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Understanding the ECG. Part 9: Myocardial ischaemic & infarction (part B)

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Introduction

Myocardial ischaemia and infarction are common causes of mortality, morbidity and hospital admission (Nabel & Braunwald, 2012). They are usually caused by coronary heart disease (CHD), a progressive, inflammatory condition that results in narrowing or blockage of the coronary arteries (British Heart Foundation, 2015). In last month's instalment of our ECG series, we examined the anatomy of the coronary circulation, and outlined the areas of the heart supplied by the three main coronary arteries. We also discussed the pathophysiology of CHD, and related this to patient presentation with stable angina or acute coronary syndromes (ACS). We completed our initial examination of this topic by discussing the role of the ECG in the diagnosis of ST elevation myocardial infarction (STEMI), and briefly considering current treatment recommendations.

In this penultimate part of our ECG series, we return to STEMI to answer the following questions.

- Firstly, what are the differential diagnoses for ST elevation on the 12-lead ECG?
- Secondly, how can we detect STEMI affecting the right ventricle (RV) or posterior wall of the left ventricle (LV), given that they are poorly seen by the standard ECG leads (Garcia, 2015)?
- Thirdly, how does left bundle branch block (LBBB) affect the diagnosis of acute myocardial infarction?

We also turn our attention to non-ST elevation MI (NSTEMI) and unstable angina, and evaluate the role of the ECG in the diagnosis and management of these conditions.

Differential diagnosis of ST elevation

Diagnosing STEMI quickly ensures that suitable patients are offered reperfusion therapy, limiting infarct size, and reducing complications and mortality (McNamara et al, 2006). It is important, however, to ensure that misdiagnosis is not made, as this can result in inappropriate treatment (Edhouse et al, 2009). In a study carried out in the emergency department of a university hospital, only 15% of patients presenting with chest pain and ST elevation on the ECG were diagnosed with STEMI (Brady et al, 2001). A range of other cardiac, and non-cardiac, diagnoses were made in the remaining 85%.

Determining the cause of ST elevation on the ECG can be difficult in clinical practice (Wang et al, 2003). Although many causes of ST elevation are associated with characteristic ECG features, these

are not conclusive, and may not be present in every patient (Hampton, 2013). The ECG is therefore only one part of the diagnostic picture, and must be considered alongside patient symptoms, age and medical history (O'Donovan, 2013). Physical examination, and the results of additional diagnostic tests are also important (Houghton & Gray, 2014). To illustrate this point, the diagnostic features of some of the common causes of ST elevation are discussed below; a full list of common differentials can be found in *table 1*.

Condition	Diagnostic features
STEMI	• Upsloping or convex ST elevation in a coronary territory • Dynamic ECG changes • Reciprocal ST depression may be present • Crushing central chest pain, unaffected by posture or breathing
LV aneurysm	• Persistent ST elevation over the affected area of the heart • Recent history of acute MI • Aneurysm visible on echocardiogram
Acute pericarditis	• Widespread ST elevation and PR depression • ST elevation is usually concave • There may be reciprocal ST depression in aVR / V1 • Sharp, pleuritic chest pain
Aortic dissection	• 'Tearing' chest pain, radiating to the back • Different blood pressure in each arm • Neurological / pulse deficits, aortic regurgitation • Mediastinal widening at chest X-ray
Prinzmetal's (vasospastic) angina	• ECG appearance mimics STEMI • Transient – ST segments return to baseline if spasm is relieved
Left ventricular hypertrophy	• Tall QRS complexes in leads facing the LV, deep S waves in V1/V2 • ST elevation seen in V1/V2, with ST depression/T-wave inversion in V5/V6. T-wave inversion is asymmetrical.
Left bundle branch block	• Typical pattern of deep S waves in right sided precordials, and monophasic, notched R-wave in V6 / lead I • ST elevation is a normal feature in leads V1-V3
Benign early repolarisation	• Mild ST elevation in the precordial leads, with tall T-waves • The ST segment is concave, and there may be notching at the J point • Common in young men • There is no reciprocal ST depression
Ventricular paced rhythm	• The QRS is broad, often with a left bundle branch pattern • Pacing spikes will be visible on the ECG
Brugada syndrome	• Right bundle branch pattern • Coved ST elevation ≥ 2mm and T-wave inversion in leads V1-V3
Hyperkalaemia	• Wide QRS complexes with down-sloping ST elevation • Tall, peaked T-waves • P waves low amplitude or absent
Raised intracranial pressure (e.g. cerebral bleed)	• ST elevation is widespread and concave, similar to pericarditis • Reciprocal change is seen only in aVR and V1 • Neurological symptoms will be present

Table 1. Common causes of ST elevation

STEMI

During STEMI, ST elevation typically has a flat, upsloping or convex shape, and is seen in contiguous leads that reflect the territory of one or more coronary artery (Thygesen et al, 2012) (*figure 1*). This is often accompanied by reciprocal ST depression in other areas of the ECG (Morris & Brady, 2009). ECG changes are usually dynamic; serial ECGs will reveal changes in the degree of ST elevation, as well as the development of Q-waves and T-wave inversion (Steg et al, 2012). Symptoms are also characteristic. Patients typically present with chest pain that is substernal, heavy or crushing, and unrelieved by nitrates, posture or breathing (Marshall, 2011). This is often accompanied by nausea, vomiting, and sweating (Resuscitation Council UK, 2016).

STEMI is more likely in patients who are older, and who have risk factors for CHD (Yusef et al, 2004). These include hypertension, diabetes and hypercholesterolaemia, as well as lifestyle issues such poor diet, excessive alcohol, cigarette smoking and lack of exercise (Kennedy, 2008). Males and individuals with a family history of premature cardiovascular disease are also at higher risk of STEMI, and tend to present at a younger age (Yunyun et al, 2014).
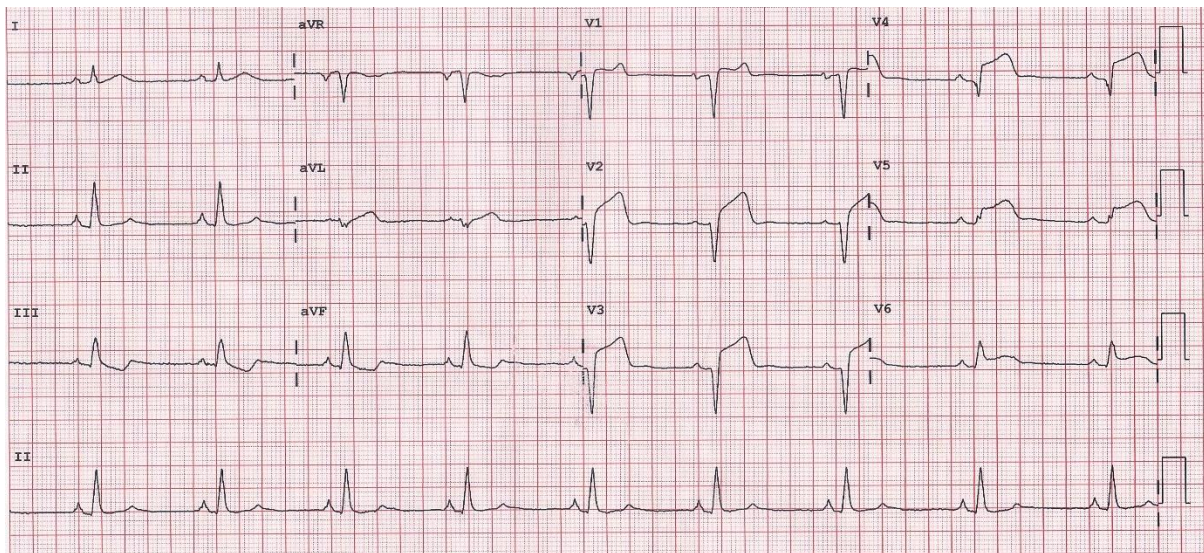

Figure 1. Anterior STEMI. There is upsloping ST elevation in the anterior chest leads, suggesting acute occlusion of the left anterior descending artery. Reciprocal ST depression can be seen in leads III and aVF.

Acute pericarditis

In acute pericarditis, ST elevation is typically widespread, and does not correspond with coronary territories as it does in STEMI (Hampton, 2013). The appearance of the ST segment is also different, usually having a concave or saddle-shaped appearance (Porela et al, 2012). There may be PR segment depression in the same leads, and reciprocal ST depression in leads aVR and V1 (Snyder et al, 2014) (*figure 2*). The pain of pericarditis is typically sharp and pleuritic; it is worse on inspiration, and relieved by sitting forwards (Houghton & Gray, 2014). A pericardial friction rub is a common finding at physical examination, occurring in up to 85% of patients (Snyder et al, 2014). Unlike the

typical STEMI patient, individuals presenting with pericarditis are usually below the age of 50 years, although like STEMI they are often male (Snyder et al, 2014). In two studies looking at patients undergoing angiography for suspected ACS, pericarditis was the most common diagnosis reached when the coronary arteries were found to be normal (Gu et al, 2008; Widimsky et al, 2006).
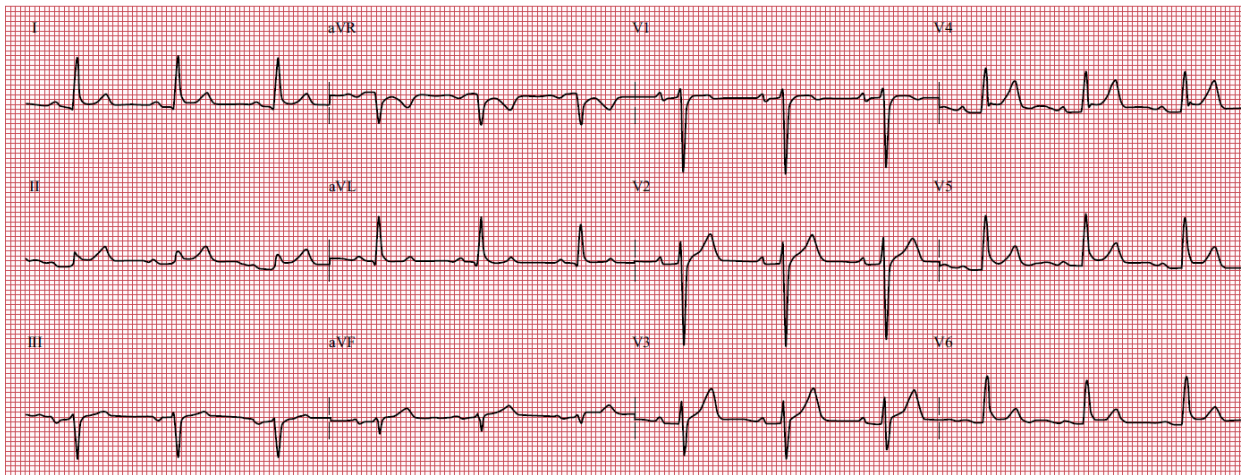
Figure 2. Acute pericarditis. There is widespread concave ST elevation, and PR depression. Note the reciprocal ST depression in lead aVR.

Left ventricular aneurysm

LV aneurysm is a late complication of STEMI, and occurs in around 10% of survivors (Houghton & Gray, 2014). The characteristic finding is persistent ST elevation in one or more coronary territories, although unlike acute STEMI there are no dynamic changes on serial ECGs (Garcia, 2015). Most commonly the anterior and apical LV are affected; ST elevation is therefore seen in the anterior chest leads (Wang et al, 2012). Patients may present with chest pain, heart failure or arrhythmias, and will have a recent history of myocardial infarction (Houghton & Gray, 2014). Aneurysm can be confirmed by echocardiography, which also has an important role in assessing the degree of LV dysfunction (Wang et al, 2012). If this is severe, surgical treatment to repair the aneurysm and restore normal LV geometry may be necessary (Antunes et al, 2005).

Aortic dissection

If the coronary arteries are disrupted by acute dissection of the aorta, a STEMI-like ECG can result (Houghton & Gray, 2014). It may be impossible to differentiate the two conditions from the ECG alone, however other characteristic features are often present. Unlike STEMI, the chest pain associated with aortic dissection tends to be sharp, tearing or ripping, and often radiates to the back (Hampton, 2013). Pain onset is abrupt, and immediately severe, lacking the build-up that may be reported in STEMI (Thrumurphy et al, 2011). Physical examination may reveal neurological or pulse deficits, a difference in blood pressure between the arms, or the murmur of aortic regurgitation (Resuscitation Council UK, 2016). Mediastinal widening may be seen at chest x-ray, although more

advanced imaging such as CT angiography is required to confirm dissection, and to guide management (Golledge and Eagle, 2008).

Benign early repolarisation

In benign early repolarisation (BER), ST elevation is usually mild (<5mm) and is seen in the precordial leads, typically V2-V4 (Houghton & Gray, 2014). As in pericarditis, the ST segment is usually upwardly concave, and there may be 'fish hook' notching of the J-point (Burns, 2016) (*figure 3*). The T-wave in affected leads may be unusually tall; reciprocal ST depression is absent (Garcia, 2015). BER is common in young men, less pronounced in women, and rare in the elderly (Wang et al, 2003). Although it does not cause symptoms, BER may be mistaken for STEMI in patients who present with non-cardiac chest pain, as may chronic causes of ST elevation such as left ventricular hypertrophy (LVH) (Brady et al, 2001).


Figure 3. Lead V4 from an individual with benign early repolarisation. Note the concave ST segment elevation and 'fish hook' notching of the J-point.

In summary, the shape and distribution of ST elevation is characteristic in STEMI, and contrasts with that seen in conditions such as pericarditis and BER (Garcia, 2015). Additional features such as reciprocal ST depression and dynamic change are also useful diagnostic markers (Morris & Brady, 2009). Even in the presence of these typical features, however, diagnosis cannot be made from the ECG alone (Hampton, 2013). A STEMI-like ECG may be seen in LV aneurysm, aortic dissection and Prinzmetal's angina (Houghton & Gray, 2014). A thorough evaluation of symptoms, history, physical findings and test results will help to differentiate between these conditions (Steg et al, 2012). Careful patient evaluation will also provide clues to support a suggested ECG diagnosis, for example an ECG showing widespread, concave ST elevation is more likely to be pericarditis in a young man with pleuritic chest pain and no risk factors for CHD (Snyder et al, 2014). Equally, it should be remembered that most chest pain does not have cardiovascular cause; ST elevation on the ECG may be unrelated to patient presentation, as in BER, ventricular hypertrophy and bundle branch blocks (Brady et al, 2001).

Right ventricular infarction

Because the right ventricle (RV) is poorly seen by the 12 standard ECG leads, infarction of the RV may be overlooked (Hanna & Glancy, 2011). In most individuals, the right coronary artery (RCA) supplies the inferior surface of the LV, as well as the RV (Cademartiri et al, 2008). In consequence, up to half of inferior STEMI are complicated by RV involvement, although isolated RV infarction is rare (Ondrus et al, 2013). Current guidelines suggest evaluating all patients with inferior STEMI for associated RV infarction (Steg et al, 2012).

On the ECG, RV involvement is suggested by several features during inferior infarction. Inferior STEMI is characterised by ST elevation in leads II, III and aVF (Hampton, 2013). When the RV is also involved, ST elevation may be greater in lead III than lead II, and there may be additional ST elevation in lead V1 (Somers et al, 2003) (*figure 4*). Although these findings are highly suggestive, RV infarction can only be confirmed by recording leads placed over the right ventricle, in particular V3R and V4R (Steg et al, 2012) (*Figure 5*). Because voltages are typically smaller in the RV, the diagnostic threshold in these leads is lower. In men below the age of 30 years, 1mm of ST elevation is diagnostic of RV infarction; in all other individuals only 0.5mm is required (Thygesen et al, 2012).
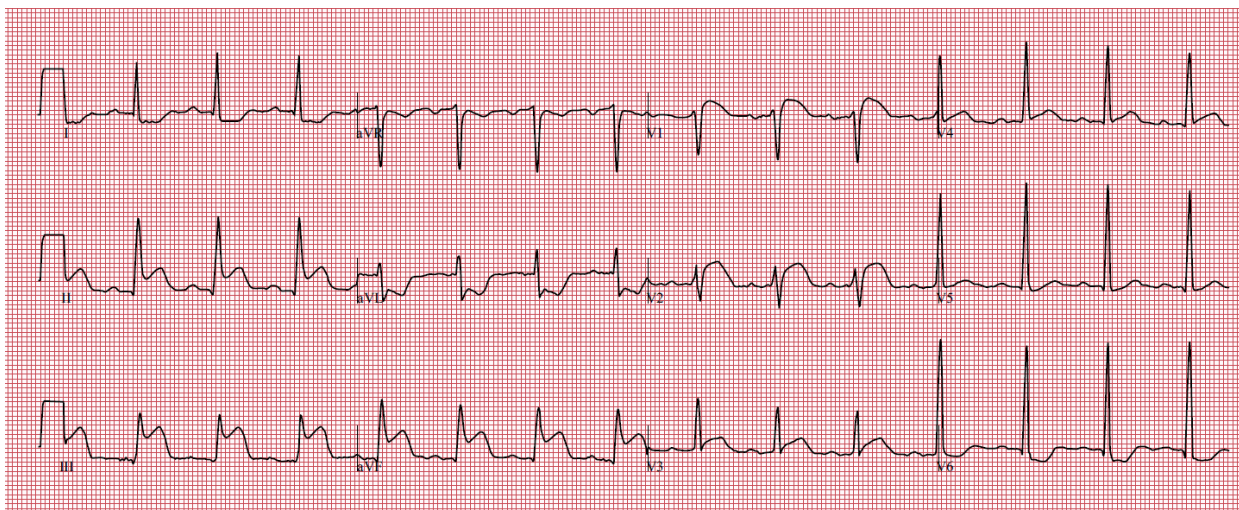
Figure 4. Inferior STEMI with RV involvement. The ST elevation is greater in lead III than in lead II, and there is ST elevation in V1. Lead V4R subsequently demonstrated ST elevation of 3mm.
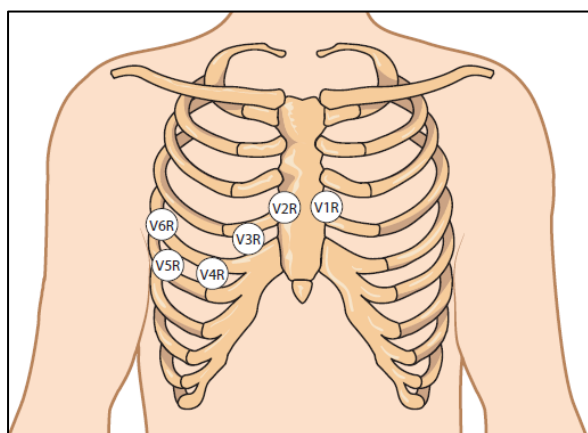

Figure 5. Placement of right precordial electrodes. Positions are a mirror image of the normal left sided electrodes.

Diagnosing RV infarction is important for several reasons. Firstly, RV infarction is associated with a greater incidence of ventricular arrhythmias, complete heart block and cardiogenic shock than simple inferior STEMI, due to the larger area of damaged myocardium (Somers et al, 2003). Secondly, a significant number of patients with an RV infarct present with hypotension and jugular venous distension due to acute right heart failure (Ondrus et al, 2013). Failure to diagnose RV infarction as the cause may result in inappropriate haemodynamic management (Hampton, 2013). In patients with an LV infarct, acute heart failure is managed by withholding intravenous (IV) fluid, and using vasodilators and diuretics to offload fluid and reduce LV preload (Whitlock & MacInnes, 2014). This relieves back pressure on the pulmonary circulation, caused by LV systolic dysfunction, and reduces pulmonary oedema (Serrano-Gomez and Thompson, 2009). In an RV infarct, LV function is often preserved; hypotension is due to low LV filling pressures secondary to RV systolic dysfunction, and pulmonary oedema is absent (Houghton & Gray, 2014). In this situation, IV fluids should be given to increase LV preload while vasodilators and diuretics should be avoided (Morris and Brady, 2009). As with all types of STEMI, definitive treatment remains the opening of the occluded artery and reperfusion of the ischaemic myocardium (Steg et al, 2012).
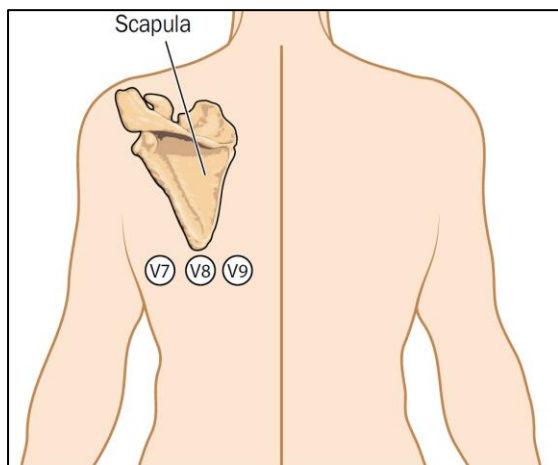
Posterior infarction

The posterior wall of the LV is supplied by the RCA or left circumflex artery (LCx) (Cademartiri et al, 2008). Posterior infarction can therefore complicate either inferior or lateral STEMI, although it occasionally occurs in isolation (Somers et al, 2003). Where posterior STEMI is found in association with infarction of another cardiac territory, the greater infarct size results in higher mortality and a greater incidence of complications (Rinta-Kiikka et al, 2014). In studies of isolated posterior STEMI, the culprit lesion is most commonly in the LCx (Agarwal et al, 1999; Pride et al, 2010).

On the ECG, the signs of posterior STEMI are less obvious, because the 12 standard leads of the ECG do not visualise the back of the heart directly (Garcia, 2015). 'Mirror image' changes can, however, be seen in leads V1 to V3 (Hampton, 2013). The principal finding is ST depression in these leads, typically with upright T-waves (Somers et al, 2003) (*figure 6*). The R-waves in the same leads may also become taller and wider, creating dominant R-waves in leads V1 and/or V2 (Houghton & Gray, 2014). These changes are the reverse of the Q-waves, ST elevation, and T-wave inversion that would be seen if the electrodes were placed over the posterior wall of the heart (Morris & Brady, 2009). As with RV infarction, posterior STEMI can be confirmed by recording additional ECG leads, in this case V7 to V9 (Garcia, 2015) (*figure 7*). As with leads V3R and V4R, the diagnostic cut-off is ST elevation of 0.5mm, although this is increased to 1mm in men below the age of 40 (Thygesen et al, 2012).
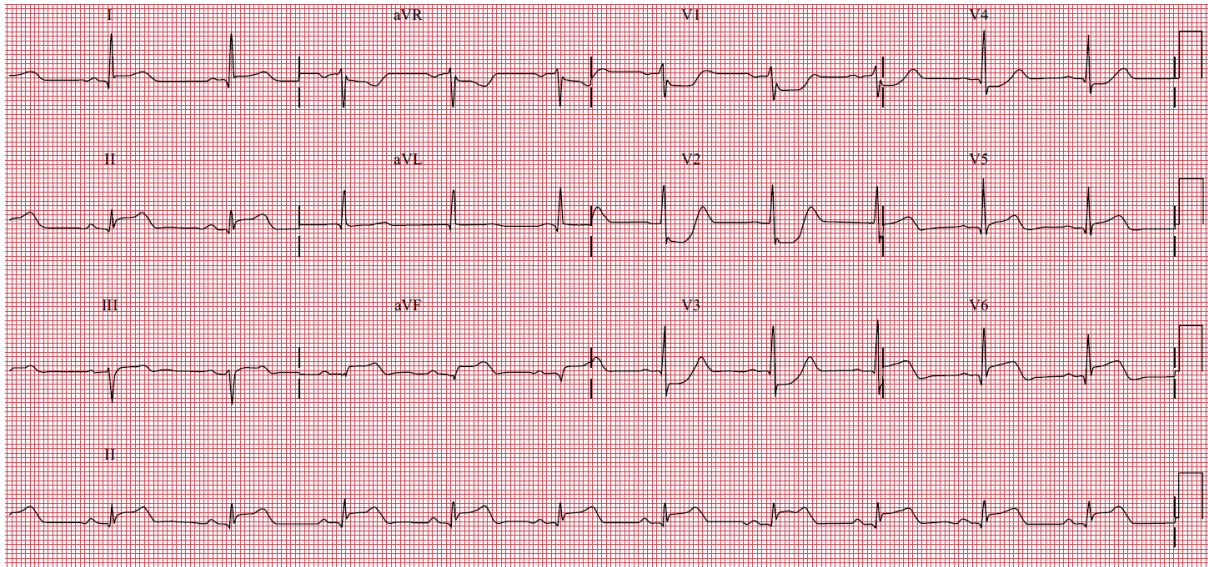
Figure 6. Inferolateral STEMI with posterior involvement. Note the ST elevation in the inferolateral leads, and marked ST depression in V1 to V3. There is a dominant R-wave in lead V2.

Figure 7. Posterior electrode placement. V7 is placed in the left posterior axillary line, V8 in the left mid-scapular line, and V9 at the left paraspinal border.

When posterior infarction occurs in the context of inferior or lateral STEMI, there is a good chance of correct diagnosis and treatment due to the presence of ST elevation on the ECG (Hampton, 2013). This is less certain when posterior infarction occurs in isolation; the lack of ST elevation and presence of ST depression in the right sided chest leads may result in an incorrect diagnosis of NSTEMI or unstable angina (Khan et al, 2012). This may result in a failure to offer reperfusion, and impaired patient outcomes (Pride et al, 2010). Current European guidelines suggest a high index of suspicion in any patient with typical symptoms and ST depression in leads V1 to V3, especially when T-waves are upright (Steg et al, 2012). Posterior chest leads (V7 to V9) should be recorded in these individuals (Thygesen et al, 2012). There may also be some benefit in recording posterior leads when the ECG is non-diagnostic; in a study of 58 such patients, posterior STEMI was diagnosed in 18 individuals, all but one of whom went on to receive percutaneous coronary intervention (PCI) (Agarwal et al,1999).

Left bundle branch block

The final challenge that we need to consider when diagnosing STEMI is the individual presenting with LBBB. New or presumed new LBBB, in the presence of typical symptoms, is considered a STEMI equivalent, and an indication for immediate reperfusion (Steg et al, 2012). This is straight forward; the difficulty arises when the patient has pre-existing LBBB, but presents with symptoms consistent with acute myocardial infarction. We know that in LBBB, abnormalities in the ST segment and T-waves are a common and normal finding (Garcia, 2015). Distinguishing between these normal findings, and abnormal changes that might indicate acute ischaemia is difficult, however the orientation and magnitude of the ST segment and T-wave provides useful diagnostic information (Houghton & Gray, 2014).

To understand the diagnosis of STEMI in LBBB, we need to define the term 'concordance'. In ECG terms, concordance means that the T-wave follows the same direction as the QRS (Garcia, 2015). So, in leads where there is an upright QRS, the T-wave is also upright. In LBBB, the normal rules of concordance are reversed (Houghton & Gray, 2014). In leads with negative QRS complexes, such as V1, there are upright T-waves, as well as ST elevation. In contrast, QRS complexes that are positive, for example V6, have inverted T-waves and ST depression (Hampton, 2013) (*figure 8*). These normal findings in LBBB are referred to as 'appropriate discordance' (Edhouse et al, 2009). In other words, the T-waves and ST segments are discordant, but that's normal in this situation.
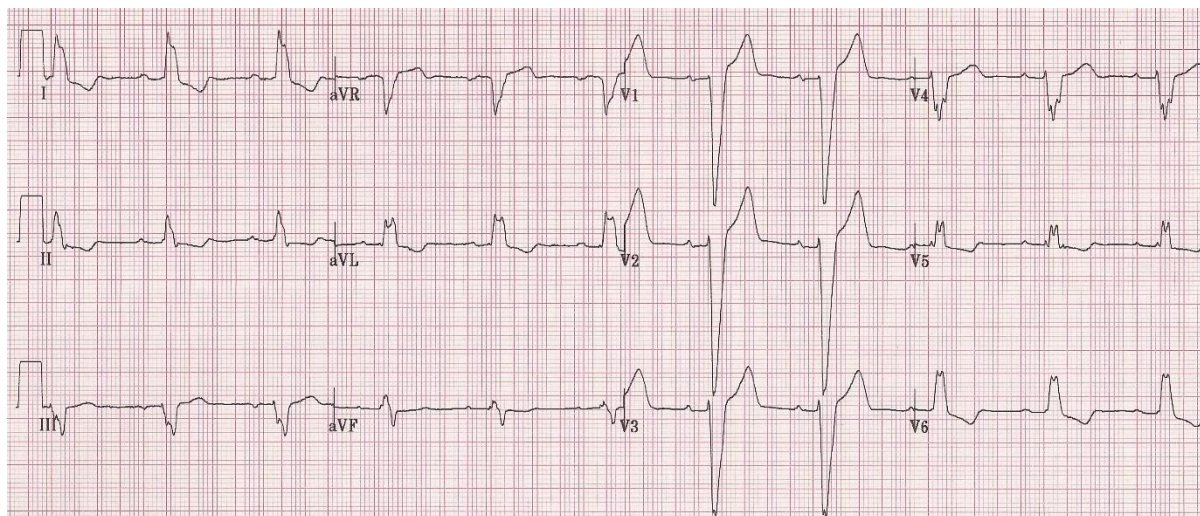
Figure 8. Left bundle branch block without acute ischaemia. Note the appropriate discordance, for example the ST elevation and upright T-waves in leads V1-V3, and the ST depression and T-wave inversion in leads I, aVL, V5, V6.

In the patient with chronic LBBB and acute myocardial ischaemia, the ST segment or T-wave may become concordant (Houghton & Gray, 2014). This is referred to as 'inappropriate concordance'; in other words, there is now concordance, but it's not normal in LBBB. Another change that suggests acute ischaemia is when discordant ST elevation (normal in LBBB) becomes exaggerated (Smith, 2015). These changes may be more evident over serial ECGS, or when compared with historical recordings (Edhouse et al, 2009).

The changes that occur in LBBB during acute ischaemia are the basis of a scoring system that predicts the likelihood of STEMI. This system, developed by Sgarbossa and colleagues (1996), uses three diagnostic criteria:

- Concordant ST elevation of 1mm or more (5 points)
- ST depression of 1mm or more in leads V1, V2 or V3 (3 points)
- Discordant ST elevation of 5 mm or more (2 points)

According to Sgarbossa et al (1996), a score of 3 or more has a sensitivity of 78% for STEMI, with a specificity of 90%. Smith (2015) argues that this is has similar diagnostic accuracy to the criteria used in the non-LBBB ECG (i.e. ST elevation in contiguous leads), however others have been critical of the criteria, suggesting that they are complex and lack diagnostic certainty (Shlipak et al, 1999; Tabas et al, 2008). Current guidelines suggest that concordant ST elevation has the best predictive value, but note that most cases of chest pain with LBBB evaluated in the emergency department do not have STEMI (Steg et al, 2012). There is a high rate of false negatives in patients taken for coronary angiography, in other words patients with LBBB and chest pain, but no critical coronary artery stenosis (Larson et al, 2007).

NSTEMI and unstable angina

NSTEMI and unstable angina are collectively referred to as non-ST elevation ACS (NSTEACS) (Marshall, 2011). The incidence of NSTEACS has risen over recent years, while that of STEMI has declined (Plakht et al, 2016). This is reflected in data from the UK; of 89,724 heart attacks reported in 2013-14, 39% were STEMI, and 61% NSTEMI (Myocardial Ischaemia National Audit Project, 2014). Although the reasons for this shift are unclear, several explanations have been proposed. Firstly, the demographics of ACS have changed, with more elderly, female, diabetic and obese patients (McManus et al, 2011). Secondly, a change in CHD risk profile has been seen in Western populations, in particular a decline in smoking and an increased use of statins (Bhatnagar et al, 2015; British Heart Foundation, 2015). It has been argued that these alterations have contributed to a change in the predominant pathology responsible for ACS (Libby and Pasterkamp, 2015).

In STEMI, coronary artery plaques tend to be large, lipid rich lesions covered by a thin fibrous cap (Libby and Pasterkamp, 2015). Acute rupture of this cap results in a thrombus that completely occludes the coronary artery, resulting in transmural ischaemia and ST elevation on the ECG (Wei et al, 2013). Unless the occluded artery is reopened swiftly, permanent myocardial damage occurs (Rinta-Kiikka et al, 2014). Immediate reperfusion is recommended in clinical guidelines because it limits infarct size, prevents complications, and improves patient outcomes (National Institute of Health and Care Excellence (NICE), 2013; Steg et al, 2012). Vulnerability of the fibrous cap to rupture has been linked to inflammatory processes driven by traditional risk factors such as smoking and hypercholesterolaemia (Libby, 2012).

In contrast to STEMI, the plaques associated with NSTEACS tend to be smaller, with less lipid and a thicker fibrous cap (Libby and Pasterkamp, 2015). Lesion disruption typically occurs through erosion, rather than rupture, and the subsequent thrombus may be smaller (Overbaugh, 2009). As a consequence, arterial occlusion is usually incomplete, and the clot may embolise to block a smaller, more distal vessel (Resuscitation Council UK, 2016). This usually results in subendocardial, rather than transmural, ischaemia, and permanent tissue damage may not occur (Nikus et al, 2010).

Persistent ST elevation is not seen on the ECG (Hampton, 2013). The benefit of immediate reperfusion in NSTEACS is less clear, and a decision on treatment is based on several factors including the risk of death or reinfarction over the coming months (Roffi et al, 2015).

Diagnosis of NSTEACS

The diagnosis of NSTEACS is based on typical symptoms, in association with ECG changes suggesting acute ischaemia (Overbaugh, 2009). The measurement of cardiac biomarkers, usually troponin I or T, is also an essential component of the diagnostic process (Roffi et al, 2015). Troponins are cellular proteins that are released by dying myocytes, and are therefore indicative of cellular necrosis (Shah et al, 2013). They are measured by serial blood tests in all patients presenting with suspected ACS (Marshall, 2011). If significant changes in troponin level are detected, a diagnosis of NSTEMI is made (Thygesen et al, 2012). In contrast, the signs and symptoms of ACS without troponin change suggests that no permanent tissue damage has occurred, and the diagnosis is unstable angina (Roffi et al, 2015). Although the ECG is useful in making a diagnosis of NSTEACS, it cannot differentiate between NSTEMI and unstable angina (Hampton, 2013).

The ECG in NSTEACS

The typical ECG changes seen during NSTEACS are ST segment depression and/or T-wave inversion, although transient ST elevation may also occur (Nikus et al, 2010). In up to a third of cases, no ECG changes are detected (Savonitto et al, 1999). The classic progression of ECG changes that occurs in STEMI is absent in NSTEACS, however dynamic changes in the ST segments and T-waves do occur (Hampton, 2013). Given the possibility of both dynamic change, and transient abnormalities, serial ECGs are as important in NSTEACS as they are in STEMI (Roffi et al, 2015).   A 12-lead ECG should be recorded at regular intervals, and whenever there is a change in reported pain (Overbaugh, 2009).

As with STEMI, any ECG abnormalities detected must be distinguished from normal variants, or the effects of chronic disease. T-wave inversion is normal in leads aVR and V1, and may be a normal variant in lead III (Houghton & Gray, 2014). In children, T-wave inversion is normal in all of the right sided precordials (V1 to V3), and this may persist into early adulthood (Hampton, 2013). This 'persistent juvenile pattern' is more commonly in young women, especially those of African descent (Hanna & Glancy, 2011).

T-wave inversion in any other lead is considered abnormal, although it is a recognised feature of the secondary repolarisation abnormalities that occur in bundle branch blocks and ventricular hypertrophy (Garcia, 2015). In these conditions, changes in the ST segments and T-waves have characteristics features (Hampton, 2013): -

- ST depression is down-sloping, with asymmetrical 'reverse tick' T-wave inversion (*figure 8*)
- ST depression and T-wave inversion are discordant to the QRS complex
- In the short term, ST segment and T-wave changes are fixed; there is no dynamic change on serial ECG recordings

- ST depression and T-wave inversion occur in predictable leads: In leads facing the LV (e.g. I, aVL, V5, V6) in LVH and left bundle branch block, and in leads facing the RV (e.g. V1, V2) in right ventricular hypertrophy and right bundle branch block.

The ECG changes that occur during NSTEACS can be difficult to distinguish from these chronic changes, however there are a number of ECG characteristics that are consistent with acute ischaemia. These include: -

- ST depression that is horizontal or down sloping, with an upright T-wave; the ST segment may be concordant with the QRS complex (Hanna & Glancy, 2011). In mild ischaemia there may be flattening of the ST-segment rather than depression, resulting in a sharp angle between the ST segment and T-wave (Channer and Morris, 2009) (*figure 9*).
- T-wave inversion that is deep and symmetrical (Garcia, 2015). Other variants include T-waves that are flattened, biphasic, or 'pseudonormal' (T-waves that are usually inverted, but have flipped upright due to ischaemia) (Houghton & Gray, 2014).
- Dynamic changes in the ST segment or T-waves over serial recordings (Hampton, 2013).
- ECG changes seen in contiguous leads, consistent with the territory of one or more coronary artery (Edhouse et al, 2009).
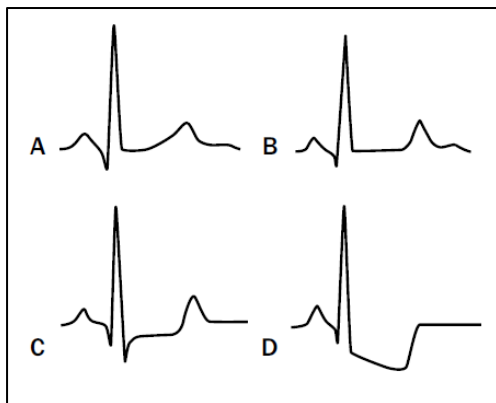
Figure 9. In the normal ST segment (A), the ST segment is isoelectric, and blends seamlessly with the T-wave. Early ischaemia may result in T-wave flattening (B), with loss of this smooth transition. Ischaemic ST depression may be flat (C) or down-sloping (D).

Figure 10 illustrates some of these features. Current guidelines suggest that ST depression of at least 0.5mm, occurring in two contiguous leads, is strongly indicative of NSTEACS, while recognising that other ECG findings, or a normal ECG are also possible (Roffi et al, 2015).
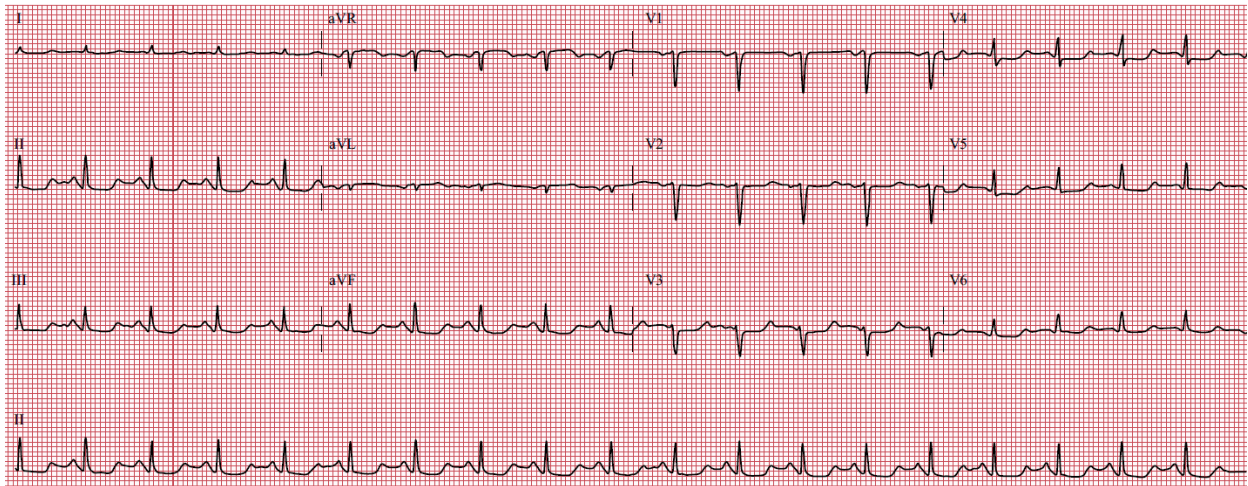
Figure 10. NSTEACS. There is horizontal ST depression with upright T-waves in leads II, III, aVF, and V3-V6.

Localising NSTEACS

In contrast to STEMI, there is a poor correlation between ECG abnormalities and affected coronary territory during NSTEACS (Hanna & Glancy, 2011). It is therefore harder to predict the culprit artery, and to assess prognosis. Despite this, conclusions can be drawn from ECG in several circumstances.

Firstly, a number of studies have demonstrated that outcomes are worse in patients presenting with ST depression, than with T-wave inversion or a normal ECG (Mueller et al, 2004; Savonitto et al, 1999). There is a linear relationship between the extent of ST depression (number of leads multiplied by millimetres of ST depression) and the risk of death or complication (Savonitto et al, 2005).

Secondly, although ECG changes in the inferior and lateral leads often results from poorly localised subendocardial ischaemia, changes in the anterior chest leads often reflect disease in the left anterior descending artery (LAD) (Nikus et al, 2010). In particular, deep symmetrical or biphasic T-wave inversion in leads V2 and V3, with or without similar change in V1 and V4 to V6, is strongly associated with critical stenosis of the proximal LAD. In patient with unstable angina, this ECG pattern is referred to as Wellen's syndrome (Hollar et al, 2015). Other ECG features associated with this syndrome include little or no ST elevation, normal precordial R-wave progression, and an absence of Q-waves (Khan et al, 2013) (*figure 11*).
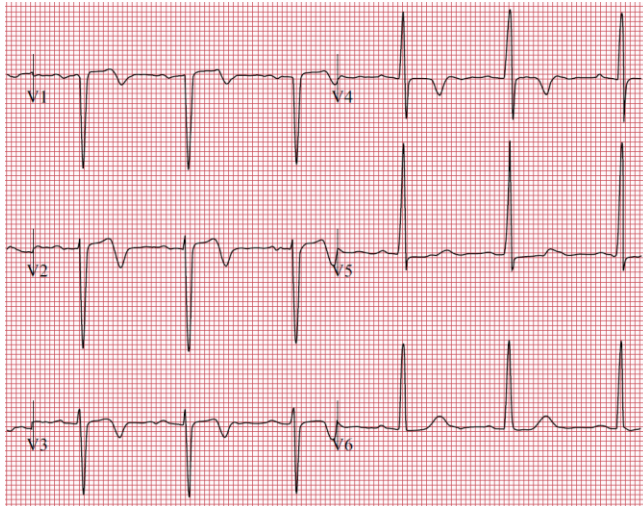
Figure 11. Wellen's syndrome. There is biphasic T-wave inversion in leads V1-V3, and deep symmetrical T-wave inversion in lead V4. R-wave progression is preserved, there are no Q-waves, and only minor ST elevation is present. The patient is at risk of an extensive anterior STEMI.

Because individuals with Wellen's syndrome present with unstable angina, cardiac biomarkers are typically normal, and pain intermittent (Hollar et al, 2015). The characteristic ECG pattern described above is recorded when patients are pain-free; during pain there may be transient ST elevation or hyperacute T-waves in the anterior chest leads, consistent with brief occlusion of the LAD (Hanna & Glancy, 2011). The syndrome was identified during research by Wellen and colleagues; in their study, outcomes were evaluated in patients who did or did not undergo angiography for ACS (de Zwaan et al, 1982). Of the patients with Wellen's syndrome who were managed without angiography, 75% developed an extensive anterior infarction. This led the authors to recommend urgent angiography in any patient with these characteristic ECG findings. Subsequent studies have reached similar conclusions, and have found the features of Wellen's syndrome in 14% of patients presenting with unstable angina (Hanna & Glancy, 2011).

Differential diagnosis

As with ST elevation, numerous cardiac and non-cardiac conditions can result in ST depression or T-wave inversion, and must therefore be excluded when evaluating the ECG for NSTEACS (Hanna & Glancy, 2011). As with STEMI, careful consideration of the patient, presenting symptoms, medical history, physical findings, and other diagnostic tests are important, and must be considered alongside the ECG (Roffi et al, 2015). Common causes of ST depression and T-wave inversion are shown in *table 2.*

Secondary repolarisation abnormalities • Left and right bundle branch block • Left and right ventricular hypertrophy • Cardiomyopathies • Pre-excitation
Normal variants • T-wave inversion normal in leads aVR, V1 • T-wave inversion a normal variant in lead III • T-wave inversion normal in V1-V3 in children, and in persistent juvenile pattern
Acute ischaemia • NSTEACS • Demand or rate related ischaemia (e.g. during exercise tolerance testing, arrhythmias)
Wellen's syndrome • Deep symmetrical or biphasic T-wave inversion in leads V2/V3, +/- V1, V4, V5. • Denotes critical LAD stenosis, and high risk of anterior STEMI
Posterior STEMI • ST depression greatest in V1-V3 +/- dominant R-waves in V1/V2 • Record additional posterior leads V7 to V9 to confirm or exclude
Reciprocal change • ST elevation will be seen in another coronary territory
Pulmonary embolism • T-wave inversion possible in the anterior and/or inferior leads, but various other presentations also occur, including acute RV strain pattern (similar to RVH). The most common ECG finding is sinus tachycardia
Hypokalaemia • ST depression and T-wave flattening may occur, and there may be a prominent U wave
Digoxin effect • ST depression and T-wave flattening are seen with therapeutic levels
Pericarditis • Widespread T-wave inversion may occur following resolution of ST elevation
Intracranial haemorrhage • Giant T-wave inversion may be seen
T-wave memory • T-wave inversion caused by transient ventricular arrhythmia, pacing or bundle branch block may persist for some time after normal rhythm is restored

Table 2. Causes of ST depression and T-wave inversion (Hanna & Glancy, 2011)

Acute treatment of NSTEACS

As with STEMI, immediate treatment priorities include nitrates and opiates to relieve pain, anti-emetics, oxygen if indicated, serial ECGs, and close monitoring of heart rhythm and vital signs (Marshall et al, 2011). Unlike STEMI, immediate reperfusion is not indicated unless there is deemed to be a high risk of death or adverse cardiovascular events (Roffi et al, 2015). Current UK guidelines recommend the use of a risk prediction tool such as the Global Registry of Acute Cardiac Events [GRACE] score (Granger et al, 2003; NICE, 2010).

The GRACE score predicts the risk of death in the next six months, and is used to place patients in risk categories according to the likelihood of a future adverse cardiovascular event (NICE, 2010) (*table 3*). For those at intermediate or higher risk, angiography is recommended within 96 hours, with progression to PCI if necessary (NICE, 2010). Early angiography is also recommended for patients with ongoing ischaemia, and should be performed urgently in individuals who are unstable or at high ischaemic risk (NICE, 2010). Low risk individuals can be managed conservatively (Roffi et al, 2015).

The other treatment priority for patients with NSTEACS is the prevention of further coronary thrombosis (Resuscitation Council UK, 2016). All patients should be commenced on an aggressive anti-thrombotic regime to inhibit clot formation (Marshall, 2011). A typical protocol includes dual anti-platelet therapy in the form of aspirin plus a $P2Y_{12}$ inhibitor (clopidogrel, prasugrel or ticagrelor) (Khan, 2015). Loading doses are given if the patient is not already established on these drugs (Overbaugh, 2009). A parenteral anticoagulant is also started, usually fondaparinux, although unfractionated heparin is preferred in patients with significant renal impairment (NICE, 2010).

Predicted 6-month mortality	Risk of future adverse cardiovascular events
1.5% or below	Lowest
>1.5% to 3%	Low
>3% to 6%	Intermediate
>6% to 9%	High
Over 9%	Highest

Table 3. Risk of future adverse cardiovascular events according to predicted six-month mortality (NICE, 2010)

Conclusion

The ECG plays an important role in the diagnosis of both STEMI and NSTEACS. In STEMI, persistent ST elevation indicates complete occlusion of an epicardial coronary artery, and transmural cardiac ischaemia (Wei et al, 2013). Although urgent reperfusion is mandated to limit myocardial damage, care must be taken to exclude alternative causes of ST elevation such as pericarditis, aortic dissection, and BER (Houghton & Gray, 2014). Careful evaluation of the ECG alongside patient age, history, symptoms and physical findings are the key to correct diagnosis (Hampton, 2013).

Care must also be taken to evaluate the ECG for possible RV or posterior STEMI, as these are not obvious from the standard 12 leads (Somers et al, 2003). Additional ECG leads should be considered in inferior STEMI, when there is ST depression in V1-V3, or when there are typical symptoms but a non-diagnostic ECG (Thygesen et al, 2012). LBBB should be considered a STEMI equivalent if it is new or presumed to be so; diagnosis of acute infarction in a patient with chronic LBBB is more difficult but examination of ST segments for exaggerated or concordant changes can be useful (Steg et al, 2012).

In NSTEACS, ECG changes are more variable, and have a less direct relationship with coronary anatomy and prognosis (Nikus et al, 2010). The degree of ST depression is, however, a useful

prognostic indicator, as are the signs of Wellen's syndrome (Hanna and Glancy, 2011). As with STEMI, normal variants, chronic changes, and differential diagnoses must be considered when reaching a diagnosis, and thorough patient assessment must accompany scrutiny of the ECG (Houghton & Gray, 2014). Initial treatment follows similar lines to STEMI, however risk assessment is used to evaluate the benefit of angiography, and aggressive anti-thrombotic treatment is started while assessment takes place (NICE, 2010).

Next month, we complete our examination of the 12-lead ECG by considering some important presentations that we have yet to cover during our series. These include the patient who is paced, the effect of cardiovascular drugs on the ECG, and the changes that occur during common electrolyte disturbances.

Key points

- There are numerous causes of ST elevation on the ECG. Careful evaluation of the shape and distribution of ST elevation, the presence of reciprocal ST depression, and dynamic change during serial ECGs helps to differentiate STEMI from other causes. This must be combined with thorough patient assessment; the ECG alone is not diagnostic.

- Infarction of the RV often accompanies inferior STEMI, and carries an adverse prognosis. It should be suspected in all patients with inferior STEMI, especially if ST elevation is greater in lead III than lead II, and when there is ST elevation in V1. Diagnosis can be confirmed using leads V3R and V4R.

- Posterior STEMI may occur in association with inferior or lateral infarction, or as an isolated finding. As with RV infarction, the greater loss of myocardium in combined infarcts confers a worse prognosis. ECG features include ST depression in leads V1-V3, and an increase in the height and width of the R-waves in these leads. Confirmation of diagnosis is by posterior leads V7 to V9.

- New, or presumed new, LBBB is a STEMI equivalent, and mandates immediate reperfusion. In chronic LBBB, it is difficult to identify ischaemic changes because of chronic abnormalities in the T-waves and ST segments. Discordant ST elevation of more than 5mm suggests STEMI, as does concordant change in the ST segment, especially concordant ST elevation.

- The ECG during NSTEMI and unstable angina typically shows ST depression or T-wave inversion, although a normal ECG is present in up to one third of cases. The correlation between affected leads and coronary territory is weaker, although changes in the anterior leads are often due to LAD disease.

- Although outlook is harder to predict in NSTEACS, ST depression is associated with a worse prognosis than T-wave inversion or a normal ECG. In patients with unstable angina, deep symmetrical or biphasic T-wave inversion in leads V2 and V3 is suggestive of Wellen's syndrome, and critical LAD stenosis. There is a high probability of future anterior infarction in these patients if they do not undergo coronary intervention.

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