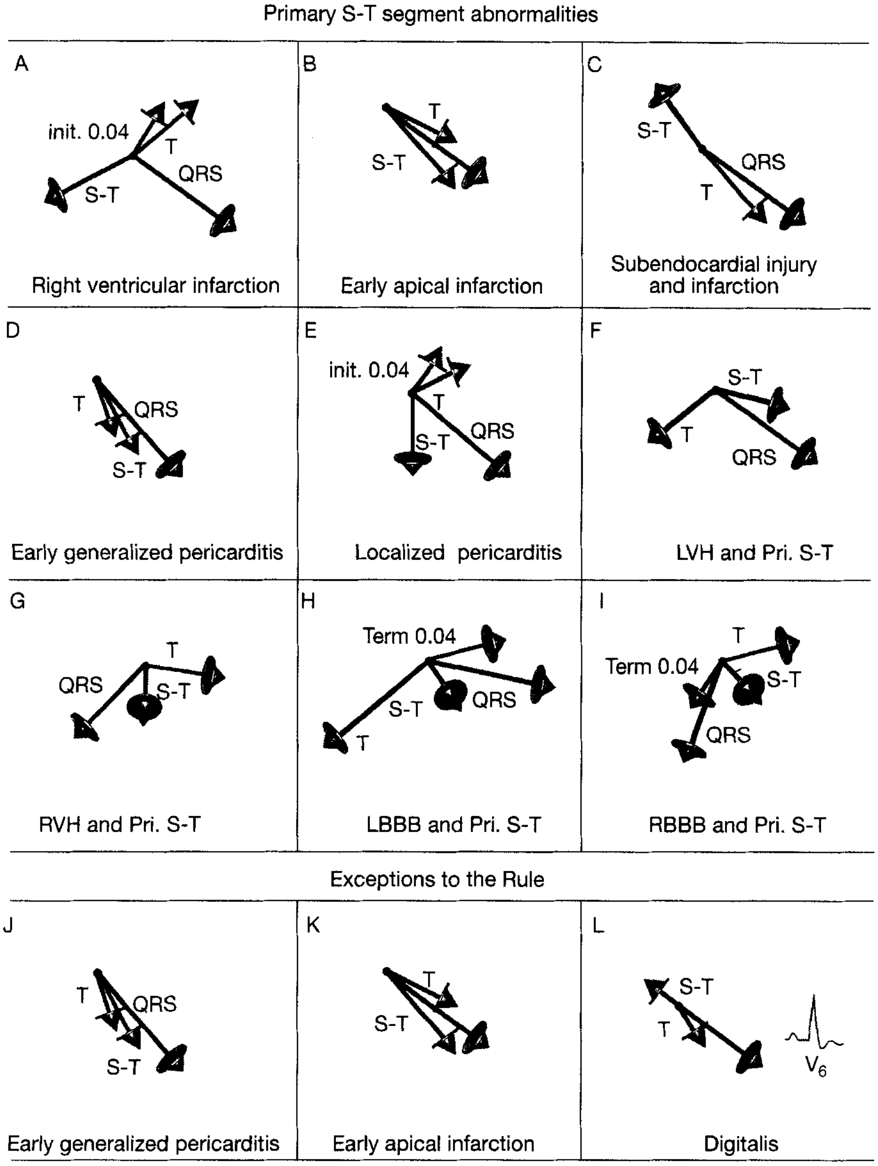


FIG. 6 Primary S-T segment abnormalities. Note that the S-T vector is not relatively parallel to the T vector in A, C, E, F, G, H, and I, because it is a *primary S-T segment vector*. The exceptions to the rule are duplicated in J and K where the S-T segment vector is parallel to the T vector, but is a primary S-T force. The S-T vector is opposite to the QRS vector and T vector in L but is a *secondary S-T segment* vector; this is another exception to the rule (see text). LVH = left ventricular hypertrophy, RVH = right ventricular hypertrophy, LBBB = left bundle-branch block, RBBB = right bundle-branch block.

abnormalities at all times by electrocardiography. The clinical syndromes are, of course, usually quite different. There are rare cases, however, in which it is not possible to make a definite diagnosis by ECG.

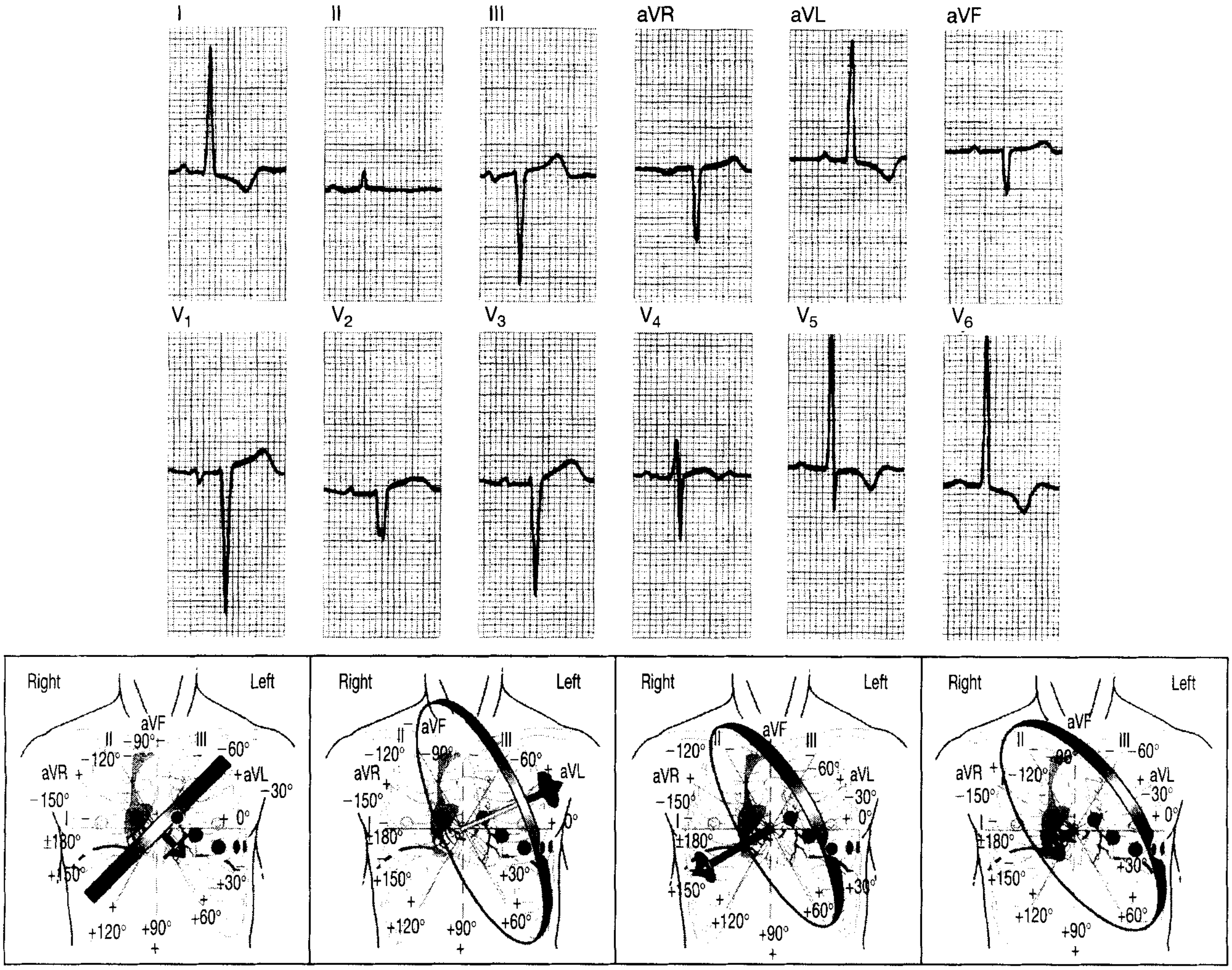
Localized pericarditis: Localized pericarditis can occur in the left ventricle secondary to trauma, cardiac surgery, or myocardial infarction.

The S-T segment vector in patients with localized pericarditis due to trauma or cardiac surgery may be directed toward the localized epicardial injury of a segment of the left ventricle. The mean T vector may be directed away from the area of segmental epicardial ischemia. This, of course, simulates myocardial infarction.

The pericarditis of myocardial infarction deserves special emphasis. When the mean S-T vector, which is directed toward the epicardial injury, becomes abruptly larger it may be due to localized pericarditis (Fig. 6E). This is an ominous finding because the possibility of myocardial rupture is in the offing.

Primary S-T Segment Displacement in Patients with Left or Right Ventricular Hypertrophy and Left and Right Bundle-Branch Block

As discussed earlier, S-T segment displacement occurs in patients with left or right ventricular hypertrophy and in those with left or right bundle-branch block. When the S-T segment



(A) Mean P vector (B) Mean QRS vector (C) Mean T vector (D) Mean ST vector

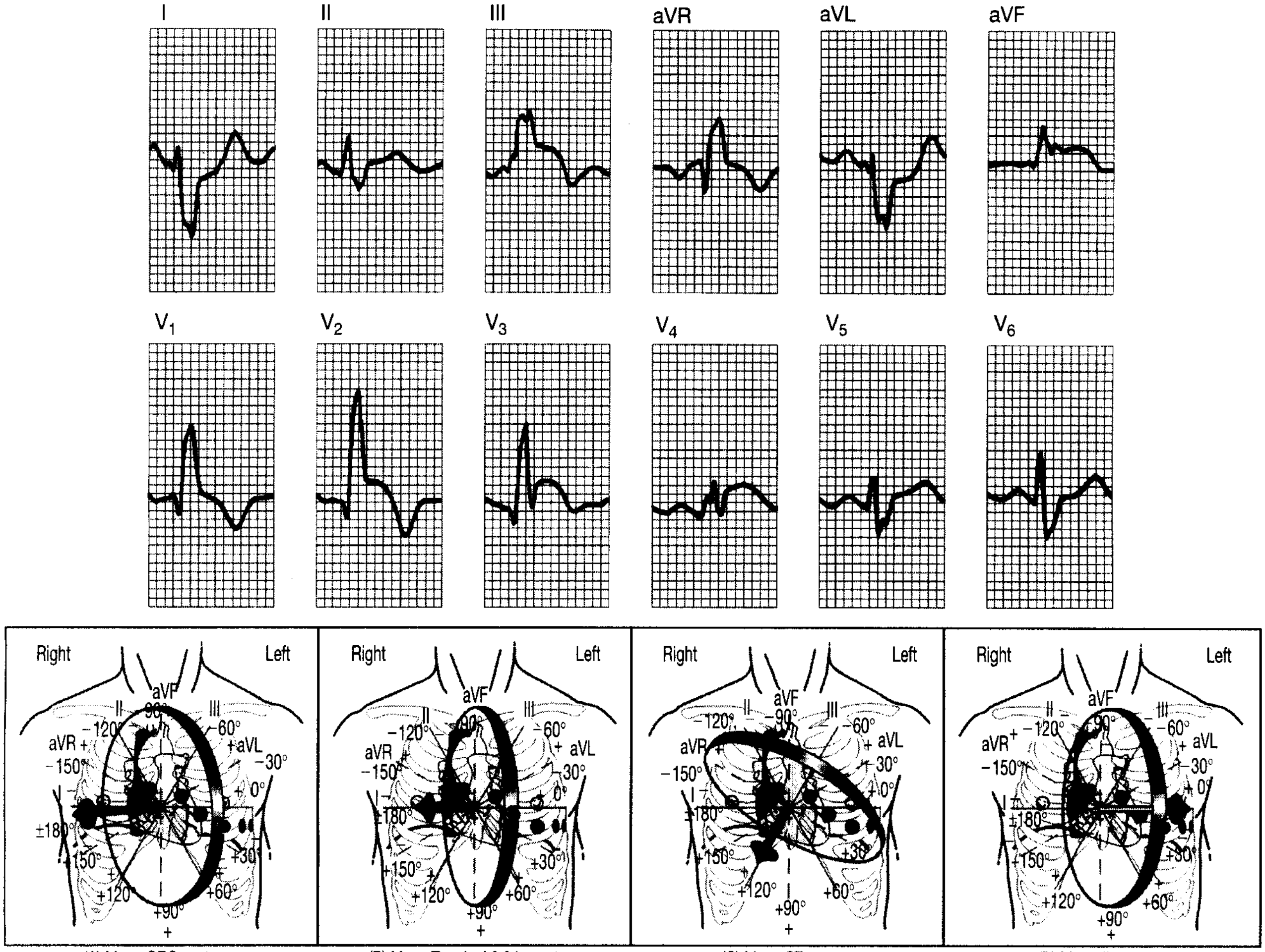
FIG. 7 Left ventricular hypertrophy due to systolic pressure overload of the left ventricle. Rate and rhythm: Rate = undetermined on short strip. There were 70 depolarizations per minute in a longer strip; rhythm = normal sinus rhythm. Intervals: P-R interval, 0.20 s; QRS duration, 0.09 s; Q-T interval, 0.40 s. Vector diagrams of the electrical forces: See (A), (B), (C), and (D) below the electrocardiogram. Electrophysiological considerations: The P-R interval is 0.20 s; this is at the upper limit of normal but is more likely to be abnormally long for this individual patient. The mean P vector is directed about +50° inferiorly and is parallel with the frontal plane. The last half of the P wave in lead V_1 measures −0.08 mm/s. This indicates a definite left atrial abnormality. The mean QRS vector is directed about −25° to the left and 50°–60° posteriorly. The 12-lead QRS amplitude is 202 mm. This indicates left ventricular hypertrophy. The *mean T vector* is directed +150° to the right and 30° to 40° anteriorly. Note that it is directed opposite to the mean QRS vector. The *mean ST vector* is parallel with the mean T vector. It is characteristic of a *secondary S-T segment abnormality.* These abnormalities are characteristic of left ventricular hypertrophy due to systolic pressure overload of the left ventricle. Clinical differential diagnosis: Systolic pressure overload of the left ventricle may be caused by aortic valve stenosis, systemic hypertension, primary hypertrophy of the heart, or may occur late in the course of aortic regurgitation. This electrocardiogram was recorded from a 66-year-old man with aortic valve stenosis. The systemic gradient across the aortic valve was 119 mmHg. Reproduced from Ref. 3, p. 283, with permission.

displacement is represented as a vector that is directed relatively parallel with the mean T vector, it is labeled as a secondary S-T segment abnormality; in other words, it is due to repolarization and is therefore part of the T wave; if this is not the case, it is most likely due to electrical forces that are unrelated to repolarization and is therefore labeled as a primary S-T segment abnormality (Figs. 6F–6I). This type of S-T segment abnormality is often caused by epicardial injury due to myocardial infarction. It is one of the three ways uncomplicated bundle-branch block becomes complicated.

Summary

When the S-T vector is not directed relatively parallel with the direction of the mean T vector it is labeled as a primary S-T segment abnormality. This implies that the S-T segment displacement is due to electrical forces that are independent of the electrical forces produced by ventricular repolarization.

There are three exceptions to this rule. The early phase of generalized pericarditis or early apical myocardial injury due to infarction produces an early S-T vector that is parallel with



(A) Mean QRS vector (B) Mean Terminal 0.04s vector (C) Mean ST vector (D) Mean T vector

FIG. 8 Complicated right bundle-branch block plus left posteroinferior division block, primary T-wave abnormality, and primary S-T segment abnormality. Rate and rhythm: Rate = undetermined in short strip. There were 104 depolarizations/min in a longer strip; rhythm = sinus tachycardia. Intervals: P-R interval = 0.15 s; QRS duration = 0.12 s; Q-T interval = 0.36 s. Vector diagrams of electrical forces: See (A), (B), (C), and (D) below the electrocardiogram. Electrophysiologic considerations: The P waves are normal. The duration of the QRS complex is 0.12 s. The *mean QRS vector* is directed about +175° to the right and about 50° anteriorly. This degree of rightward deviation of the mean QRS vector is greater than it should be when there is uncomplicated right bundle-branch block. The mean terminal 0.04 s QRS vector is directed +180° to the right and about 25° to 30° anteriorly, signifying the presence of right bundle-branch block. The mean terminal 0.04 s QRS vector is directed farther to the right and more anteriorly than it is when there is uncomplicated right bundle-branch block. The extreme rightward deviation of the mean QRS vector and mean terminal 0.04 s QRS vector is probably caused by additional left posteroinferior division block. The *mean S-T vector* points toward an area of epicardial injury. It is directed about +120° inferiorly and about 30° anteriorly and is caused by an inferoanterior myocardial infarction. Note that this is a *primary S-T segment* abnormality because the mean S-T vector is not parallel with the mean T vector, as it is when there is a secondary S-T segment displacement. The *mean T vector* is directed at ±0° in the frontal plane and about 35° posteriorly. The ventricular gradient is abnormal, suggesting myocardial ischemia. Clinical differential diagnosis: This cluster of electrocardiographic abnormalities is due to an acute inferior-anterior myocardial infarction. A portion of the right ventricle may also be infarcted. No other diagnostic option should be considered. Discussion: This electrocardiogram was recorded from a 56-year-old man with an acute myocardial infarction. Coronary arteriography revealed 80% obstruction of the left anterior descending coronary artery, which wrapped around the cardiac apex, 70% ob-struction of the first diagonal, and 60% obstruction of the right coronary artery. Reproduced from Ref. 3, p. 345, with permission.

the mean T vector (Figs. 6J, 6K). It is a primary S-T segment abnormality even though the mean S-T vector is relatively parallel with the mean T vector. The final exception is produced by the secondary S-T segment abnormality due to digitalis in which the S-T segment vector is directed opposite to the mean QRS vector and the original mean T vector, but is in reality part of the T wave (Fig. 6L).

Limitations of the Method

There are two factors that limit the utility of the approach discussed here.

1. The words "relatively parallel," "in general," "tends to," and "directed away from" used here are nonscientific expressions. Regrettably, at this point in time we can do no better.

The question is what S-T–T angle, measured in degrees, indicates a secondary S-T segment abnormality and what S-T–T angle, measured in degrees, indicates a primary S-T segment abnormality?

When the spatial S-T–T angle is less than about 60° it indicates, with only two exceptions, that the S-T segment displacement is due to repolarization and is part of the T wave; it is a secondary S-T segment abnormality. The two exceptions to this rule are the injuries produced by pericarditis or early apical infarction in which the mean S-T vector is parallel with the mean T vector but is actually a primary S-T vector abnormality.

Obviously, when the spatial angle between the direction of the mean S-T vector and mean T vector is 120°–180°, it is usually due to electrical forces other than those associated with repolarization. Such an S-T segment vector is a primary abnormality. The exception to this rule is created by the unique alterations of the S-T–T waves due to digitalis. The S-T segment vector of digitalis is directed opposite to the terminal T vector and QRS vector, but is a secondary S-T vector because it is due to repolarization forces.

2. When the vector method of analysis is used, the frontal plane direction of an electrical force can usually be computed to be located within 5° of its actual direction. The anteroposterior direction of a vector can be computed to be within 15° of its actual direction but may be difficult to establish at times. The error in such cases could be as much as 30°–45° unless recordings are made from additional electrode sites on the chest.

Obviously, at present, no one can state the limits of the S-T–T angle that always indicates that an S-T segment vector is a secondary S-T segment abnormality and that a larger S-T–T angle is due to a primary S-T segment abnormality. Since an S-T–T angle of ≤60° is normal and a spatial S-T–T angle of 120°–180° is abnormal, how do we label a spatial S-T–T angle of 60°–120°? The point is that additional data are needed to establish the normal spatial S-T–T angle.

3. Many of the explanations given for the alteration of the repolarization process (T wave and at times the S-T segment) are purely speculative. The explanations were arrived at by deductive and inductive reasoning and may or may not describe accurately the phenomena that are under scrutiny.

Examples

The ECG reproduced in Figure 7 is shown as an example of a secondary S-T segment abnormality, and that reproduced in Figure 8 as an example of a primary S-T segment abnormality.

Conclusion

Robert Grant developed vector electrocardiography in the late 1940s.[1] His views and concepts can now be extended because new technology has enabled clinicians to correlate the new data acquired by these procedures with ECG abnormalities.[2–4] His method is reviewed in this document and his approach to the identification of S-T segment abnormalities is emphasized.

The normalcy of the S-T segment can be determined by identifying the contribution made by the duration of the S-T segment to the Q-T interval and by determining the relationship of the mean spatial S-T vector to the mean spatial T vector.

There are two types of S-T segment displacement: *secondary* and *primary* S-T segment displacement.

The mean S-T vector tends to be relatively parallel with the mean T vector when there is a secondary S-T segment abnormality. The S-T segment displacement in such ECGs is due to repolarization forces. Two exceptions to this rule are discussed.

The mean S-T vector is directed away from the direction of the mean T vector when there is a primary S-T segment abnormality. The S-T segment displacement in such cases is due to electrical forces that are independent of the electrical forces responsible for repolarization. One exception to this rule is discussed, as are the limitations of this method of analysis.

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