The P wave represents the sequential activation of the right and left atria.
- P duration < 0.12 sec (120 mseg)
- P amplitude < 2.5 mm (0.25 mv)

P-wave questions to address: Are they present?.
Do they occur regularly?. Is there one P-wave for each QRS complex?.
Are the P-Waves smooth, rounded, and upright?
Do all P-Waves have similar shapes?
PR INTERVALS Normal Value

PR interval
- travel time from SA node to AV node
- beginning of P to beginning of QRS
- 120 msec to 200 msec

PR Interval questions to address:
Does the PR-Interval fall within the norm of 120 - 200 msec?
Is the PR-Interval constant across the ECG tracing?
The QRS complex: Q is the first negative deflection from the baseline. R is the first large positive deflection after the Q. S is the negative deflection that follows R. The Q and the S are very close to the R and often seem to overlap it. The QRS complex corresponds to ventricular depolarization and contraction.
When ventricular despolarisation is longer than 110 milliseconds, this is a conduction delay. Possible causes of a QRS duration > 110 milliseconds include:
- Left bundle branch block
- Right bundle branch block
- Idioventricular rhythm and paced rhythm
Multiple variations of the QRS complex.
The QT interval is measured from the start of the QRS complex to the end of the T wave - the end of the T wave was defined as the point of return to the isoelectric line.

- ventricular depolarization & repolarization
- beginning of QRS to end of T
- Q-T interval 0.35 - 0.43 sec  350 – 430 ms
- no > than ½ of R to R interval
The T wave is broad, but the tangent crosses the baseline before the T wave joins the baseline. The QT interval would be overestimated when this last definition of the end of the T wave would be used.

The ECG does not meet the baseline after the end of the T wave. Still, the crossing of the tangent and baseline should be used for measurements.

A bifasic T wave. The tangent to the 'hump' with the largest amplitude is chosen. This can change from beat to beat, making it more important to average several measurements.
Normal QT is heart rate dependent (upper limit for QTc = 0.46 sec)
Long QT Syndrome: LQTS (based on corrected QTc:
QTc 450 msec for males and 460 msec in females
The eyeballing method to estimate QT prolongation. If the QT interval ends before the imaginary boundary halfway two QRS complexes, the QTc is probably normal. If the QTc reaches beyond the halfway line, the QTc is probably prolonged. This method is only 'valid' in registrations with normal (60-100/min) heart rates.
• The amplitudes of all the QRS complexes in the limb leads are < (0.5 mV)
• or The amplitudes of all the QRS complexes in the precordial leads are < (1 mV)

Causes:
Obesity, Pneumothorax, Constrictive pericarditis, Previous massive MI
Causes of poor R wave progression:
- Anterior myocardial infarction
- Faulty ECG recording technique
- Left bundle branch block
- Ventricular hypertrophy
- Wolff–Parkinson–White syndrome
In lead V1, the R wave should be small. The R wave becomes larger throughout the precordial leads to the point where the R wave is larger than the S wave in lead V4.

10.- R Wave Progression
The Q wave represents the normal left-to-right depolarisation of the interventricular septum. Small ‘septal’ Q waves are typically seen in the left-sided leads (I, aVL, V5 and V6).

Myocardial infarction
Cardiomyopathies — Hypertrophic (HOCM), infiltrative myocardial disease
Rotation of the heart — Extreme clockwise or counter-clockwise rotation
Lead placement errors — e.g. upper limb leads placed on lower limbs

Q waves after an Inferior MI

- > 40 ms (1 mm) wide
- > 2 mm deep
- > 25% of depth of QRS complex
- Seen in leads V1-3
The ST segment represents the early part of ventricular repolarization. *This is the area from the end of the S (QRS) to the onset of the T wave. It can be a little bit above or below the baseline. Note if it significantly dips below the baseline (depressed), goes above the baseline (elevated),*
“In this acute anterior MI
Persistent ST elevation after acute MI suggests ventricular aneurysm
ST elevation during exercise testing suggests extremely tight coronary
artery stenosis or spasm (transmural ischemia)
ST segment changes
ST segment depression --most likely associated with ischemia
ST segment elevation-less specificity, but suggestive if it is known that the patient has coronary vascular disease

**ST Segment Depression**
The T wave can be positive, negative, or biphasic (having two deflections, one negative, one positive); in this example it is positive. The T wave corresponds to ventricular depolarization or relaxation.
T Waves Inversion

Q wave and non-Q wave MI (e.g., evolving anteroseptal MI):
Myocardial ischemia. Subacute or old pericarditis. Myocarditis
Myocardial contusion (from trauma)
Different forms of T wave morphology

T Wave
1. P wave: upright in leads I, aVF and V3 - V6, normal duration of less than or equal to 110 ms; polarity is positive in leads I, II, aVF and V4 - V6;
2. PR interval: Normally between 120 ms and 200 ms.
3. QRS complex: Duration less than or equal to 110 ms, amplitude greater than 0.5 mV in at least one standard lead, and greater than 1.0 mV in at least one precordial lead. Upper limit of normal amplitude is 2.5 - 3.0 mV.
4. ST segment: isoelectric, slanting upwards to the T wave in the normal ECG can be slightly elevated (up to 2.0 mm in some precordial leads). never depressed greater than 0.5 mm in any lead.
5. T wave: T wave deflection should be in the same direction as the QRS complex in at least 5 of the 6 limb leads, normally rounded and asymmetrical, should be upright in leads V2 - V6, inverted in aVR.
6. QT interval: Durations normally less than or equal to 400 ms for males and 440 ms for females.
ECG Recorder Specification

- 12 leads real time data acquisition
- Sampling rates: 1000 samples/sec.
- Frequency response: 0.05 - 300 Hz
- Resolution: 16 bit A/D conversion
- Sensitivity: Better than 0.4 μV
- CMRR: 120 dB
- Defibrillator protected input circuits and patient cable
- Power Consumption: 280 mA max. from USB port
- Suspend Current: Less than 500 μA
- Dimension: 113x80x30 (mm), Weight: 300 gr

Patient Safety and Regulations
- Patient Leakage Current: Less than 10 μA
- EN 60601-1 Electrical Safety
- EN 60601-1-2 EMC
- CE Directive 93/42/EEC
JIAPU PAN AND WILLIS J. TOMPKINS, in 1985 have developed a real-time algorithm for detection of the QRS complexes of ECG signals. It reliably recognizes QRS complexes based upon digital analyses of slope, amplitude, and width.

**R-Pick detection algorithm**
The ECG waveform contains, in addition to the QRS complex, P and T waves, 60-Hz noise from power line interference, EMG from muscles, motion artifact from the electrode and skin interface, and it is necessary to extract the signal of interest, the QRS complex, from the other noise sources such as the P and T waves.

**QRS Power Spectra Based on FFT**
First, in order to attenuate noise, the signal passes through a digital band-pass filter composed of cascaded high-pass and low pass filters.

**Low-Pass Filter**

The transfer function of the second-order low-pass filter is

\[ H(z) = \frac{(1 - z^{-6})^2}{(1 - z^{-1})^2}. \]  

The amplitude response is

\[ |H(\omega T)| = \frac{\sin^2 (3\omega T)}{\sin^2 (\omega T/2)} \]  

where \( T \) is the sampling period. The difference equation of the filter is

\[ y(nT) = 2y(nT - T) - y(nT - 2T) + x(nT) \]
\[ - 2x(nT - 6T) + x(nT - 12T) \]  

where the cutoff frequency is about 11 Hz and the gain is 36. The filter processing delay is six samples.
The most noticeable result is the attenuation of the higher frequency QRS complex. Any 60-Hz noise or muscle noise present would have also been significantly attenuated.

Low Pass Filter attenuation
Figure 12.1  Relative power spectra of QRS complex, P and T waves, muscle noise and motion artifacts based on an average of 150 beats.
The ECG passes through the bandpass filter. Note the attenuation of the T and P wave due to the high-pass filter.

High Pass Filter attenuation
Electrocardiogram sampled

Low-pass filtered ECG.

The ECG passes through the bandpass filter. Note the attenuation of the T and P wave due to the high-pass filter.

Ban-dpass-filtered ECG

Band-Pass Filter
R-Pick detection algorithm
**Derivative**

After filtering, the signal is differentiated to provide the QRS-complex slope information. We use a five-point derivative with the transfer function

\[ H(z) = \left( \frac{1}{8T} \right) (-z^{-2} - 2z^{-1} + 2z^1 + z^2). \]  

(7)

The amplitude response is

\[ |H(wT)| = \frac{1}{4T} \left[ \sin(2\omega T) + \sin(\omega T) \right]. \]  

(8)

The difference equation is [7]

\[ y(nT) = \left( \frac{1}{8T} \right) \left[ -x(nT - 2T) - 2x(nT - T) \right. \]

\[ \left. + 2x(nT + T) + x(nT + 2T) \right]. \]  

(9)

Fig. 4 shows that the frequency response of this derivative is nearly linear between dc and 30 Hz (i.e., it approximates an ideal derivative over this range). Its delay is two samples.

Fig. 4. Amplitude response of the digital derivative filter.
Band-Pass Filter and Differentiation

Electrocardiogram sampled

Low-pass filtered ECG.

Band-pass-filtered ECG

ECG after band-pass filtering and differentiation
The squaring process intensifies the slope of the frequency response curve of the derivative and helps restrict false positives caused by T waves.
Band-pass filtered ECG after subjecting to derivative filtering and squaring function
Moving-Window Integration

The purpose of moving-window integration is to obtain waveform feature information in addition to the slope of the R wave. It is calculated from

\[ y(nT) = \frac{1}{N} \left[ x(nT - (N - 1) T) + x(nT - (N - 2) T) + \cdots + x(nT) \right] \]  

(11)

where \( N \) is the number of samples in the width of the integration window.

Generally, the width of the window should be approximately the same as the widest possible QRS complex.

Moving-Window Integration
Fiducial Mark. The QRS complex corresponds to the rising edge of the integration waveform. The time duration of the rising edge is equal to the width of the QRS complex.

Output from Moving Integral Filter
The thresholds are automatically adjusted to float over the noise. Low thresholds are possible because of the improvement of the signal-to-noise ratio by the bandpass filter.

**Adjusting the Thresholds**
If the program does not find a QRS complex in the time interval corresponding to 166 percent of the current average RR interval, the maximal peak detected in that time interval that lies between these two thresholds is considered to be a possible QRS complex (the lower of the two thresholds is applied).

Adjusting the Thresholds
The higher of the two thresholds in each of the two sets is used for the first analysis of the signal. The lower threshold is used if no QRS is detected in a certain time interval so that a search-back technique is necessary to look back in time for the QRS complex.

**Adjusting the Thresholds**
ECG Waveform with R-Peaks Identified
Typical steps of Pan-Tompkins algorithm for detecting QRS complex: (a) band-pass filtered ECG signals; (b) after differentiation; (c) after performing squaring operation; (d) moving window integration; and (d) R peak detection.

Matlab QRS Detection Algorithm
Identification of inflexion points