Introduction

Myocardial infarction is a major cause of death and disability worldwide. Coronary atherosclerosis is a chronic disease with stable and unstable periods. During unstable periods with activated inflammation in the vascular wall, patients may develop a myocardial infarction ***(Kristian et al., 2007).***

It is recommended that patients with acute ST-segment elevation myocardial infarction (STEMI) receive reperfusion therapy with fibrinolysis or, preferably, primary percutaneous coronary intervention (PPCI) as soon as possible after symptom onset. Over the years, several large-scale trials have established significant prognostic indicators for the outcome in these patients ***(Jacob et al., 2009).***

It is known that the T wave reflects the myocardial repolarization, and changes in the T-wave configuration are among the first to indicate an AMI. Several studies from the thrombolytic era have investigated the prognostic significance of early T-wave changes in patients with AMI ***(Jacobsen et al., 2005) (Adler et al., 2000) (Hochrein et al., 1998)***. It has been demonstrated that post-thrombolytic T-wave changes may reflect microvascular reperfusion status ***(Sgarbossa et al., 2000).***

Aim of the Work

To study the correlation between T-wave changes at time of reperfusion with myocardial salvage in patients with acute ST-Segment elevation myocardial infarction.

Cardiac Electrical Activity and Surface ECG

Anatomic and physiologic considerations:

Myocardial electrical activity is attributed to the generation of action potentials in individual cardiac cells, and the normal coordinated electrical functioning of the whole heart is readily detected in surface electrocardiograms.

The generation of myocardial action potentials reflects the sequential activation and inactivation of ion channels that conduct depolarizing, inward (Na+ and Ca2+), and repolarizing, outward (K+), currents. The waveforms of action potentials in different regions of the heart are distinct, owing to differences in the expression and/or the properties of the underlying ion channels. These differences contribute to the normal unidirectional propagation of excitation through the myocardium and to the generation of normal cardiac rhythm ***(Antzelevitch et al., 2002, Nerbonne et al., 2003).***

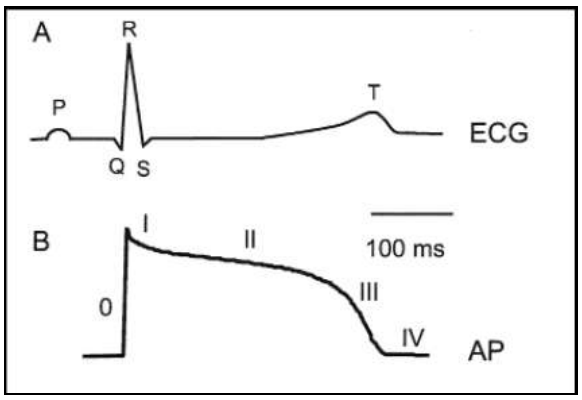

Figure (1): Cardiac action potential and ECG ***(Zipes et al., 1998).***

Phases of cardiac repolarization: (figure 2)

Phase 1, initial repolarization:

Phase 1 is a brief period of repolarization, which immediately follows the upstroke, it has two explanations; a-The inactivation gates on the Na+ channels close in response to depolarization, resulting in stoppage of the inward Na+ current, b-the outward K+ current caused by large driving force on k+ ions ***(Linda, 2001).***

Phase 2, the plateau:

During the plateau, there is a long period (150 to 200 msec) of relatively stable, depolarized membrane potential. A balance of inward and outward currents is achieved during the plateau as there is an increase in Ca^{2+} conductance, which results in a slow inward Ca^{2+} current. The Ca^{2+} channels that open during the plateau are L-type channels ("L," for long-lasting). To balance the inward Ca^{2+} current, there is an outward K^+ current, driven by the electrochemical driving force on K^+ ions. Thus, during the plateau, the net current is zero, and the membrane potential remains at a stable depolarized value ***(Linda, 2001).***

Phase 3, repolarization:

During phase 3, repolarization results from a combination of a decrease in Ca^{2+} conductance (previously increased during the plateau) resulting in a decrease in the inward Ca^{2+} current, and an increase in K^+ conductance (to even

higher levels than at rest) resulting in an increase in the outward K^+ current (I_K), with K^+ moving down a steep electrochemical gradient ***(Linda, 2001).***

Phase 4, resting membrane potential:

The membrane potential fully repolarizes during phase 3 and returns to the resting level of approximately -85 mV ***(Linda, 2001).***

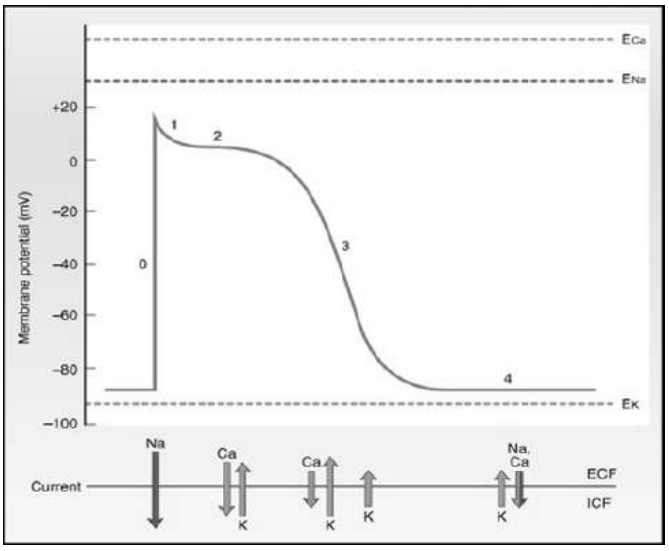

Figure (2): Currents responsible for ventricular action potential. The length of the *arrows* shows the relative size of each ionic current. E, Equilibrium potential; ECF, extracellular fluid; ICF, intracellular fluid ***(Jeanne et al., 2005).***

Repolarization on surface ECG:

Ventricular repolarization on surface ECG is shown collectively by the QT interval. It can be divided into: ST segment, T wave, and U wave (Figure 3).

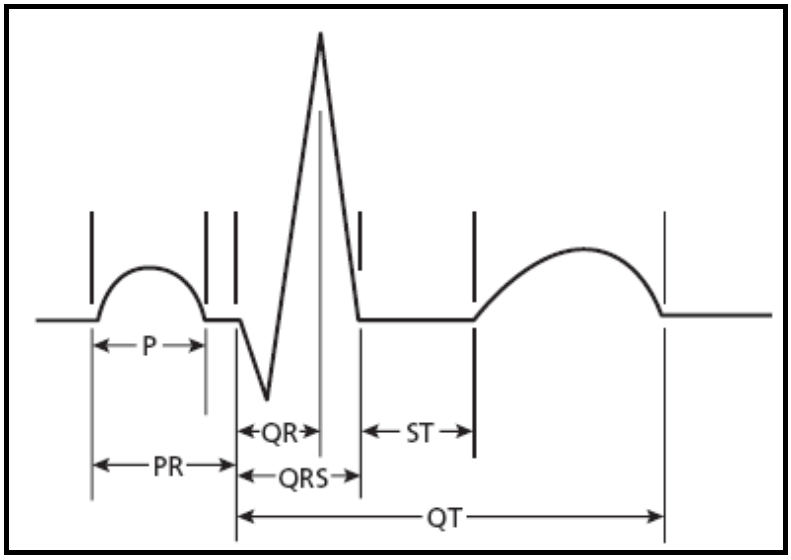

Figure (3): P wave, PR interval, QRS duration, ST segment, QT interval, T wave **(*Zainul et al., 2008*).**

(A) ST Segment:

Definition:

It is the isoelectric portion of the ECG from the end of the QRS complex to the beginning of the T wave ***(Ary, 2006)*** (Figure 5).

Physiological basis: It represents the isoelectric period at the beginning of ventricular repolarization (phase 2; plateau) ***(Ary, 2006).***

Normal ST segment:

It is usually isoelectric yet minor deviations may occur (usually by less than 1 mm) ***(Ary, 2006).***

At its junction with the QRS complex (J point), the ST segment typically forms a nearly 90-degree angle with the upslope of the S wave, and then proceeds nearly horizontally until it curves gently into the T wave (Figure 4). The length of the ST segment is influenced by factors that alter the duration of ventricular activation. Points along the ST segment are designated with reference to the number of milliseconds beyond the J point, such as "J + 20," "J + 40," and "J + 60" ***(Galen et al., 2008).***

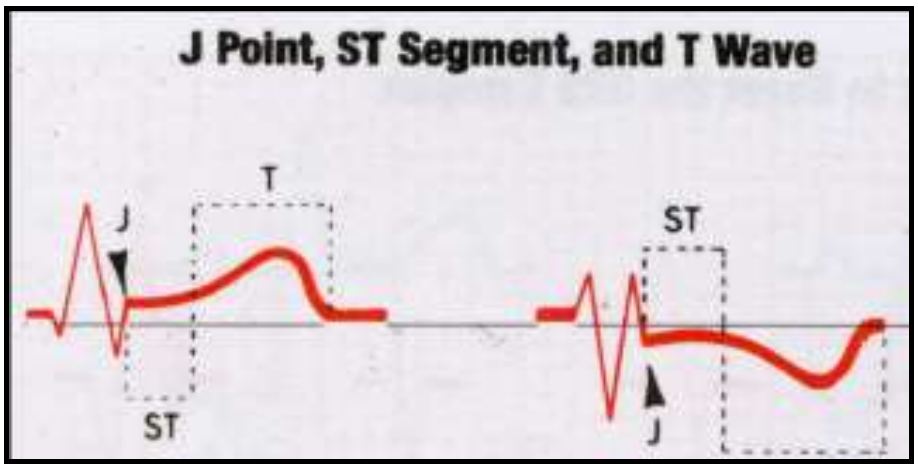

Figure (4): Normal ST segment and T wave ***(Ary, 2006).***

(B): T wave:

Definition:

It is the first deflection (whether positive or negative) on ECG after the QRS complex ends ***(Galen et al., 2008).***

The ECG findings associated with myocardial ischemia/infarction:

They vary depending on the specific evolutionary phase of myocardial infarction. Myocardial infarction is associated with several characteristic ECG changes: ***(Fred, 2009)***

1. T wave peaking.
2. ST segment changes.
3. Abnormal ventricular depolarization (Q waves).
4. Prominent and deeply inverted T waves.
5. Acute left budle

1) The first ECG finding that can be observed during a myocardial infarction is T wave peaking, characterized by prominent T waves with a relatively narrow base.

   T wave peaking can be observed also in hyperkalemia because the phase 3 down-stroke of repolarization becomes steeper.

   During ischemia, activation of I_{KATP} leads to outward flow of K+ and accumulation of K+ in the extracellular spaces of affected myocytes.

   This ion concentration changes are responsible for peaked or “hyperacute” T waves that can be observed during acute myocardial infarction/ ischemia.

2) Accumulation of extracellular K+ is also an important mechanism for ST segment changes observed in ischemia. Increased K+ permeability can cause ST elevation due to effects during diastole and during systole.

During phase 4, accumulation of extracellular K+ at baseline due to increased I_{KATP} will produce a resting voltage difference between injured and non-injured areas of the myocardium. If extracellular K+ is higher, the membrane will be depolarized. For a positive electrode over an injured region of myocardium, the relatively negative surface charge will result in depression of the resting T-P segment (figure 5).

(Fred, 2009)

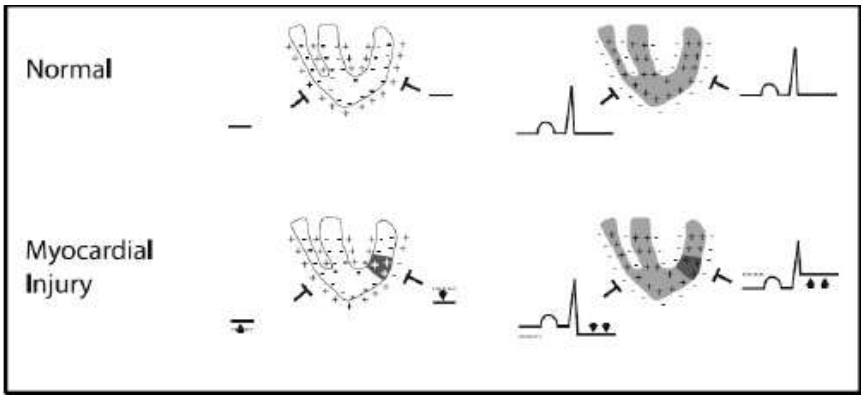

Figure (5): Mechanism for ST segment changes during myocardial infarction ***(Fred, 2009).***

Since all ECG machines take the T-P segment as zero, T-P segment depression will cause ST segment elevation.

Conversely, for a positive electrode "looking" at this region through normal tissue, T-P elevation will be observed. T-P elevation in these "distant" leads will produce ST segment depression.

Activation of I_{KATP} will cause earlier repolarization of epicardial tissue compared to M cells (mid-myocardial cells) and endocardial tissue, because epicardial cells have a greater response to low ATP (due either to a larger number of channels that are responsible for I_{KATP} or to channels with different gating characteristics) ***(Fred, 2009).***

Repolarization changes with STEMI

Repolarization changes are among the first to indicate an AMI. Several studies from the thrombolytic era have investigated the prognostic significance of early T-wave changes in patients with AMI.

It has been demonstrated that post-thrombolytic T-wave changes may reflect micro-vascular reperfusion status ***(Jacobsen et al., 2005).***

However, data on the value of T-wave changes in the setting of primary PCI are limited ***(Sgarbossa et al., 2000).***

Significance of repolarization ECG changes in assessing success of primary PCI is gaining increased interest and is currently the center of many studies

Parameters of importance are:

(A) T-wave amplitude and morphology: (figure 6)

T-wave morphology is usually studied in the lead with the most pronounced ST-segment elevation based on the assumption that this lead most accurately reflects depolarization and repolarization changes in the infarct related region ***(Jacob et al., 2009).***

The end of the ST segment is determined in leads without ST-deviation, and T-wave deflection is recorded from the end

of the ST-segment. The time interval measured from the beginning of the QRS complex to the start of the T wave is then applied to the lead with maximal ST-elevation to determine the beginning of the T- wave. If there are no leads without ST deviation, the start of the T wave is established from the lead with the smallest ST deviation ***(Jacob et al., 2009) (Herz et al., 1999)***

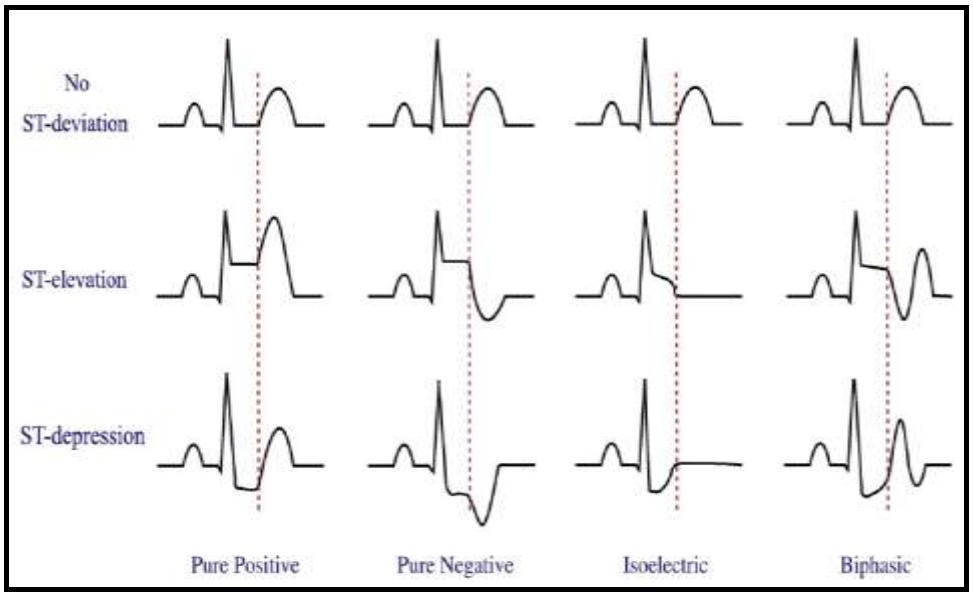

Figure (6): Determination of beginning of T wave **(*Jacob Thorsted Sørensen,et al., 2009)***

T-wave morphology is categorized as:

1. **Pure positive:** only positive deflection. In leads with ST-depression, the T-wave is also categorized as positive if the T wave begins below the TP baseline but the direction is never negative.

2. **Pure negative:** only negative deflection. In leads with ST elevation, the T wave is also categorized as negative if the T wave begins above the TP baseline but the direction is never positive.

3. **Biphasic:** initial negative deflection, followed by positive deflection or initial positive deflection, followed by negative deflection.

4. **Isoelectric:** deflection of less than 0.025 mV in any direction. ***(Jacob et al., 2009).***

All T-wave amplitudes are categorized into 4 groups:

- Negative (net amplitude, $-\infty$ to < 0 mV).
- Slightly positive (net amplitude, 0 to < 0.50 mV).
- Moderately positive (net amplitude, ≥ 0.5 to < 1.00 mV), and
- Highly positive (net amplitude, ≥ 1 mV).

(Wong et al., 1999)

(B) Tpeak-Tend interval: (figure 7)

The interval from the peak to the end of the T wave (Tpeak-Tend interval, or TpTe) has been proposed to represent repolarization dispersion in the heart. A prolonged TpTe has been associated with arrhythmic events in various clinical conditions, but little is known about TpTe in the acute setting of transmural myocardial ischemia and reperfusion ***(Antzelevitch et al., 2001).***

Action potential duration (APD) in the ischemic zone briefly increases (lasting seconds to a few minutes), thereafter a shortening of the APD is seen. During early reperfusion, APD remains shortened or may even shorten further before APD restitution begins. In brief, the overall dispersion between normal or less affected tissue compared with the infracted tissue and ischemic border zone is increased in the infracted heart ***(Carmeliet et al., 1999).***

TpTe is best evaluated in non–infarct-related leads, that is, leads with ST-segment deviations below 0.055 mV at the J-point in the pre-pPCI ECG, to avoid difficulties in assessing T wave markers.

The preferred leads for measurement of TpTe in descending order are: V5, V4, V6, II, III, and I. This selection is based on previous experience with TpTe in a healthy population, where TpTe in these leads are almost identical, whereas difficult T wave morphology gives longer or shorter TpTe in V1-V2 and augmented leads ***(Haarmark et al., 2009).***

There are limited data on the reference range of TpTe in healthy individuals, but most studies have found values below 100 milliseconds in healthy populations. In groups of patients with increased risk of arrhythmias, the TpTe was often more than 100 milliseconds Tpeak- Tend interval greater than 100 milliseconds could therefore be considered as prolonged ***(Watanabe et al., 2004).***

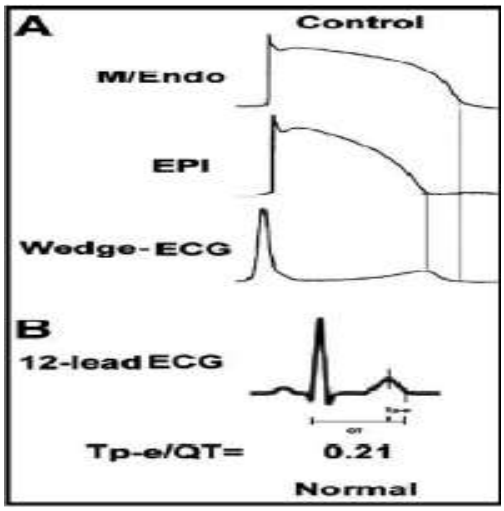

Figure (7): Tpeak-Tend correlation with AP ***(Haarmark et al., 2009).***

(D) T-wave alternans (TWA):

Alternans is a transient phenomenon appearing in the surface electrocardiogram (ECG) as beat-to-beat changes in the repolarization morphology (ST segment and T wave) on an every-other-beat. It is defined as a change in the amplitude and/or morphology of a component of the ECG that occurs on an every-other beat basis ***(Windle et al., 1993).***

TWA has been reported in a wide range of clinical and experimental situations including long QT syndrome, myocardial infarction, Printzmetal angina, acute ischemia, etc.

Although visible TWA is an infrequent phenomenon, in recent years, computerized analysis of digital ECG recordings allowed the identification of subtle (microvolt) TWA, much more common than visible TWA. Recently, several studies showed that TWA is related to cardiac instability and high risk