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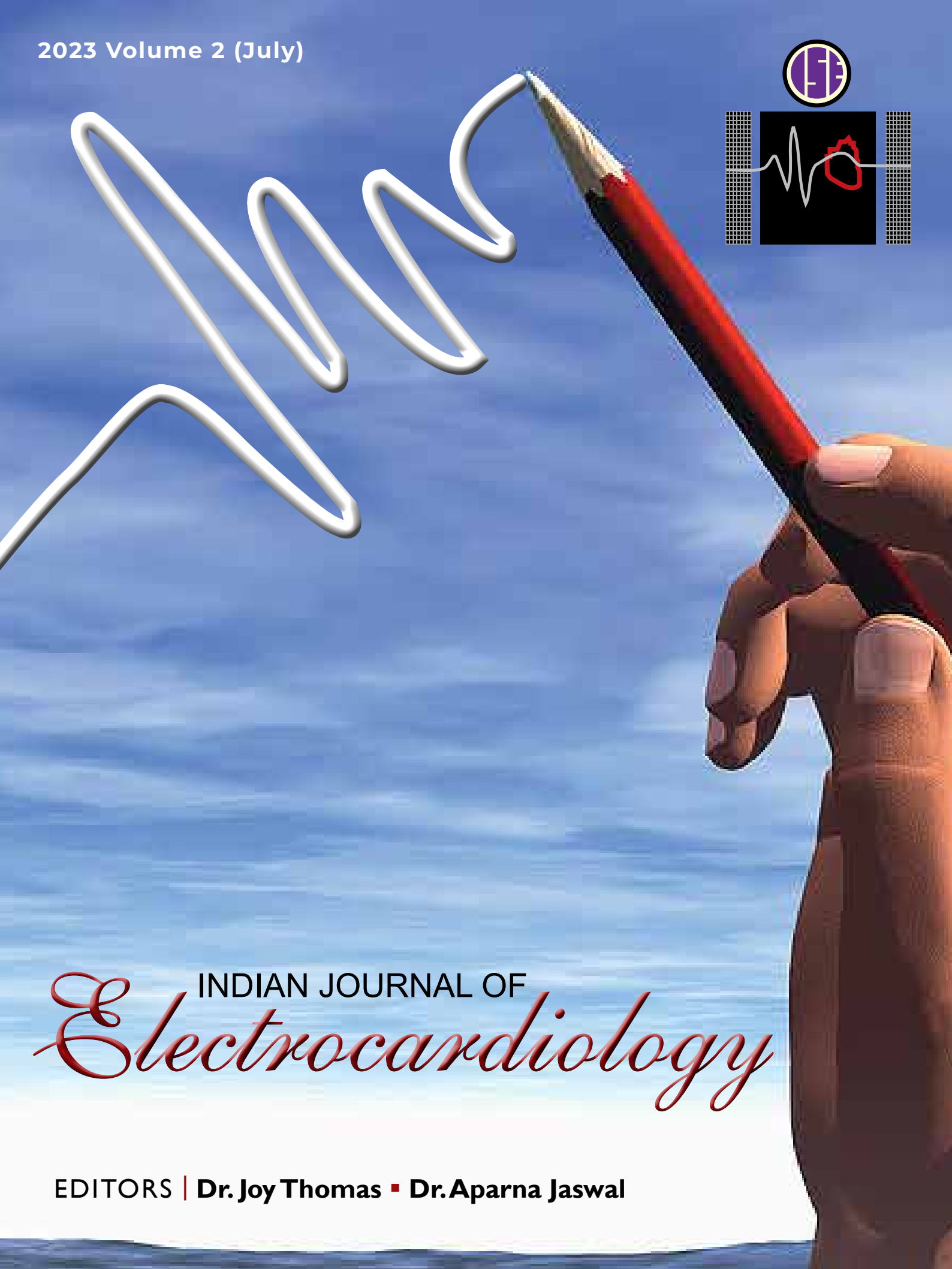

INDIAN JOURNAL OF Electrocardiology

EDITORS | Dr. Joy Thomas ▪ Dr. Aparna Jaswal

C O N T E N T S

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Editorial

Revisiting the ECG

The Mid term ISECON in the city of Solapur on the banks of the Bheema which flows into the mighty Krishna river will once again ignite our minds to the various aspects of the Electrocardiogram. In this issue released during this event we have invited some articles on the ECG from some of the great Electrophysiologists of the country

Most Holter 24 hours ambulatory ECG recording reports show a heart rate variability report. Often, this report is skipped by the physician. A clear understanding of its various parameters and its clinical application will help in the utilising the information on Heart Rate variability in clinical practice.

Some children diagnosed as having seizure disorder have been later found to have ECG evidence of abnormal QT interval and the occurrence of polymorphic VT which can account for the syncopal spells . The erroneous diagnosis and the inappropriate drugs can be dispensed with and the patient given the right advice and treatment, effectively preventing further episodes.

That brings us to sudden cardiac death that can result from a long QT based polymorphic VT. The markers in ECG which point to person in the population who are at risk of a sudden cardiac arrest should be known in order that such persons can be identified and treated.

The morphology of the P wave can provide a wealth of information on the hemodynamics of the circulation, its effects on the cardiac chambers, help in the diagnosis of arrhythmias and in assessing the autonomic status of the person.

One of the great breakthroughs in recent times is the pacing in the conduction system of the heart to get over the left bundle branch block and yield a normal ECG. This right ventricular route pacin g of the left ventricle through the capture of the left bundle has revolutionized pacing and opened up a new field in cardiac electrophysiology-conduction system pacing. The ECG of such patients may reach the desk of the physician and it is useful to know the features of such an ECG and learn the physiology behind the procedure.

Its been an exhilarating ride through various topics on pure ECG ever since we have taken up the editorship and we thank the Indian Society of Electrocardiology for the honour.

Joy M Thomas **Aparna Jaiswal**

From the Desk of Advisor

Dear Members,

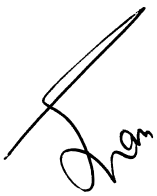
It is indeed a great pleasure that after a long gap, Indian Journal of Electrocardiology, the Official Journal of Indian Society of Electrocardiology is being brought in succession and really hope that our distinguished Journal Editors will keep it going.

Current issue of Indian Journal of Electrocardiology is full of important articles which will benefit the practicing physicians

I would like to thank Dr Vanita Arora, President ISE, Dr Ashish Nabar, Treasurer ISE and the back bone to bring out this issue and Dr Ketan Mehta, Secretary ISE for his support.

The Journal Editors, Dr Joy Thomas and Dr Aparna Jaswal had done lot of efforts to get the important articles on time. No words can express my thanks to them for their untiring efforts to bring back the glory to IJE and bring the issue well in time.

Long Live ISE.



Dr. S.B. Gupta
Advisor
Indian Society of Electrocardiology

From the President's Desk

Importance of ECG in medicine

ECG the "Rhythm of Life" is the most basic requirement to analyse a cardiac patient. Yet it is underrated and less understood by not only medical student but many practicing doctors.

It is the toughest call to label An ECG as Normal, and to take that call the basics of ECG should be clear in the mind.

Education is the key for better diagnosis in clinical practice, so education around making the concepts of ECG clear is the Aim of my thought process as President of Indian Society of Electrocardiology.

Aim to do ECG Learning Courses at the State level and Zonal level is the Aim of my Campaign which is dedicated to highlighting the importance of this very simple modality.

Highlighting further is the Role of "Artificial Intelligence" in ECG analysis is the future of Cardiology and needs the due credit. It has taken the world by revolution and requires its due credit in the field of diagnostics.

Collaborations are required of ISE with medical collages to educate young physicians and cardiologists in various part of the country as students are our future, their perspective and education matters the most.

I wish all the best to the Organisers for the Mid Term meeting at Sholapur in July 2023 and

Annual meeting in Feb 2024 at Ahemdabad.

"It is Our Choices that show what we Truely are, Far more than Our Abilities"

Dr. Vanita Arora
President
Indian Society of Electrocardiology

Heart Rate Variability and its Clinical Uses

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Heart rate varies from time to time and is seldom a constant number, its value varying with the interplay of the autonomic balance that results from the sympathetic and parasympathetic systems. Heart rate variability (HRV) is the physiological phenomenon of variation in the time interval between heartbeats. It is measured by the variation in the beat-to-beat interval and statistical derivatives are used to provide metrics to quantitate and exhibit the role of its influencers. The 24 hours Holter report provide us with some of these metrics and its understanding will help us to manage various clinical situations. Other terms used include "cycle length variability", "R–R variability" and "heart period variability".[1]

Methods of analysis of HRV[1,2]

Time-domain methods:

These are based on the beat-to-beat or NN intervals, which are analysed to give different variables. (See Fig. 1)

Non-linear methods [2]

The most commonly used non-linear method of analysing heart rate variability is the Poincaré plot. Each data point represents a pair of successive beats, the x-axis is the current RR interval, while the y-axis is the previous RR interval. HRV is quantified by fitting mathematically defined geometric shapes to the data. Other methods used are the correlation dimension, symbolic dynamics, non-linear predictability, point wise correlation dimension, approximate entropy, sample entropy, multiscale entropy analysis, sample asymmetry and memory length (based on inverse statistical analysis). It is also possible to represent long range correlations geometrically. Sequences of RR intervals have been found to have long-term correlations. However, one flaw with these analyses is their lack of goodness-of-fit statistics, i.e. values are derived that may or may not have adequate statistical rigor. Different types of correlations have been found during different sleep stages.

Physiological correlates of HRV components[1,2]

Autonomic influences of heart rate

Heart rate and rhythm are primarily under the control of the autonomic nervous system, despite the fact that cardiac automaticity is intrinsic to distinct pacemaker tissues. The vagus nerve releases acetylcholine, which mediates the

Table 1:

Variable (Statistical measures)	Description
SDNN(ms)	Standard deviation of all NN intervals
SDANN(ms)	Standard deviation of the averages of NN intervals in all 5min segments of the entire recording.
RMSSD (ms)	The square root of the mean of the sum of the squares of differences between adjacent NN intervals.
SDNN index(ms)	Mean of the standard deviations of all NN intervals for all 5 min segments of the entire recording.
SDSD(ms)	Standard deviation of differences between adjacent NN intervals.
NN50 count	Number variants are possible counting all such NN intervals pairs or only pairs in which the first or the second interval is longer
pNN50(%)	NN50 count divided by the total number of all NN intervals.
Geometric measures	
HRV triangular index	Total number of all NN intervals divided by the height of the histogram of all NN intervals measured on a discrete scale with bins of 7.8125 ms(1/128s)
TINN(ms)	Baseline width of the minimum square difference triangular interpolation of the highest peak of the histogram of all NN intervals.
Differential index(ms)	Difference between the widths of the histogram of differences between adjacent NN intervals measured at selected heights
Logarithmic index	Coefficient ø of the negative exponential curve $k \cdot e^{-øt}$ which is the best approximation of the histogram of absolute differences between adjacent NN intervals.

Table 2: Frequency domain-

Variable	Units	Description	Frequency range
Analysis of short-term recordings (5 min)			
5min total power	ms^2	The variance of NN intervals over the temporal segment	approx≤0.4Hz
VLF	ms^2	Power in very low frequency range	≤0.04Hz
LF	ms^2	Power in low frequency range	0.04-0.15Hz
LF norm	n.u.	LF power in normalized units (LF/Total Power-VLF)×100	
HF	ms^2	Power in high frequency range	0.15-0.4Hz
HF norm	n.u.	HF power in normalized units HF/(Total Power-VLF)×100	
LF/HF		Ratio LF [ms^2]/HF[ms^2]	
Analysis of entire 24hr			
Total power	ms^2	Variance of all NN intervals	approx. ≤0.4Hz
ULF	ms^2	Power in the ultra low frequency range	≤ 0.003 Hz
VLF	ms^2	Power in the very low frequency range	0.003-0.04Hz
LF	ms^2	Power in the low frequency range	0.04-0.15Hz
HF	ms^2	Power in the high frequency range	0.15-0.4Hz
α		Slope of the linear interpolation of the spectrum in a log-log scale	approx. ≤0.01Hz

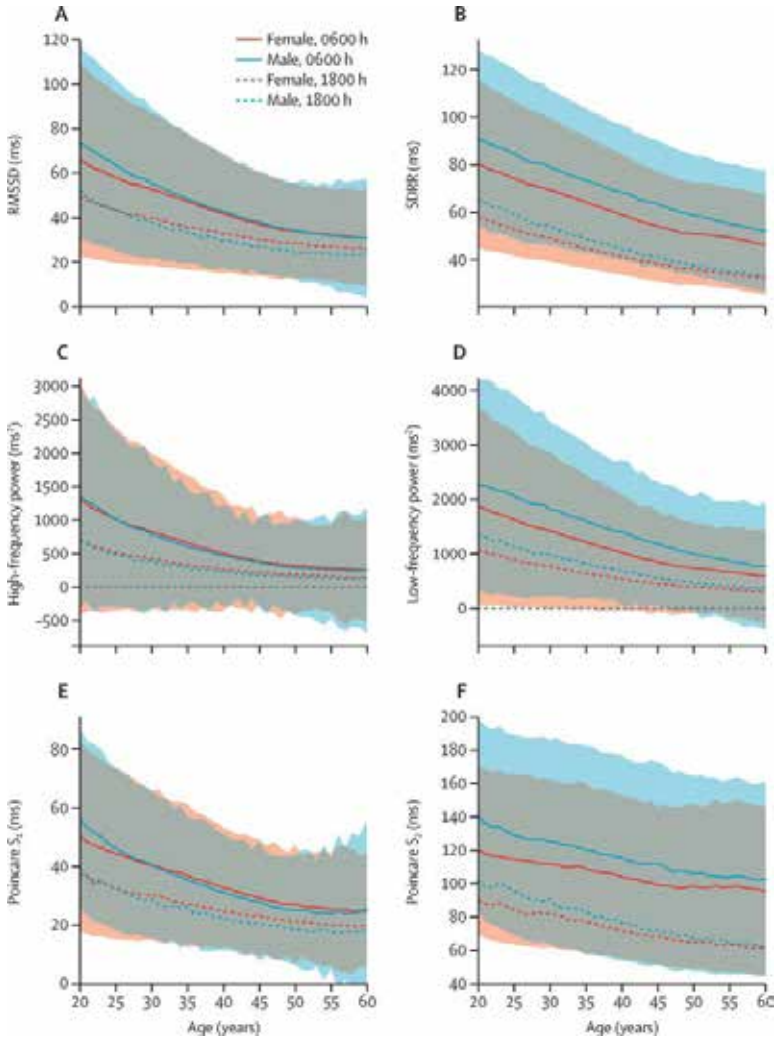

Figure 1: Heart Rate variability parameters relation with age. ***Courtesy:*** The Lancet, Author Arvind Natarajan et al, Dec, 2020.2:12

Table: Normal values of standard measures of HRV [1,2,3]

Time Domain Analysis			Spectral Domain Anlaysis		
Variable	**Units**	**Normal Values mean±SD)**	**Variable**	**Units**	**Normal Values**
SDNN	ms	50±16	LF	ms^2	519±291
RMSDD	ms	42±15	HF	ms^2	657±777
IBI	ms	926±90	LF	nu	52±10
			HF	nu	40±10
			LF/HF ratio		2.8±2.6

parasympathetic influence on heart rate. The main way that muscarinic acetylcholine receptors react to this release is by increasing the K+ conductance of the cell membrane. Additionally, acetylcholine blocks the "pacemaker" current that is activated by hyperpolarization. According to the "Ik decay" concept, diastolic depolarization, which is what causes pacemaker depolarization, is caused by the slow deactivation of the delayed rectifier current, Ik_r. The "I_f" hypothesis, on the other hand, contends that after the termination of an action potential, I_f offers a slowly activating inward current that predominates over Ik_r's decay, starting a steady diastolic depolarization.

The sympathetic influence on heart is mediated by release of epinepherine and norepinephrine. When β-adrenergic receptors are activated, membrane proteins are phosphorylated by cAMP, which also causes a rise in ICaL and I_f. As a result, the gradual diastolic depolarization is accelerated.

At rest, vagal tone predominates, and fluctuations in heart rate are predominantly influenced by vagal modulation. Both sympathetic and vagal activity are continually interacting. The sinus node is rich in acetylcholinesterase; therefore any vagal impulse has a short-lived effect since the acetylcholine is hydrolyzed quickly. Through at least two separate mechanisms, parasympathetic effects exceed sympathetic effects: a cholinergically induced decrease in norepinephrine released in response to sympathetic activity, and a cholinergic attenuation of the response to an adrenergic stimulus.[1,2]

Components of HRV

The beat-by-beat fluctuations in cardiac autonomic inputs are represented by the RR interval variations present under resting conditions. However, as demonstrated in clinical and experimental observations of autonomic maneuvers such electrical vagal stimulation, muscarinic receptor blockage, and vagotomy, efferent vagal (parasympathetic) activity is a key contributor to the HF component. The interpretation of the LF component is more challenging. It was once believed to be a sign of sympathetic modulation (particularly when expressed in normalised units), but is now known to incorporate both sympathetic and vagal influences. For instance, the tachycardia that results from sympathetic activation frequently is accompanied by a significant drop in overall power, whereas vagal activation has the opposite effect. As a result, the spectral components shift in the same direction and do not indicate that LF faithfully reflects sympathetic effects.[1,2]

Rather than measuring the average level of autonomic inputs to the heart, HRV measures fluctuations in autonomic inputs to the heart. Decreased HRV can therefore be caused by both withdrawal and excessively high levels of autonomic input to the heart.[1,2]

Changes related to biologic states and pathologies

A reduction of HRV has been reported in several cardiovascular and non-cardiovascular diseases

Myocardial infarction

A decrease in vagal activity directed to the heart may be the cause of depressed HRV following MI. A decrease in both the overall and the individual power of spectral components is observed in HRV in patients surviving an acute MI. A blunting of the day-night variations of the RR interval also indicates an alteration in neural control. Most of the residual energy is dispersed in the VLF frequency range below 0.03 Hz in post-MI patients with severely reduced HRV, with only a small respiration-related variations.[1,2]

Diabetic neuropathy

A decrease in time domain HRV parameters appears to not only carry a poor prognostic value but also to precede the clinical manifestations of autonomic neuropathy associated with diabetes mellitus which involves small nerve fibres. Reduction of the absolute power of LF and HF under controlled conditions was also found in diabetic patients without signs of autonomic neuropathy. Similarly, a decrease in HRV can be used to distinguish diabetic patients from healthy controls.[4]

Heart transplants

Patients with recent heart transplant have been observed to have a severely decreased HRV with no definite spectral components. In a small number of individuals, the emergence of discrete spectral components is thought to be due to cardiac reinnervation. Reinnervation is thought to have sympathetic origins. An association between respiratory rate and the HF component of HRV seen in some transplant patients further suggests that a nonneural mechanism that may be responsible for a respiration-related rhythmic oscillation.[1,4]

Myocardial dysfunction (see Fig. 2)

Patients with heart failure have consistently shown to have a lower HRV. A correlation between variations in HRV and the degree of left ventricular dysfunction was identified in this syndrome, which is characterised by symptoms of sympathetic activity such as higher heart rates and high levels of circulating catecholamines. The association between spectral components and indicators of ventricular dysfunction actually appears to be more complex than that between the decline in time domain measures of HRV and the severity of the disease. In particular, despite the clinical symptoms of sympathetic activation in the majority of patients with a very advanced stage of the disease and a marked decline in HRV, an LF component could not be identified. This illustrates the fact that, as was previously indicated, the LF might not adequately reflect cardiac sympathetic tone.[1,2]

Liver cirrhosis

Reduced HRV is seen in liver cirrhosis, has prognostic significance and predicts mortality. In this patient population, loss of HRV is also associated with increased plasma levels of pro-inflammatory cytokines and diminished neurocognitive performance.[1]

Sepsis

In sepsis patients, HRV is reduced. In newborns with sepsis, loss of HRV has diagnostic and prognostic value. Although the etiology of decreased HRV in sepsis is poorly understood, experimental data suggest that it may be related to the partial uncoupling of cardiac pacemaker cells from autonomic neural regulation during acute systemic inflammation.[1]

Quadriplegia

Efferent vagal neural circuits pointing to the sinus node are unaltered in patients with chronic total high cervical spinal cord injuries. However, in certain quadriplegic patients' HRV and arterial pressure variations can be seen to have an LF component. In those who do not have intact sympathetic inputs to the heart, the LF component of HRV therefore represents vagal regulation.[1,4]

Sudden cardiac death

Victims of sudden cardiac death have been found to have had lower HRV than healthy individuals. HRV is also depressed in SCD survivors, who are at high risk for subsequent episodes.

Cancer

Patients in the early stages of cancer have a significantly higher HRV when compared to patients in the later stages of cancer, suggesting disease severity influences HRV.[1,2,3]

Pregnancy

HRV mean values are decreased in pregnancy, both healthy pregnancy as well as pregnancy with gestational diabetes.[1,2,3]

Mood and anxiety disorders

Low RMSSD, thought to represent vagal tone, have been associated with major depression. Lower SDNN and elevated LF/HF are found in those with bipolar disorder, and in particular those characterized as having greater illness severity. Patients with PTSD also have lower HF, a measure of vagal tone.[1,4]

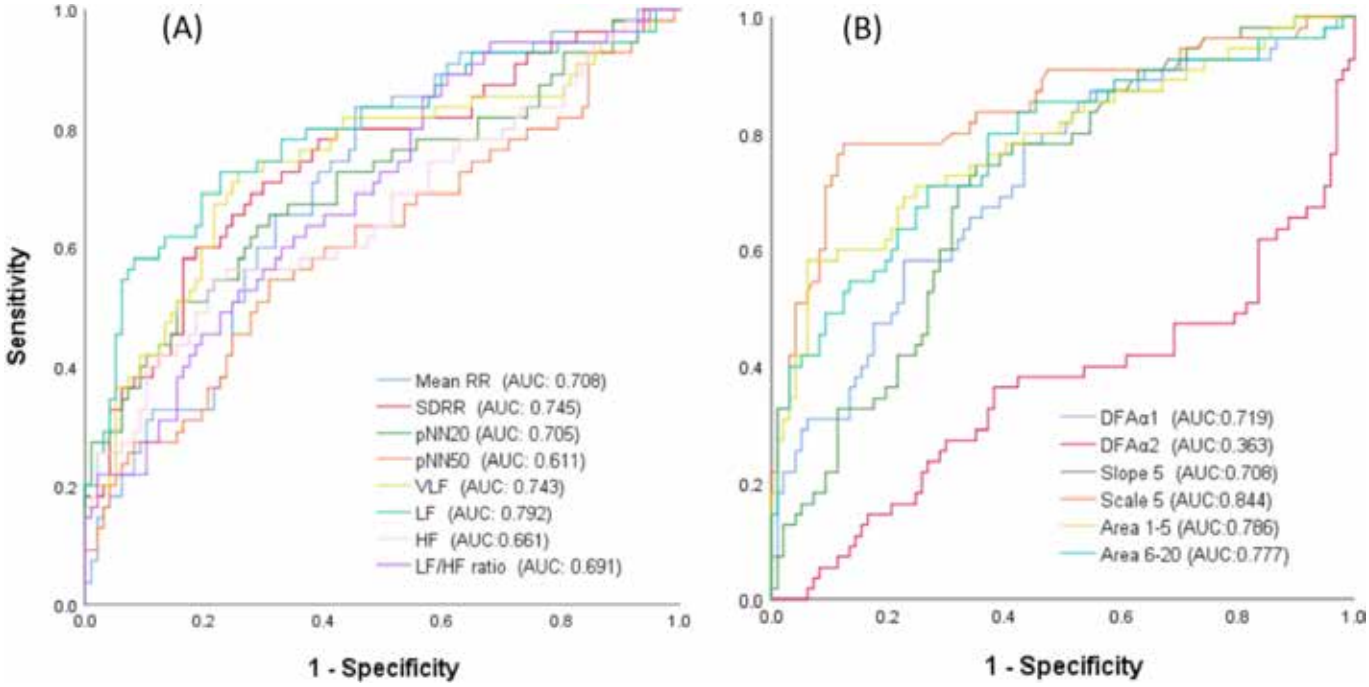

Figure 2: Heart Rate Variability characteristics to distinguish Heart Failure. ***Courtesy:*** Scientific Reports (Sci Rep) ISSN 2045-2322 (online)

Modification of HRV by specific intervention

Interventions that augment HRV may be protective against cardiac mortality and sudden cardiac death. Despite the growing consensus that increases in vagal activity can be beneficial, it is not as yet known how much vagal activity (or HRV as a marker) has to increase in order to provide adequate protection.[1,3]

β-Adrenergic blockade

The data on the effect of β-blockers on HRV in post-MI patients are surprisingly scant. The unexpected observation that before MI, β-blockade increases HRV only in the animals destined to be at low risk for lethal arrhythmias after MI may suggest novel approaches to post-MI risk stratification.[1,4]

Antiarrhythmic drugs

Flecainide and propafenone but not amiodarone decrease time domain measures of HRV in patients with chronic ventricular arrhythmia. Propafenone reduces HRV and decreases LF much more than HF. It is not known whether these changes in HRV have any direct prognostic significance.[1,3]

Scopolamine

Scopolamine and low dose atropine can markedly increase HRV. However, though the heart rate slowing is proportional to the (low) dose of atropine, the increase in HRV varies widely across and within individuals.[1]

Thrombolysis

In a study, HRV was higher 90 minutes after thrombolysis in the patients with patency of the infarct-related artery. However, this difference was no longer evident when the entire 24 hours were analyzed.[1]

Exercise training

Exercise training may decrease cardiovascular mortality and sudden cardiac death. Individuals who exercise regularly have a 'training bradycardia' (i.e., low resting heart rate) and generally have higher HRV than sedentary individuals.[1]

Biofeedback

The technique called resonant breathing biofeedback teaches how to recognize and control involuntary heart rate variability. A meta-analysis of 24 studies showed that HRV biofeedback training is associated with a large reduction in self-reported stress and anxiety.[1]

Clinical use of heart rate variability

Conditions that are also associated with reduced HRV, are myocardial infarction, diabetic neuropathy, congestive heart failure, post–cardiac-transplant depression, susceptibility to SIDS and poor survival in premature babies, as well as fatigue severity in chronic fatigue syndrome. However, a general consensus of the practical use of HRV in adult medicine has been reached only in two clinical scenarios. Depressed HRV can be used as a predictor of risk after acute MI and as an early warning sign of diabetic neuropathy.[1,2,3]

Assessment of risk after acute myocardial infarction:

Independent of other known risk factors, low HRV is a predictor of death and arrhythmic consequences following acute MI. Most experts agree that HRV should be assessed about a week after index infarction. Although HRV calculated in nominal 24-h recordings is a better risk predictor, HRV assessed from short-term recordings still offers predictive information. All acute MI survivors may undergo an initial screening using HRV measurements derived from short-term recordings. The time-domain HRV measures (such as the SDNN or HRV triangle index) that assess overall HRV are the best predictive indicators of HRV at the moment. Other metrics, such as the ULF of a 24-hour spectral study, also work well. The dichotomy limitations of SDNN can be used to choose a high risk group.[1,2]

Assessment of Diabetic Neuropathy:

There are three HRV methods from which to choose for the patient presenting with a real or suspected diabetic neuropathy: (a) straightforward bedside RR interval methods; (b) long-term time-domain measures, which are more sensitive and reproducible than the short-term tests; and (c) frequency-domain analysis carried out under short-term steady state conditions and useful in differentiating sympathetic from parasympathetic abnormalities. HRV computed from 24-h Holter records are more sensitive than simple bedside tests (e.g. Valsalva maneuver, orthostatic test, and deep breathing for detecting diabetic neuropathy. Most experience has been obtained with the NN50 and SDSD methods. Using the NN50 count, where the lower 95% confidence interval for total counts range from 500 to 2000 depending on the age, about half of diabetic patients will demonstrate abnormally low counts per 24 h. Moreover, there is a strong correlation between the percentage of patients with abnormal counts and the extent of autonomic neuropathy determined from conventional measures. Besides their increased sensitivity, these 24-h time domain methods are strongly correlated with other established HRV measurements and have been found to be reproducible and stable over time. Similar to survivors of MI, patients with DAN are also predisposed to poor outcomes such as sudden death but it remains to be determined whether the HRV measures confer prognostic information among diabetics. The following abnormalities in frequency HRV analysis are associated with diabetic neuropathy: (a) reduced power in all spectral bands which is the most common finding (b) failure to increase LF on standing, which is a reflection of impaired sympathetic response or depressed baroreceptor sensitivity (c) abnormally reduced total power with unchanged LF/HF ratio and (d) a leftward shift in the LF central frequency, the physiological meaning of which needs further elucidation. In advanced neuropathic states, the resting supine power spectrum often reveals extremely low amplitudes of all spectral components making it difficult to separate signal from

noise. It is therefore recommended that an intervention such as standing or tilt be included. Another method to overcome the low signal to noise ratio is to introduce a coherence function which utilizes the total power coherent with one or the other frequency band.[1,2,4]

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The QT Interval in Daily Practice

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The ECG remains one of the the most important noninvasive tools for the diagnosis of cardiac diseases in general, and cardiac rhythm disorders, conduction system abnormalities, and myocardial ischemia in particular. Hence a systematic approach to interpretation of the ECG is important to derive its maximum benefit. The normal ECG has several waveforms indicative of the electrical events during each cardiac cycle. Measurements of intervals and segments in the ECG, are of diagnostic value. In this regard, **the QT interval** assumes significance to the clinician.

The QT interval extends from the onset of the QRS complex to the end of the T wave. It includes the entire duration of ventricular activation- depolarization and repolarization, and corresponds to the duration of the ventricular action potential[1]. Primarily, **it is a measure of ventricular repolarization**. It consists of the QRS complex, ST segment and T wave.

Measurement of the QT interval

Measurement of the QT interval is ideally done manually, in lead II and V5 as the T wave termination is the clearest in these leads. Alternatively, measurement of the QT interval in Leads V2 and V3 has also been proposed as the QT measurements are the longest in these leads.The number of small boxes in the ECG is measured from the beginning of the QRS complex up to the end of the T wave. The end of the T wave is difficult to pin point specifically and hence the following methods may be used[2].

'Tangent Method'- is the most commonly used method. A tangential line is drawn at the steepest point of the descending limb of the T wave. A perpendicular line is then dropped at the point at which it intersects the isoelectric baseline. This indicates the end of the T wave.

In ECGs where a U wave interrupts the T wave before it touches the isoelectric baseline, the 'Threshold Method' may be used.

The QT interval is rate dependent, and is inversely proportional to the heart rate. The most commonly used formula to calculate

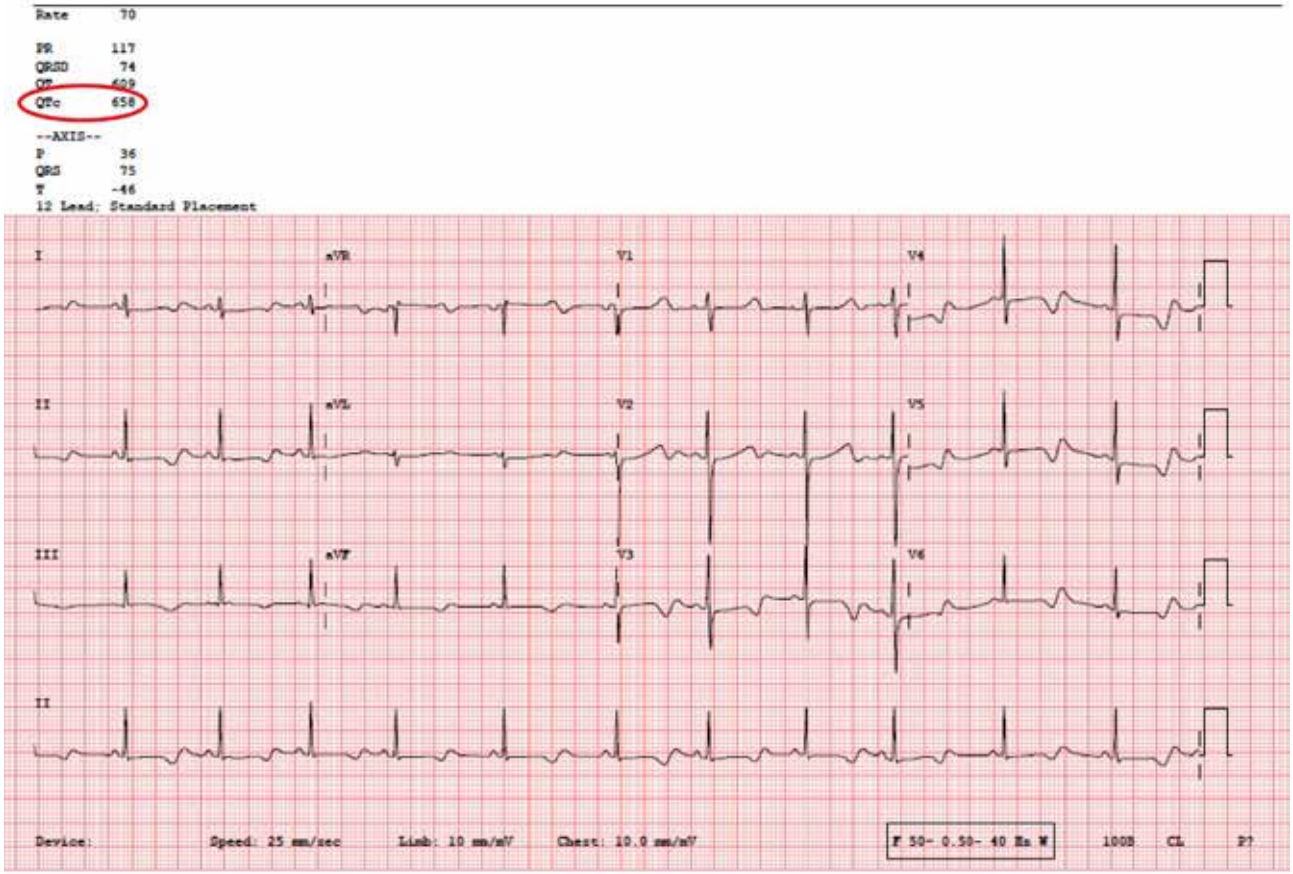

Figure: Classic ECG of Long QT - > 600msec in this example

the QT interval, corrected for the heart rate(corrected QT interval, QTc) was given by Bazett in 1920, using the formula mentioned below

Other lesser used formulae include the Friedericia, Framingham, and Hodges formulae. However, the Bazett's formula is the one widely used.

An increase in the QRS duration will lead to an increase in QT interval with no change in ventricular repolarization. The following formula is suggested to measure QT when the QRS complex is wide for instance, in complete BBB.

$QT_{modified} = QT_{measured} - (0.5 \times QRS_{measured})$, followed by correction for heart rate.

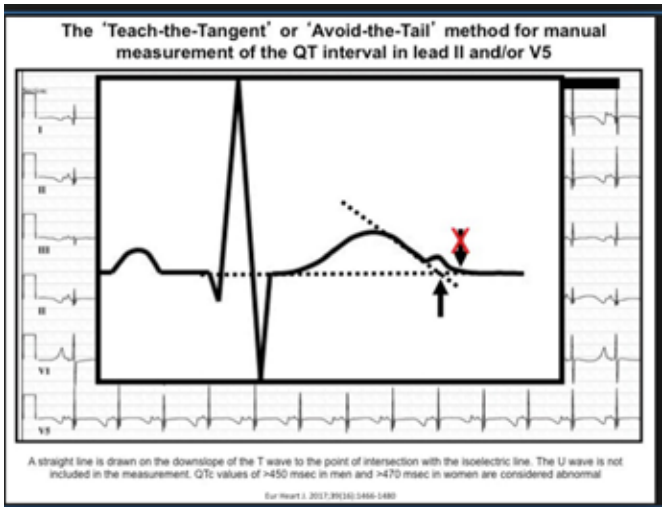

Figure: The Tangent method for accurate measurement of the QT interval

Hence, more accurate measure of ventricular repolarization is the JT interval which excludes the QRS complex. The normal JTc is <360msec.

In conditions where the heart rate is irregular, such as atrial fibrillation or sinus arrhythmia, an average of the QTc over 10 beats or measuring the QTc in the shortest and longest RR interval and then averaging the 2 may be done.

Various physiological variations in the QT interval include gender with longer intervals in women, the QT interval increases with age, circadian rhythm with a longer QT interval during sleep and changes in autonomic tone with decreasing intervals with higher sympathetic tone and vice versa.

The normal QTc interval varies between the sexes only after puberty. In infancy, a QTc of 400 +/- 20 msec is normal. Before puberty, a QTc of < 450ms is normal and > 460ms is prolonged. After puberty, QTc in females is said to be

$QTc = QT/\sqrt{RR}$

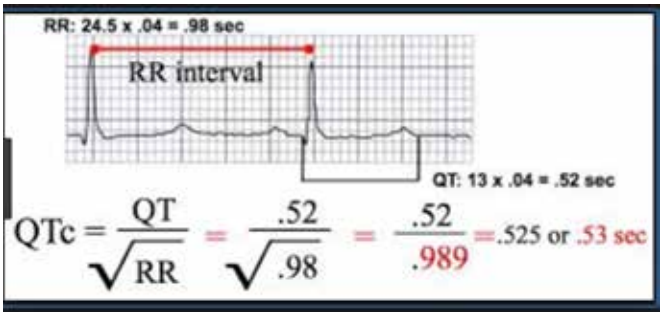

Figure: Calculation of QTc using Bazett's Formula

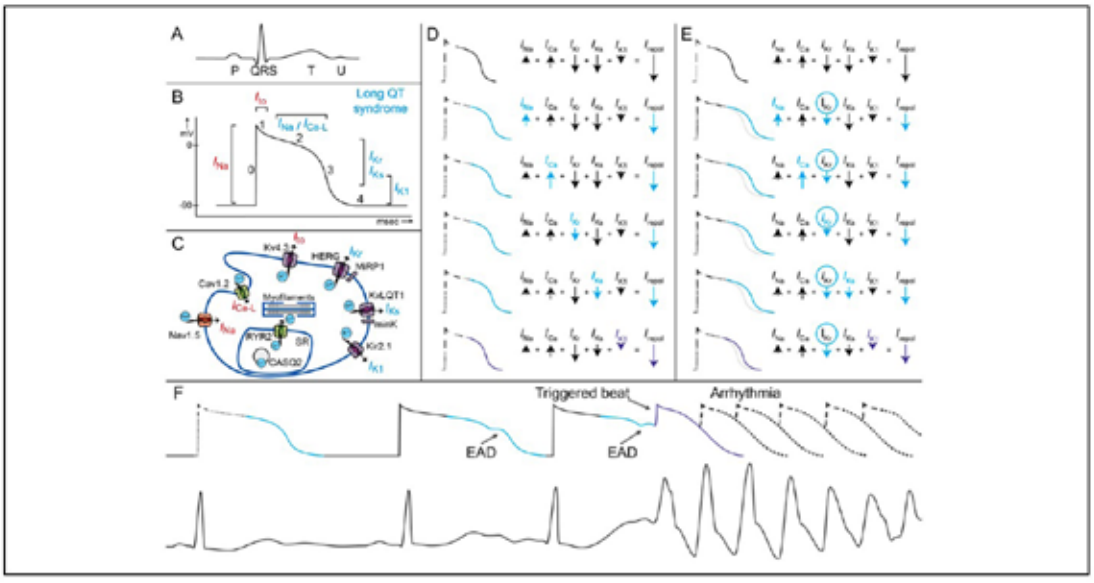

Figure: Note the EADs reaching threshold voltage triggering repetitive action potentials and TdP

prolonged when it is > 480ms and in males when > 470ms. (Fig 1. Typical example of LQTS with QTc >600ms)[2]

The clinical relevance of Long QT interval

The Long QT syndrome is a ventricular myocardial repolarization disorder, which may lead to ventricular arrhythmias and increased risk of sudden cardiac death. It is characterized by a prolonged QT interval on the ECG with the occurrence of a classical polymorphic ventricular tachycardia-Torsades de pointes(TdP). In contrast, a similar arrhythmia without LQT, is referred to as polymorphic ventricular tachycardia. (for e.g. in myocardial ischemia)

Most patients remain asymptomatic, while a small percentage may develop TdP. In this condition,the symptoms depend on the rate and duration of the arrhythmia and the presence of various comorbid conditions. If symptomatic, patients typically present with presyncope, syncope, or palpitations. The episodes are usually self-terminating. However, if the arrhythmia persists, patients may present with sudden cardiac arrest[3].

LQTS can be further classified into congenital and acquired forms.

Congenital LQTS

Mutiple pathogenic genetic variants have been implicated in congenital LQTS, of which the three main subtypes include LQTS1, LQTS2, LQTS3 encoded by three genes, KCNQ1, KCNH2 and SCN5A respectively. These account for 80-90% of all cases.

There is a prolongation of the action potential and hence the QT interval due to mutations of the slow outward rectifying Potassium channels and rarely due to mutations causing an accentuation of a late Sodium current(responsible for phase 0 or the depolarization phase of the action potential). Hence there is an increased occurrence of afterdepolarizations and triggered activity via re-entrant mechanisms, causing Tdp (Figure 2)

These patients are usually diagnosed in the first three decades of life, the timing of which depends of the severity of symptoms and the degree of QT prolongation. The most common symptom is unexplained syncope. Many patients, however may remain asymptomatic and are diagnosed due to incidental ECG recording for some other causes. In female patients, a diagnosis is usually made during puberty as cardiac events are more prevalent during this phase. Pregnancy may also provoke or exacerbate previous arrhythmias.

Although the majority of patients with arrhythmias have ventricular arrhythmias, bradycardia (more common in first 3 years of life), AV block (due to prolonged ventricular refractoriness) and atrial arrhythmias may also be seen in a small percentage of the patients.

An immediate trigger for Tdp in congenital LQTS is a sudden surge in the sympathetic tone. The left cardiac sympathetic nerves include the left stellate ganglion and the first four thoracic ganglia. These bring about the higher levels of release of norepinephrine than their right counterparts. They innervate the left and posterior portions of the ventricles. Various triggers such as exercise (especially swimming, diving),

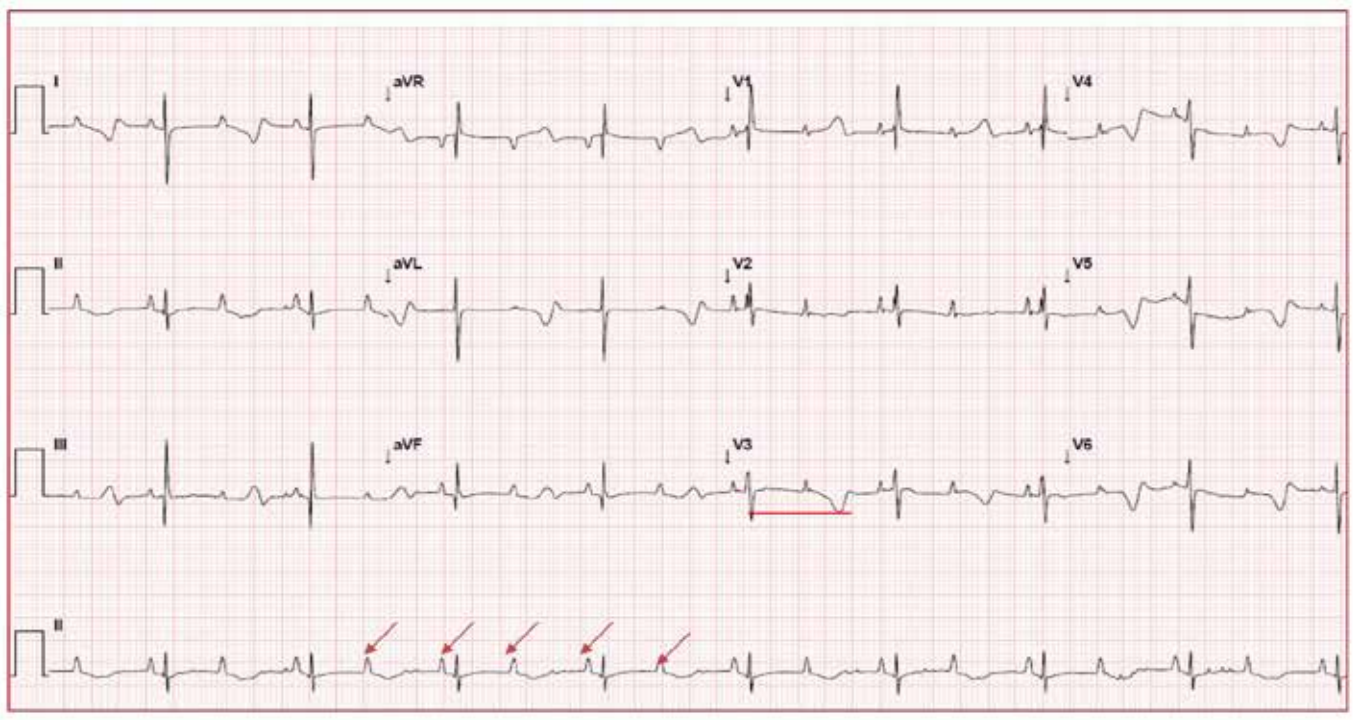

Figure: LQTS with functional 2:1 AV block. The red arrows indicate consecutive P waves. Note alternate P falling in the ventricular refractory period and hence no ventricular depolarisation occurs.

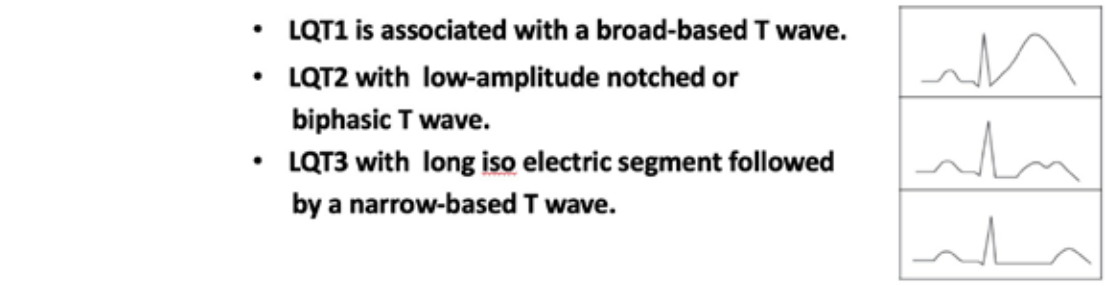

Figure: Typical phenotypic expression of the common Congenital LQTS in the ECG

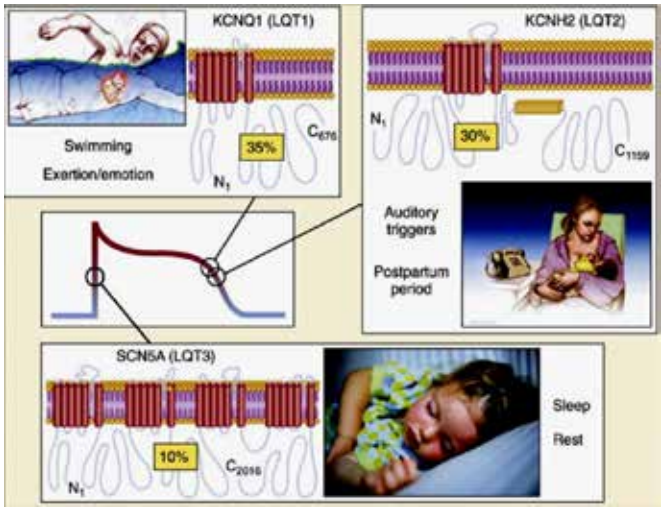

Figure: Typical triggers for arrhythmia in the 3 common forms of Congenital LQTS

stress, noise, electrolyte disturbances and QT prolonging drugs may potentiate such events.

Genotype- Phenotype correlation in congenital LQTS

The ECG patterns and the triggers for syncope/TdP give potential clues to the underlying genotype. Though the confirmatory test for the diagnosis of the specific types of congenital LQTS is by genotyping, the genotype-phenotype correlation has relevance to the clinical diagnosis and appropriate treatment.

LQT1- Mutation in KCNQ1 gene. Accounts for 45% of patients with LQTS. During exercise testing in this variant, there is an impaired shortening of QT, a decreased chronotropic response followed by an exaggerated prolongation of the QT interval. The QTc in the recovery phase is >/= 470msec. Arrhythmic events are commonly related to exercises like swimming (Family history of drowning related deaths in first degree relatives points to this subtype of congenital LQTS). There is a reduced risk of syncope seen after the onset of menopause.

LQTS2- Mutation in KCNH2 gene on Chromosome 7. Includes 25-40% of all patients with LQTS. Notching of the T wave in post-partum females with auditory triggers are characteristic of LQTS2. Auditory stimuli triggering cardiac events are typical. These patients also have a significant number of events during sleep. Patients with LQTS2 in particular, have a higher risk of cardiac events 6-9 months postpartum. The onset of menopause has been associated with a higher occurrence of syncope.

LQTS3- Mutation of the SCN5A gene encoding for the sodium channel located on chromosome 3. These patients have a prolonged QT at rest with a typical shortening of the QTc at peak exercise and recovery. High number of events are noted during sleep.

There are 2 characteristic phenotypes of congenital LQTS:

Romano Ward syndrome: Autosomal Dominant form with a purely cardiac presentation including a prolonged QT leading to cardiac events.

Jervell and Lange-Nielsen Syndrome- Autosomal recessive form associated with sensorineural deafness with Long QT. It occurs due to the mutation of the KCN1 and KCNE1(LQT5) genes which encode for the the slow component of the outward-rectifying potassium current. These mutations also result in the disruption of production of endolymph in the cochlea causing deafness. This variant has been seen to have a much more malignant course.

Approach to a patient with suspected congenital LQTS

1. History: A detailed history focusing on symptoms suggestive of an underlying cardiac arrhythmia such as syncope, palpitations, seizures, history of aborted sudden cardiac arrest must be taken for all patients. An integral part of the history taking process includes a detailed insight into the patient's family history to rule out acquired versus congenital LQTS and then to facilitate screening of family members in patients whom congenital LQTS is suspected.

2. Standard 12 lead ECG- The length of repolarization which is indicated by the QTc as well as the "look" of the repolarization in the form of the T wave morphology should be carefully assessed.

   A 24 hour ambulatory ECG may also be considered to look for arrhythmias, dynamic T wave changes such as macroscopic T wave alternans, biphasic or notched T waves, especially at night.

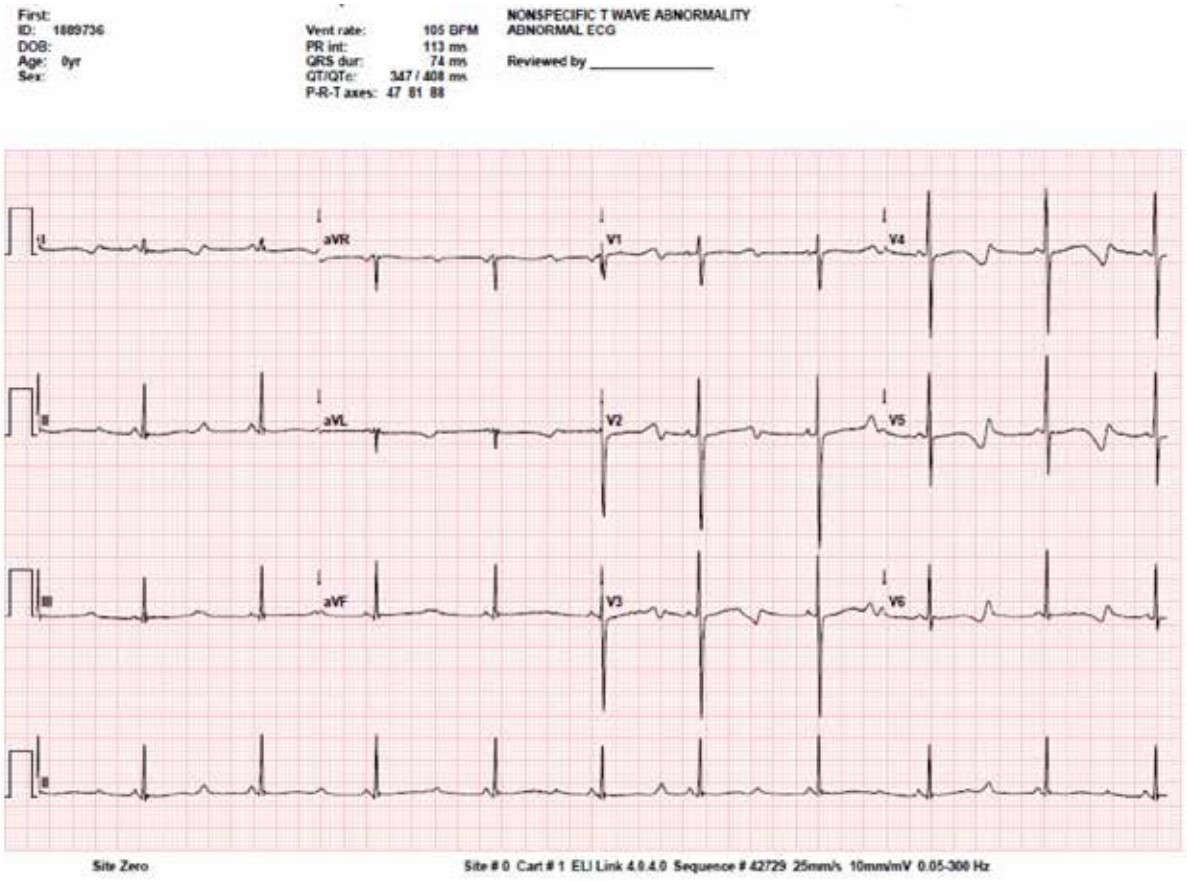

Figure: T wave alternans in 12-lead ECG

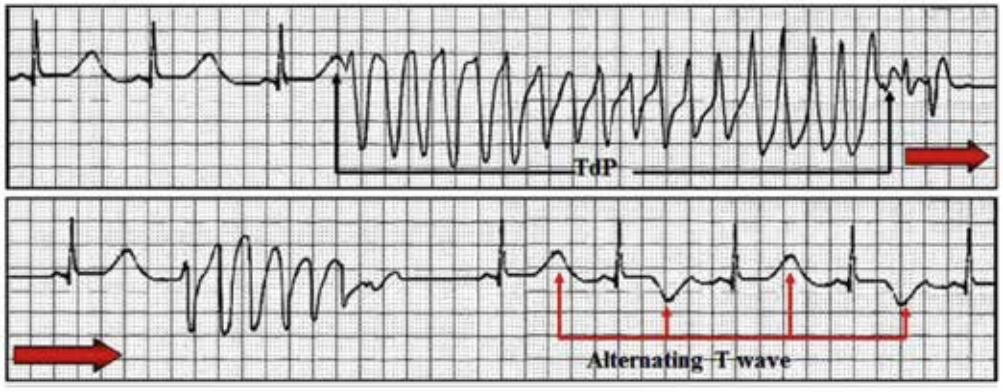

Figure: Initiation of TdP demonstrated during Holter ECG monitoring. Also note T wave alternans

If Tdp is documented in the ECG, typical findings include a prolonged QT interval, seen especially in the beat just prior to the onset of the arrhythmia, a heart rate of 160-250 beats per minute, irregular RR intervals and a QRS axis that shows a characteristic cycling pattern through 180° in every 5-20 beats. If it does not terminate spontaneously, it may degenerate into ventricular fibrillation.

3. Exercise Testing: to look for exercise associated arrhythmia, T wave morphology changes and a maladaptive QT response to exercise. During exercise in normal individuals, with an increase in the heart rate, there should be a physiological shortening of the QT interval. An accentuated heart rate recovery is a marker of heightened vagal activity and is a marker for increased risk of cardiac events.

4. Provocative Testing: ECG with catecholamines, facial immersion, abrupt supine to standing, mental stress test

5. Genetic Testing: is recommended in asymptomatic patients with a QTc of >480 msec in children and > 500 msec in adults. Patients with a high suspicion based on history, family history and ECG- given by the Shwartz score, should also undergo testing.

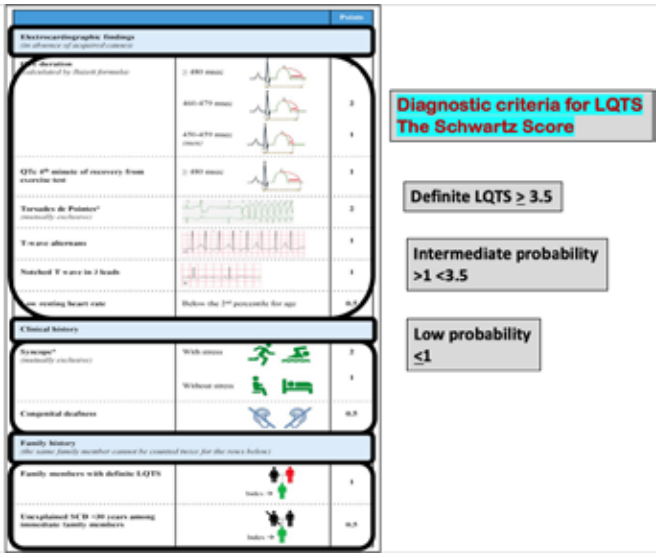

Figure: The Schwartz Scoring System in congenital LQTS

Management specific to congenital LQTS:

1. Prophylactic measures such as avoidance of QT prolonging drugs, correcting electrolyte imbalances should be thoroughly impressed upon the patient.
2. Current recommendations include universal beta blockers for all patients with congenital LQTS. Among the beta blockers, Propranolol or Nadalol are preferred due to their superior efficacy. They have been shown to reduce both syncope as well as SCD. Patients with LQT1 benefit the most with betablockade.
3. Mexiletine is an useful drug in patients with recurrent events on an optimal dose of beta blocker or is intolerant to the drug. In patients with LQT3, it particularly confers a protective effect, especially when combined with a beta blocker. Target dose- 4-6mg/kg/dose every 8 hourly.
4. Left Cardiac Sympathetic Denervation: It interrupts the norepinephrine release in the heart via preganglionic denervation and hence there is no reinnervation. It may be performed in patients with persistent arrhythmias on optimal medical therapy. It reduces the QT interval significantly and decreases the risk of Tdp.
5. Implantable Cardioverter Defibrillator: for secondary prophylaxis is recommended in all patients after an episode of aborted SCA. ICD therapy is also to be considered in patients with recurrent syncope despite maximally tolerated beta blocker therapy or LCSD. A single chamber ICD is usually recommended in these patients. Additional atrial pacing may be useful in those patients in whom bradycardia related VT/VF or a significant pause are documented.
6. The management of TdP is discussed at the end, as the principles are the same in both congenital as well as acquired forms of LQTS.

Acquired LQTS : is commonly associated with drug therapy or electrolyte abnormalities such as hypokalemia, hypomagnesemia, hypocalcemia. Bradycardia may also increase the likelihood of occurrence of drug-induced LQTS.

Most of these drugs act by inhibiting the IKr current, which are present in the cardiac myocytes. These IKr channels are coded for by the KCNH2 gene and pathogenic variants are commonly seen in drug induced LQTS (*forme fruste of genetically mediated LQTS*).This leads to prolongation of the myocardial repolarization, predisposing to early after depolarizations(EAD) and subsequently Tdp. EADs are single or multiple oscillations of the membrane potential occurring during Phase 2 or 3 of the action potential. When such EADs reach threshold potential, it is called a *triggered activity*. This results in depolarization of the cell membrane and additional action potentials, leading to ventricular premature depolarizations and VT(TdP). The Purkinje fibres and the M cells, which are a group of cells in the left ventricular free wall have been identified as the site of EAD-induced triggered activity after exposure to drugs like sotalol, quinidine and erythromycin. The development of EADs is also brought about by bradycardia, hypokalemia and hypomagnesemia.

Most common drugs implicated include cisapride, quinidine, ibutilide, sparfloxacin and anti-arrhythmic drugs, particularly those in Class IA and III. Various drugs used to treat COVID 19 such as hydroxychloroquine, azithromycin were also implicated in the same.

It is more commonly seen in females as it has been postulated that the sex hormones may affect ion channel expression, and oestrogen is known to facilitate bradycardia. Increasing age and comorbidities like LV dysfunction, severe LVH, CAD are also risk factors in predisposed individuals.

Evaluation of such patients includes a detailed in -depth history including the various medications the patient may be on including the dose, duration and initiation of the drug. It is important to also rule out any causes that may predispose the patient to electrolyte abnormalities. The presence of kidney, liver or thyroid disease should also be ruled out. Hypothermia, starvation, anorexia are some other causes that should be kept in mind.

In symptomatic patients including those with syncope even without any documented Tdp, and patients with high risk ECG markers such as T wave alternans, ventricular ectopics, AV blocks and QRS widening, warrant admission and monitoring during withdrawal of the causative drug.

Acquired LQTS can be diagnosed in a patient with abnormal QT prolongation on the ECG with a known predisposing factors, if known to be on any drug that causes a QT prolongation, or the presence of any electrolyte abnormalities, liver or kidney disease or other causes. A high index of suspicion is warranted to make a correct diagnosis of this potentially life threatening condition.

Management of Acquired LQTS

The first step is always the identification and treatment of reversible causes of long QT. This applies to even stable patients with no evidence of TdP. Correction of the electrolyte disturbances or stopping the culprit drug may result in gradual normalization of the QT interval and cessation of symptoms.

The decision to stop an essential drug may be a difficult at times. Hence, if the patient is asymptomatic and the QT prolongation is mild (QTc < 500msec, < 60 msec increase from the baseline) the drug may be continued, iof absolutely essential, with close monitoring with regular ECGs and Holter. In patients in whom the Tdp is secondary to drugs, hypokalemia should also be kept in mind and corrected at the earliest as a low serum potassium increases the degree of inhibition of IKr by the drug and hence increases the QT interval.

Long term management involves rigorous patient education about drugs that can potentially prolong the QT, adequate awareness of the increased risk of events during episodes predisposing to electrolyte imbalances such as acute gastroenteritis, diuretic use.

Caution should be exercised while starting a drug known to prolong the QT in patients with one or more risk factors. Such patients should have a baseline ECG followed by documentation of the QTC interval before and then at 8-12 hour intervals after the initiation or when the dose is being changed. The duration of monitoring is adjusted based on the half-life of the drug and one ECG should be done once steady state of the drug is achieved.

Management of Torsades de pointes

In patients with Tdp, whether a single episode or multiple episodes,the first line therapy is IV Magnesium Sulphate. For an adult patient with Tdp WITH a pulse, a standard dose of 1-2 g IV bolus is given. If there is no response or Tdp recurs, additional doses upto 4 g/hour may be given. An infusion of 0.5-1g/hour may also be used. In patients with no pulse, along with magnesium, electrical cardioversion is necessary. Here, the dose of Magnesium administered is 1-2g over 1-2 minutes to a maximum dose of 6g. In children, the bolus dose to be administered is 25-50 mg/kg.

For patients who do not respond to Magnesium, transvenous overdrive pacing – either ventricular or atrial, is the next option. The pacing rate should be set at approximately 100/minute to reduce the development of early after depolarizations, dispersions of refractoriness and hence will result in shortening of the QT interval.

Other drug alternatives include Isoproterenol, which may be used prior to overdrive pacing in patients not responding to Magnesium. It acts by increasing the heart rate and thereby decreasing the QT interval. It is started at a dose of 0.05-0.1 mcg/kg/min in children and 2mcg/min in adults with the aim of achieving a heart rate of 100beats/min.

If Tdp occurs secondary to Quinidine causing QT prolongation, administration of Sodium Bicarbonate to bring about alkalization of the plasma is the treatment of choice.

Other drugs such as Lidocaine and Phenytoin- (Class IB antiarrhythmics), shorten the action potential duration and hence may be effective in the acute treatment of Tdp and Ventricular fibrillation.

In patients with bradyarrhythmias with bradycardia dependent Tdp, a permanent pacemaker may be warranted.

Further, screening of immediate family members with a thorough history and ECG should be done.

The prognosis of patients with Tdp is grave with high in hospital and one-year mortality rates.

Summary

- Precise measurement of the QT interval and correcting it for heart rate(QTc) is important when dealing with a patient with clinical suspicion of Long QT syndrome.
- Long QT syndrome is a clinical entity which predisposes to a specific form of polymorphic ventricular tachycardia called TdP.
- LQTS can be genetically mediated by mutations in ion channel proteins

(Congenital LQTS) or present in later life due to drugs/electrolyte abnormailities in predisposed individuals(Acquired LQTS).

- High index of clinical suspicion is of paramount importance in making a diagnosis.
- Clinical diagnosis is followed by risk stratification and appropriate treatment startegies.
- Short QT syndrome is another genetically mediated condition predisposing to malignant ventricular arrhythmias (not discussed in this article)

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ECG Markers of Sudden Cardiac Death

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MD DM, Arrhythmia Associates and KEM Hospital, Mumbai

The incidence of sudden cardiac death (SCD) is rising. Acute coronary syndrome (ACS) is easily the major cause of out-of-hospital cardiac arrest (OHCA). OHCA with pre-hospital cardio-pulmonary resuscitation is the most time-critical emergency. The ability of Emergency Medical Serv ice ambulance to reach within 8-minute response time significantly influences the survival rates. The choice of appropriately locating automatic external-defibrillators is difficult, because 80% of OHCA occur in private or residential settings. First responders with basic life-support skills are an important cog in the chain of survival, but their ability to effectively deliver chest compression and ventilation may not be uniform. Implantable cardioverter defibrillator (ICD) used judiciously in secondary (after an aborted SCD) and primary (patients considered high SCD risk even before a threatening sudden cardiac arrest event) prevention setting is most effective in preventing SCD. A careful reading of the ECG should be the first step in SCD risk stratification.

SCD: Sudden death from a cardiovascular cause which occurs within 1 hour of symptom onset when witnessed or if not witnessed, an unexpected death from a cardiovascular cause where the individual was observed to be alive within the previous 24 hours.

ACS is the most common cause of OHCA. Plaque rupture can lead to sudden coronary occlusion and result in primary ventricular arrhythmias, usually polymorphic ventricular tachycardia (PMVT) or ventricular fibrillation (VF). Figures 1 and 2 are ECGs recorded in a cardiac ambulance which arrived at the site of the event for resuscitation. The 12-lead ECG in Figure 1 shows acute anterior wall myocardial infarction. Infarct-related artery is left anterior descending with proximal occlusion, identified on the ECG by ST elevation in precordial leads accompanied by ST depression in inferior leads. The 12-lead ECG in Figure 2 shows non-STEMI due critical occlusion of left main coronary artery (LMCA). LMCA occlusion should be suspected when nearly all leads show ST depression with ST elevation in lead aVR. Both patients underwent emergent coronary angiography followed by percutaneous angioplasty.

Facts to remember: Ventricular arrhythmias {sustained monomorphic ventricular tachycardia (SMVT), PMVT or VF} are responsible for SCD in 85% of patients, bradycardia is uncommonly the incriminating rhythm (15%). The underlying etiology of ventricular arrhythmia may vary according to age; coronary artery disease (CAD) being commonly responsible in patients aged over 35 years, whereas in younger patients the putative pathology could be a cardiomyopathy or inherited arrhythmia disorder. ECG reading directed at SCD risk stratification must bear this in mind. Less recognized is the fact that stable heart failure (HF) patients (NYHA II and III) are more prone to SCD than patients with advanced symptoms (NYHA IV) of HF. Unfortunately, SCD may be the first cardiac event, thus offering no opportunity for clinical diagnosis of the underlying cardiac condition. Hence, if an incidentally recorded ECG suggests structural heart disease (SHD) or is suspicious of primary electrical disorder; appropriate investigations directed at SCD risk stratification should be initiated.

For our present discussion, it would be useful to evaluate for the ECG markers of SCD under 4 categories: i) Patients with HFrEF with or without prior syncope ii) Patients with HFmrEF / HFpEF with and without syncope iii) Young patient with syncope and normal echocardiogram and iv) Incidental ECG finding in an asymptomatic patient.

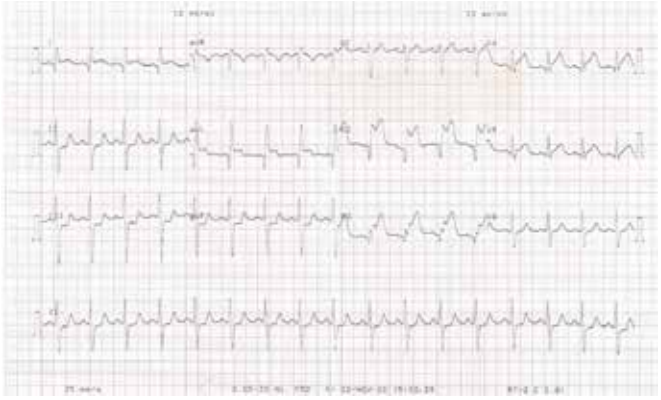

Figure 1: Acute anterior wall myocardial infarction due to proximal left anterior descending artery occlusion.

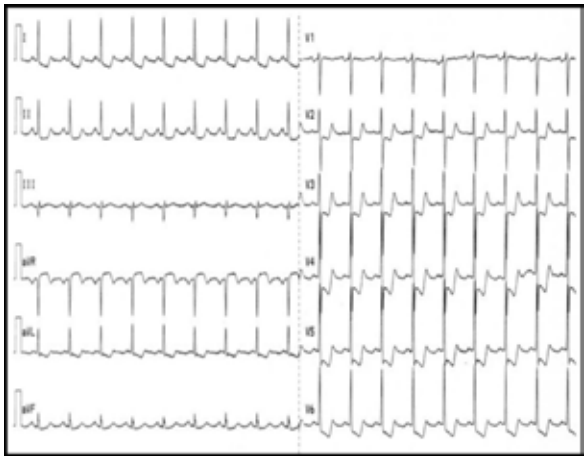

Figure 2: Non-STEMI due to left main coronary artery occlusion.

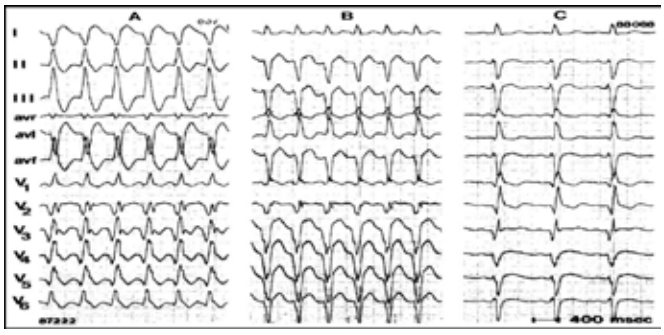

Figure 3: Panel A and B show 2 different QRS morphologies of sustained monomorphic VT, both with RBBB-type QRS morphology suggesting left ventricular origin. Panel C shows sinus rhythm with wide QRS and q waves in leads V1-6 suggesting a remote and large anterior wall myocardial infarction.

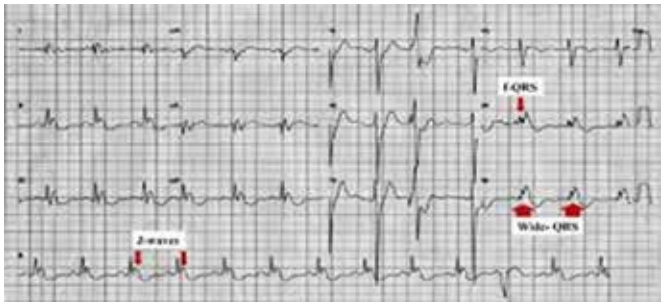

Figure 4: 12-lead ECG from a patient with nonischemic cardiomyopathy. Note the wide and fragmented QRS.

i. **Patients with HFrEF with and without prior syncope:** In a 12-lead ECG of such a patient; study the QRS width, configuration and voltage carefully (see figures 3-5). There are a variety of ventricular substrates that are associated with increased biventricular activation time and consequently QRS widening. A delay in the conduction system results in a complete bundle branch block, widening the QRS. Whereas scar, dilatation or hypertrophy of the ventricular myocardium can also increase the QRS width, the latter effected by a conduction delay in the ventricular myocardium. Bundle branch block, multiple leads with q waves and

ii. fragmented QRS are the configurations portending high SCD risk. Low QRS voltage is observed in patients with a large post-infarct scar or in patients with non-ischemic cardiomyopathy due to infiltration. Arrhythmogenic right ventricular cardiomyopathy (ARVC) is a disease that predominantly involves the right ventricle and is often diagnosed after a clinically recurrent LBBB-type sustained monomorphic VT. In patients with ARVC, ECG characteristics could be specific (epsilon in lead v1) or nonspecific (T-wave inversions in right precordial leads). Not surprisingly, in ARVC, ECG changes in the QRS-T complex are localized to right precordial leads (leads V1-V3, see figure 6). Scar-related VT, usually a SMVT, has a high recurrence rate in the first year after an episode and these patients should be routinely considered for AICD implantation for secondary prevention of SCD.

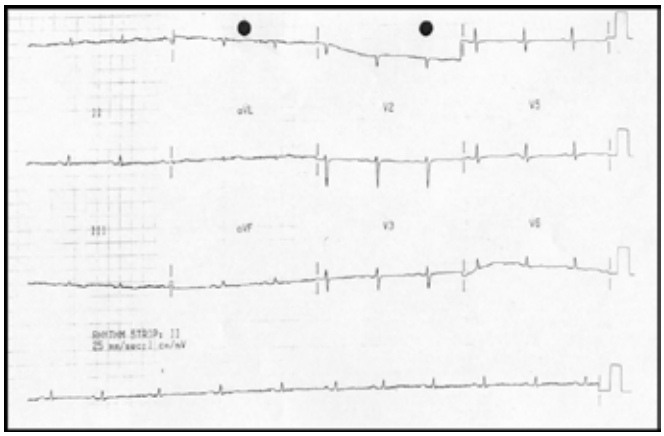

Figure 5: 12-lead ECG sourced from a patient with non-ischemic cardiomyopathy with LVEF 20%. Note the low QRS voltage, the latter defined as QRS with <5 MmV in frontal leads and <10 mV in precordial leads.

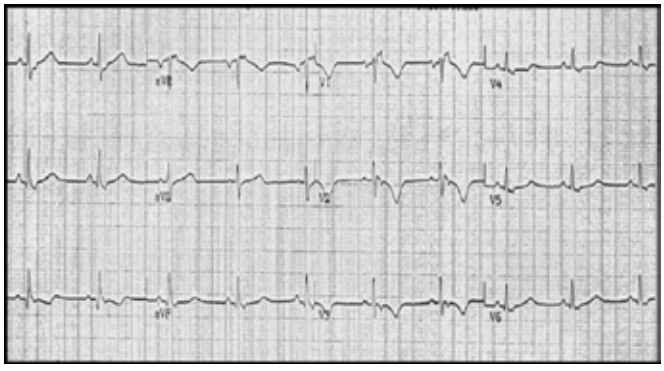

Figure 6: ARVC is characterized by an epsilon wave and T-wave inversions in leads V1-3.

iii. **Patients with HFmrEF / HFpEF with and without prior syncope:** One important condition presenting as HFpEF and associated with a higher SCD risk is hypertrophic cardiomyopathy (HCM). There are well-recognized anatomical variants of HCM viz. diffuse type, asymmetric septal hypertrophy (ASH) with subaortic obstruction or midcavitary HCM with apical aneurysm. Further, there is a published HCM (SCD) risk calculator to assess the SCD risk. Outspoken left ventricular hypertrophy (LVH) on ECG, particularly in absence of hypertension, should raise the red flag. Illustrative are ECGs in Figure 7 and 8. Figure 7 is from a patient with HCM who had suboptimal echo-window. The 12-lead ECG clearly shows LVH with deep symmetrical T waves in leads V2-V6, explaining the diffuse LVH-type of HCM confirmed on contrast enhanced cardiac MRI. Figure 8 is from a patient with HCM who had ASH and peak left ventricular outflow gradient of 120 mm Hg. ASH can be identified by deep Q waves in inferior leads. Another important differential diagnosis of HFpEF which requires SCD risk stratification is cardiac sarcoidosis (CS). This is an inflammatory cardiomyopa-

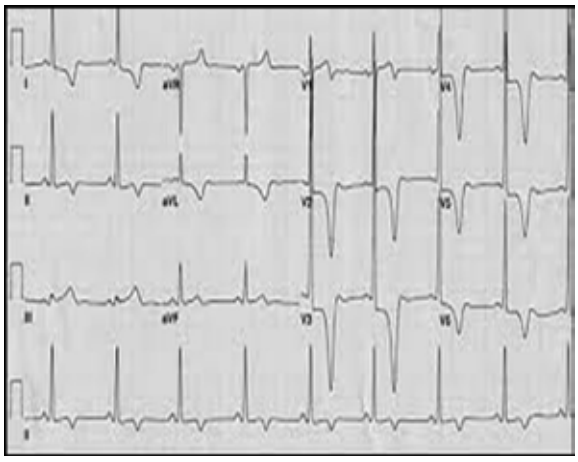

Figure 7: 12-ECG from a patient with HCM and diffuse left ventricular hypertrophy. Note the deep symmetrical T waves in precordial leads.

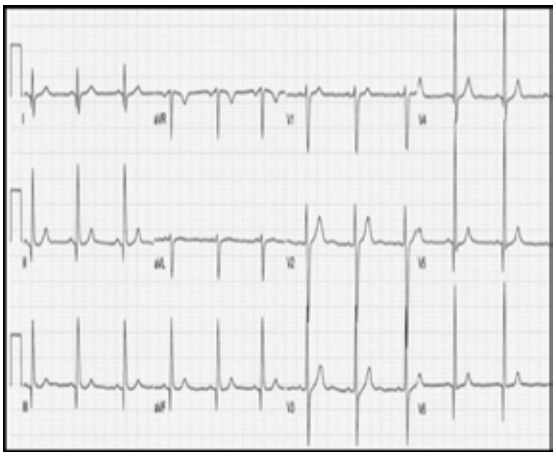

Figure 8: 12-lead ECG from a patient with HCM having ASH with thickness of 30 mm. The prominent depth of Q waves in inferior leads is commensurate with the septal activation vector.

Electrocardiographic Findings			
A	QTc	≥480 msec	3
		460–479 msec	2
		450–459 (male) msec	1
B	QTc fourth minute of recovery from exercise stress test ≥480 msec		1
C	Torsade de pointes		2
D	T wave alternans		1
E	Notched T wave in three leads		1
F	Low heart rate for age		0.5
Clinical History			
A	Syncope	With stress	2
		Without stress	1
B	Congenital deafness		0.5
Family History			
A	Family members with definite LQTS		1
B	Unexplained sudden cardiac death younger than age 30 among immediate family members		0.5

Figure 10: Schwartz score for diagnosis of LQTS. LQTS Probability: ≤1= low probability, 1.5 to 3: intermediate probability and ≥3.5= High probability of LQTS.

thy, with myocardial edema in acute phase and fibrosis later, often with associated mediastinall lymphadenopathy. Cardiac MRI and FDG-PET CT are important tools to evaluate the disease (see Figure 9). ECG findings like complete heart block and right bundle branch block are present uncommonly, only in few (3-9%) CS patients. Some form of ambulatory ECG monitoring, Holter or patch recorder, may be employed to detect subclinical arrhythmias that may be missed on the office ECG. Fig 9. Cardiac MRI is a patient with CS. Late-gadolinium enhancement, T1 and T2 mapping can diagnose active sarcoidosis as well as residual myocardial fibrosis. The basal interventricular septum involvement is pathognomonic.

iv. **Young patient with syncope and normal echocardiogram:** Long QT syndrome (LQTS) is a repolarization abnormality which could be inherited or drug induced. Importantly LQTS entails risk of SCD due to occurrence of PMVT or VF. Congenital LQTS is diagnosed if a) presence of an LQTS risk score ≥ 3.5 in the absence of a secondary cause for QT prolongation (see Figure 10) or b) presence of unequivocally pathogenic mutation in one of the genes or c) corrected QT interval (QTc) for heart rate using Bazett's formula ≥ 500ms in repeated 12 lead ECG and no secondary cause. LQTS can be diagnosed even when QTc is between 480ms and 499ms, if repeatedly observed in 12-lead ECGs in a patient with unexplained syncope and with no secondary cause for QT prolongation / no pathogenic mutation. Typical ECG patterns of LQT1 (KCNQ1 mutation, broad based T wave pattern), LQT2 (KCNH2 mutation, bifid T wave) and LQT3 (SCN5A mutation, long ST segment with a narrow peaked late-onset /biphasic T wave) have been de-

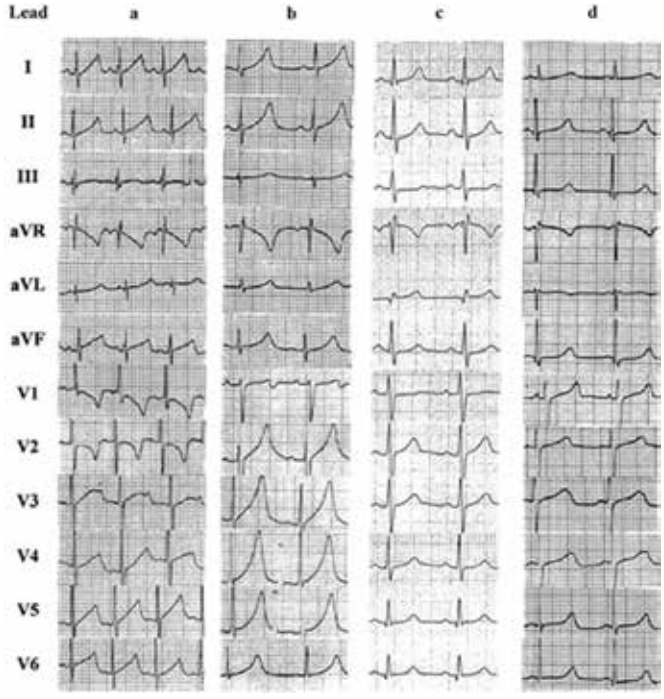

Figure 11: Typical LQT1 is identified by broad based T wave

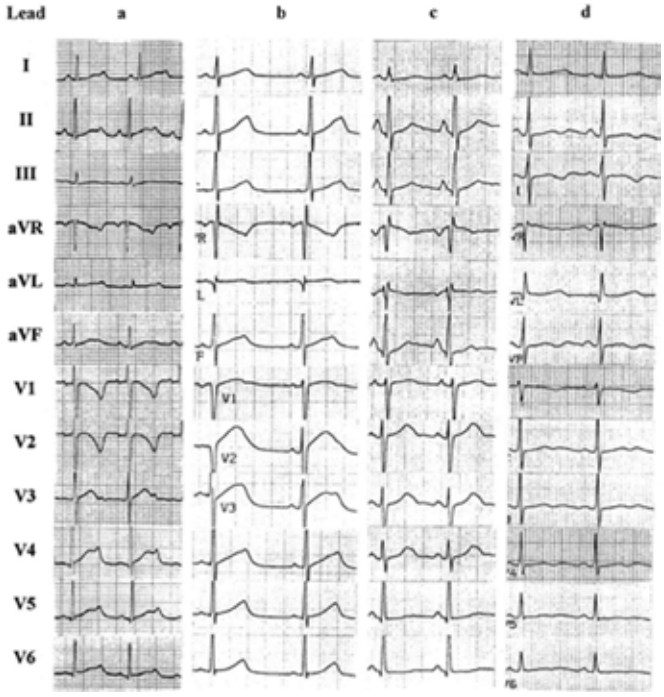

Figure 12: Typical LQT2 is identified by bifid T wave

scribed and exemplified in different panels of Figures 11, 12 and 13. Brugada syndrome is an autosomal dominant SCN5A mutation – loss of function of the cardiac sodium channel. The syndrome is electrocardiographically identified by typical ECG changes (ST segment elevation or J waves) in right precordial leads, SCD secondary to PMVT or VF and no SHD. Patients at high risk of SCD include a) symptomatic patient with type 1 ECG are at highest risk and b) symptomatic patients with type 2 ECG

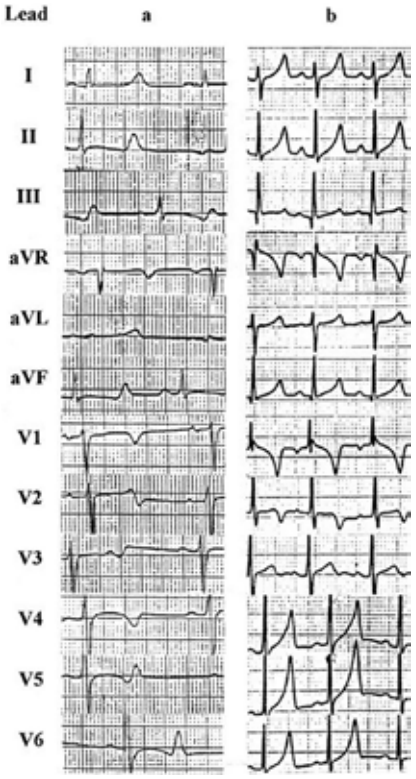

Figure 13: Typical LQT3 is identified by long ST-segment with a narrow peaked late-onset / biphasic T wave.

that converts to type I with sodium channel challenge. See Figure 14. The challenge in diagnosis of LQTS and BrugadaECG is the transient presence of diagnostic ECG findings and provocation with isoprenaline (for LQTS) and oral flecainide (for Brugada syndrome) may be required for establishing diagnosis in suspicious settings.

There are two causes of SCD which are preventable by early intervention. A patient with complete heart block has bradycardia-dependent prolonged QT interval which can make them prone to R-on-T PVC leading to torsades de pointes (see Figure 15). In this scenario emergency temporary pacing is mandated. Patient with WPW syndrome with short antegrade accessory pathway refractory period can uncommonly develop pre-excited atrial fibrillation which can potentially degenerate into VF thereby risking SCD. After acute termination of the episode, accessory pathway ablation should be planned at the earliest (see Figure 16).

V. Incidental ECG finding in an asymptomatic patient: Often, premature ventricular complexes (PVC) are incidentally noted on the office ECG. PVCs in absence of significant SHD and those that are monomorphic, isolated, originating from stereotypical sites such as ventricular outflow tract and with a QRS width ≤160 ms are often benign (see Figure 17). A further work up, documenting a low 24-hour PVC load (<10,000-20,000/24 hours on Holter study) or suppression at peak exercise (on stress test), can establish them as low risk PVCs. On the other

hand, PVCs which occur in the background of significant SHD, established by echocardiogram (reduced LVEF) and/or a prudently requested cardiac MRI (scar extent), would portend a higher SCD risk. Recurrent non sustained VT and pleomorphic VT, detected on ambulatory ECG monitoring (see Figure 18 and 19), in a patient with significant SHD, would raise the considerations for SCD prevention and counselling for ICD would be in place. Not to forget, studying the QRS morphology in sinus rhythm often suggests the underlying cardiac pathology.

This brief article can be summarized as - SCD risk stratification needs a careful assessment of the ECG for SHD

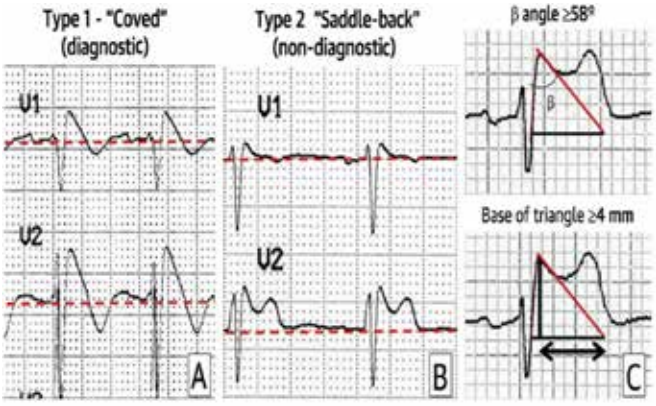

Figure 14: Brugada ECG. Look carefully at the pattern of ST elevation in right precordial leads to identify the type of Brugada ECG.

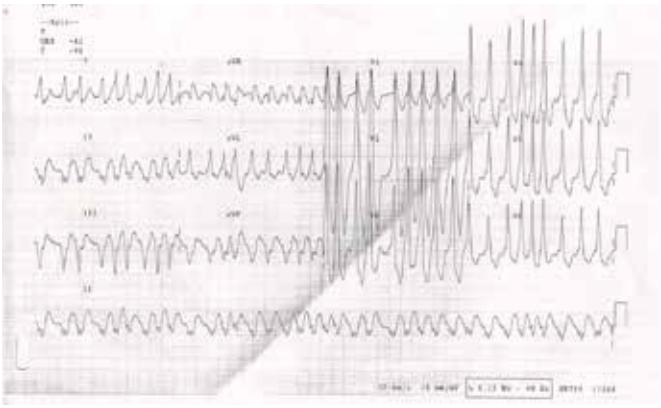

Figure 16: Pre-excited atrial fibrillation in a patient with WPW syndrome. Electrocardiographically this can be identified as a fast, wide and irregular tachycardia.

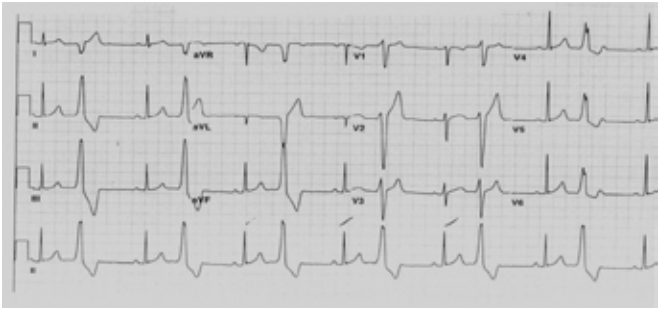

Figure 17: Outflow tract PVCs, recognized by tall R waves in inferior leads (II, III and aVF) are the most frequent type of benign PVCs.

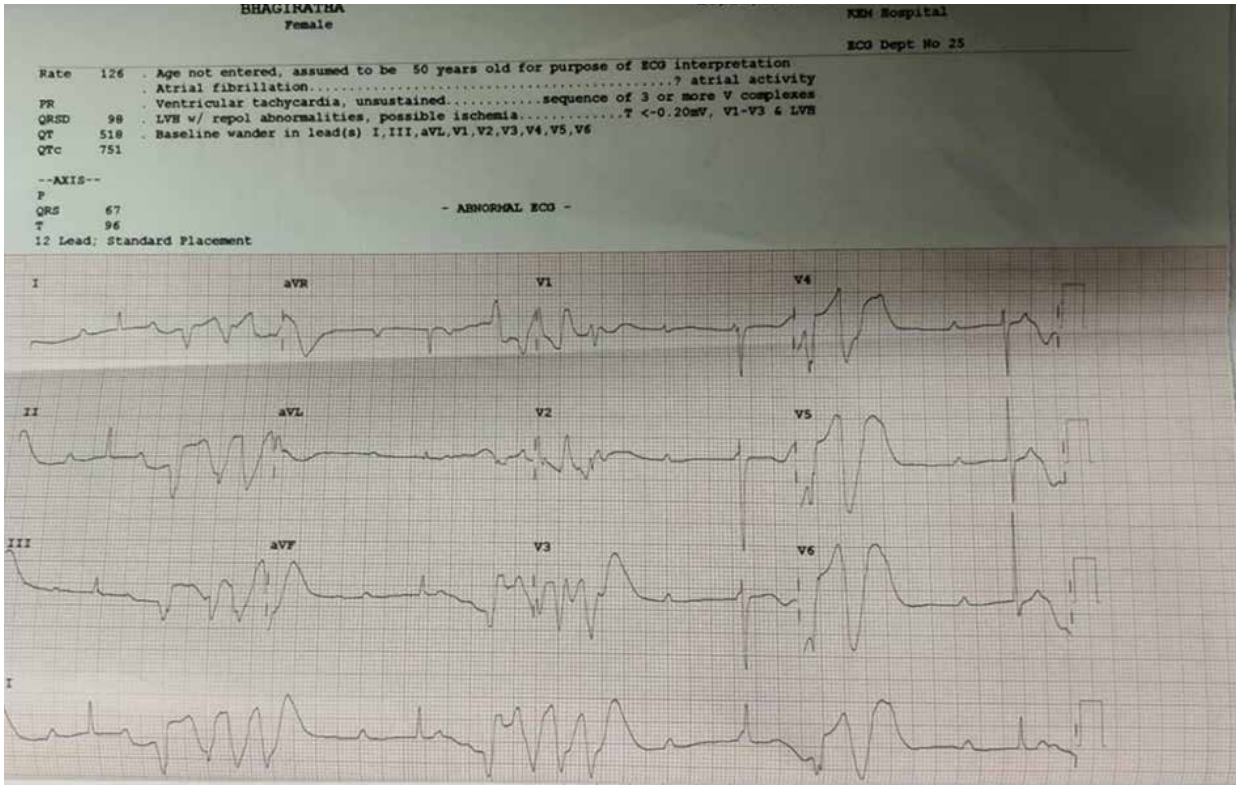

Figure 15: A patient with complete heart block is prone to recurrent syncope and SCD due to R-on-T PVC leading to torsades de pointes.

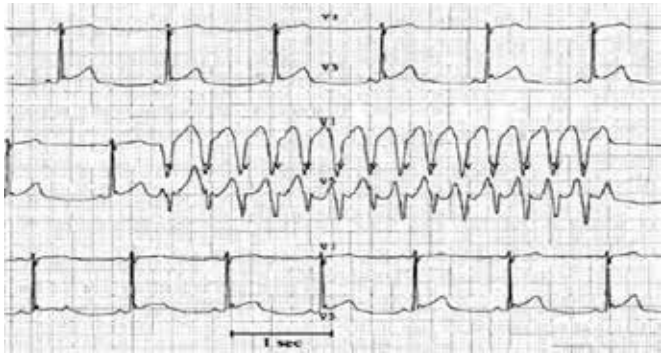

Figure 18: Monomorphic non sustained VT recorded on 24-hour Holter study. Length of the PVC run and frequency of recurrences should be considered in evaluating SCD risk.

and PVC characteristics, and an appropriate further structural (echocardiogram and cardiac MRI) and genetic evaluation before counselling about prevention strategies, the most effective being ICD implantation.

Suggested reading

1. Gorenek B, Fisher JD, Kudaiberdieva G et al., Premature ventricular complexes: diagnostic and therapeutic considerations in clinical practice : A state-of-the-art review by the American College of Cardiology Electrophysiology Council. J Interv Card Electrophysiol 2020;57(1):5-26. doi: 10.1007/s10840-019-00655-3.

2. Al-Khatib SM, Stevenson WG, Ackerman MJ, et al., 2017 AHA/ACC/HRS Guideline for Management of Patients With Ventricular Arrhythmias and the Prevention of Sudden Cardiac Death: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines and the Heart Rhythm Society. J Am Coll Cardiol 018 2;72(14):e91-e220. doi: 10.1016/j.jacc.2017.10.054.

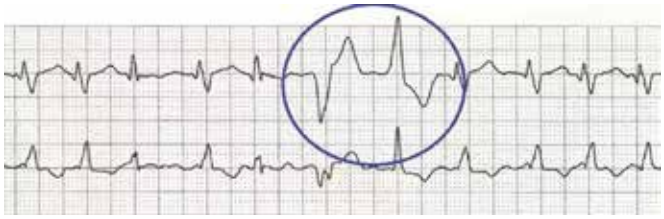

Figure 19: Pleomorphic (multiple PVC morphologies) PVCs may imply a more widespread ventricular myocardial pathology and heightened SCD risk

Morphological Analysis of P wave in Diagnosis of Supraventricular Arrhythmias

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Introduction

The term supraventricular arrhythmia used to describe tachycardia's in which atrial and/or ventricular rates in excess of 100 bpm at rest. The mechanism of which involves tissue from the His bundle or above. The prevalence of SVT in the general population is 2.29 per 1,000 people[1]. Paroxysmal SVT is a clinical syndrome characterized by the presence of a regular and rapid tachycardia of abrupt onset and termination. PSVT represents a subset of SVT.

Arrhythmia can originate from abnormal impulse initiation in an individual myocyte or more cluster of myocytes. This can occur in non-pacemaker cells through a mechanism similar to the physiological automaticity of pacemaker cells [sinus node and AV node (AVN)], and which is named 'abnormal' or 'enhanced automaticity'. An alternative form of abnormal impulse initiation involves oscillations of membrane potential, named early or delayed 'after-depolarizations' and the mechanism is called 'triggered activity'. Arrhythmias resulting from enhanced automaticity and triggered activity are defined as non-re-entrant. Reentrant arrhythmias can arise when myocardial regions activated later in propagation re-excite regions that have already recovered excitability. This results from abnormal propagation of the excitation wave front and/or of tissue refractoriness. Supraventricular arrhythmia ECG analysis can identify the mechanism as well as source of origin.

Electrocardiogram Analysis of SVT

Atrial Tachycardia

A regular atrial activation from atrial zones with centrifugal spread, due to either increased automaticity, triggered activity, or micro reentry, is called atrial tachycardia. Distinct ECG features differentiates focal and macro reentrant atrial tachycardia. Atrial tachycardias that are macro reentrant consist of common atrial flutter and other macro reentrant circuits in the right and left atrium. The foci that cause focal atrial tachycardia don't appear randomly across the atria; rather, they prefer to congregate in particular anatomical places.

Focal atrial tachycardia (AT) is a relatively uncommon cause of supraventricular tachycardia, characterized by atrial activation from a discrete location with centrifugal spreading. In the right atrium (RA), these foci include the crista terminalis, tricuspid annulus (TA), coronary sinus (CS) ostium, right-sided septum, and perinodal area; in the left atrium, sites include pulmonary vein (PV) ostia, mitral annulus, left atrial appendage (LAA), and left-sided septum. Given a predefined distribution, the P-wave on surface 12-lead electrocardiogram (ECG) may provide a useful guide in determining the likely site of origin.

P wave analysis in ECG

P-wave morphology is being described based on deviation from baseline during T- P interval as follows:

Positive (+): positive deviation from the isoelectric baseline;

Negative (-): negative deviation;

Isoelectric (iso):no P-wave deviation from baseline of ≥0.05 mV; and

Biphasic: both positive and negative (+/- or -/+) deflections from baseline.

Localization of AT Origin: Right Vs Left Atria

P wave morphology in ECG lead V_1 the most useful in distinguishing a right from a left atrial'focus. A negative or biphasic (positive, then negative) P-wave in lead V_1 was associated with a 100% specificity for a tachycardia arising from the right atrium. A positive or biphasic (negative, then positive) P-wave in ECG lead V_1 was associated with a 100% sensitivity for tachycardia originating in the left atrium[1].

P wave Morphology in Right Atrial Origin ATs

Crista Terminalis: Negative or Biphasic [+/-] P wave morphology in VI and positive in V2-V4 **(Figure 1)**

Right Atrial Appendage and Tricuspid Annulus: Negative P wave morphology in V_1 and V_{2-4}. RAA and anterior/superior TA origin ATs inferior leads shows Positive P waves **(Figure 2)** and negative P waves in inferior/posterior origin ATs. **(Figure 3)**

P wave Morphology in Left Atrial Origin ATs

Left Pulmonary Vein and Left Atrial Appendage: Positive P wave in V1, Bifid in Lead II and or V1 and isoelectric or negative P wave in Lead 1 are the features of LPV and LAA origin of ATs **(Figure 4)**. LAA origin ATs, P wave usually more deeply negative than LPV origin ATs **(Figure 5).**

Right Pulmonary veins: Positive P wave in V1 during tachycardia and biphasic during sinus rhythm more suggestive of RSPV origin **(Figure 6)**.

Classification and Definitions of SVT[2]

Types of supraventricular tachyarrhythmia	Definitions
Sinus Tachycardia	Rhythm arising from the sinus node in which the rate of impulses exceeds 100 bpm.
Physiological Sinus Tachycardia	Appropriate increased sinus rate in response to exercise and other situations that increase sympathetic tone.
Inappropriate Sinus Tachycardia	Sinus heart rate >100 bpm at rest, with a mean 24-h heart rate >90 bpm not due to appropriate physiological responses or primary causes such as hyperthyroidism or anemia.
Focal Atrial Tachycardia	An SVT arising from a localized atrial site, characterized by regular, organized atrial activity with discrete P waves and typically an isoelectric segment between P waves. At times, irregularity is seen, especially at onset ("warm-up") and termination ("warm-down"). Atrial mapping reveals a focal point of origin.
Sinus Nodal Re-entrant Tachycardia (SNRT)	A specific type of focal AT that is due to micro reentry arising from the sinus node complex, characterized by abrupt onset and termination, resulting in a P-wave morphology that is indistinguishable from sinus rhythm.
Multifocal Atrial Tachycardia	An irregular SVT characterized by ≥3 distinct P-wave morphologies and/or patterns of atrial activation at different rates. The rhythm is always irregular.
CTI Dependent Typical Atrial Flutter	Macro reentrant AT propagating around the tricuspid annulus, proceeding superiorly along the atrial septum, inferiorly along the right atrial wall, and through the cavotricuspid isthmus between the tricuspid valve annulus and the Eustachian valve and ridge. The atrial rate can be slower than the typical 300 bpm (cycle length 200ms) in the presence of antiarrhythmic drugs or scarring.
CTI Dependent Reverse Typical Atrial Flutter	Macro reentrant AT that propagates around in the direction reverse that of typical atrial flutter.
Atypical or Non-CTI Dependent Atrial Flutter	Macro reentrant ATs that do not involve the cavotricuspid isthmus. A variety of reentrant circuits may include reentry around the mitral valve annulus or scar tissue within the left or right atrium.
Junctional Tachycardia	A non-reentrant SVT that arises from the AV junction (including the His bundle).
Atrioventricular nodal reentrant tachycardia (AVNRT)	A reentrant tachycardia involving 2 functionally distinct pathways, generally referred to as "fast" and "slow" pathways. Most commonly, the fast pathway is located near the apex of Koch's triangle, and the slow pathway infero-posterior to the compact AV node tissue.
Typical AVNRT	Typical AVNRT in which a slow pathway serves as the anterograde limb of the circuit and the fast pathway serves as the retrograde limb (also called "slow-fast AVNRT").
Atypical AVNRT	Atypical AVNRT in which the fast pathway serves as the anterograde limb of the circuit and a slow pathway serves as the retrograde limb (also called "fast-slow AV node reentry") or a slow pathway serves as the anterograde limb and a second slow pathway serves as the retrograde limb (also called "slow-slow AVNRT").
Atrio-Ventricular Re-entrant Tachycardia (AVRT)	A reentrant tachycardia, the electrical pathway of which requires an accessory pathway, the atrium, atrioventricular node (or second accessory pathway), and ventricle.
Orthrodromic AVRT	An AVRT in which the reentrant impulse uses the accessory pathway in the retrograde direction from the ventricle to the atrium, and the AV node in the anterograde direction. The QRS complex is generally narrow or may be wide because of pre-existing bundle-branch block or aberrant conduction.
Antidromic AVRT	An AVRT in which the reentrant impulse uses the accessory pathway in the anterograde direction from the atrium to the ventricle, and the AV node for the retrograde direction. Occasionally, instead of the AV node, another accessory pathway can be used in the retrograde direction, which is referred to as pre-excited AVRT. The QRS complex is wide (maximally pre-excited).
Permanent form of junctional reciprocating tachycardia (PJRT)	A rare form of nearly incessant orthodromic AVRT involving a slowly conducting, concealed, usually posteroseptal accessory pathway.

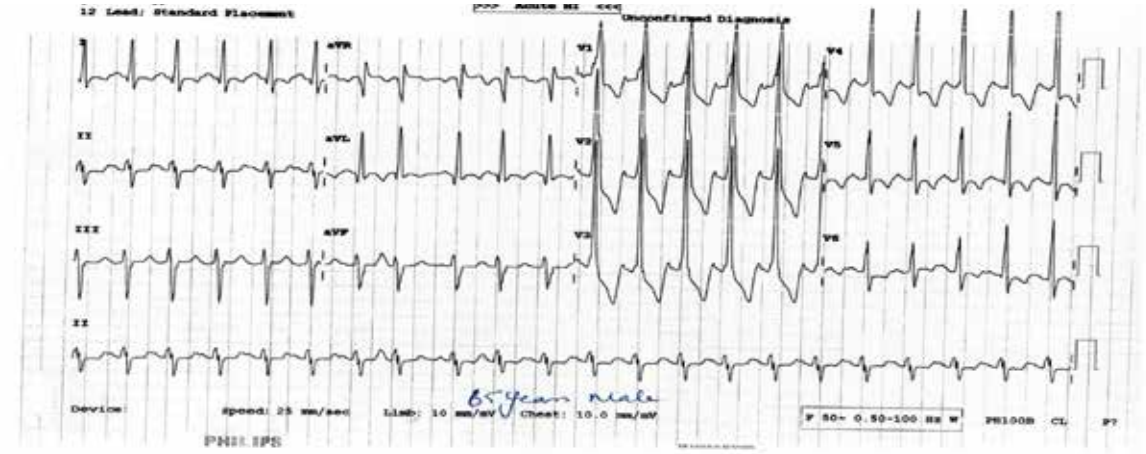


***Figure 1**

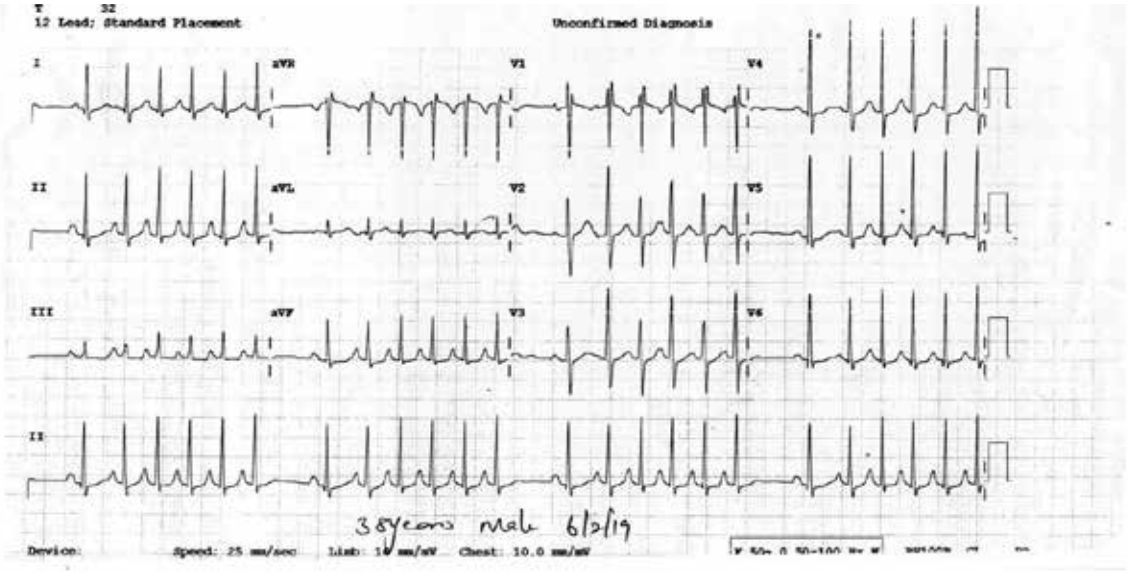


***Figure 2**

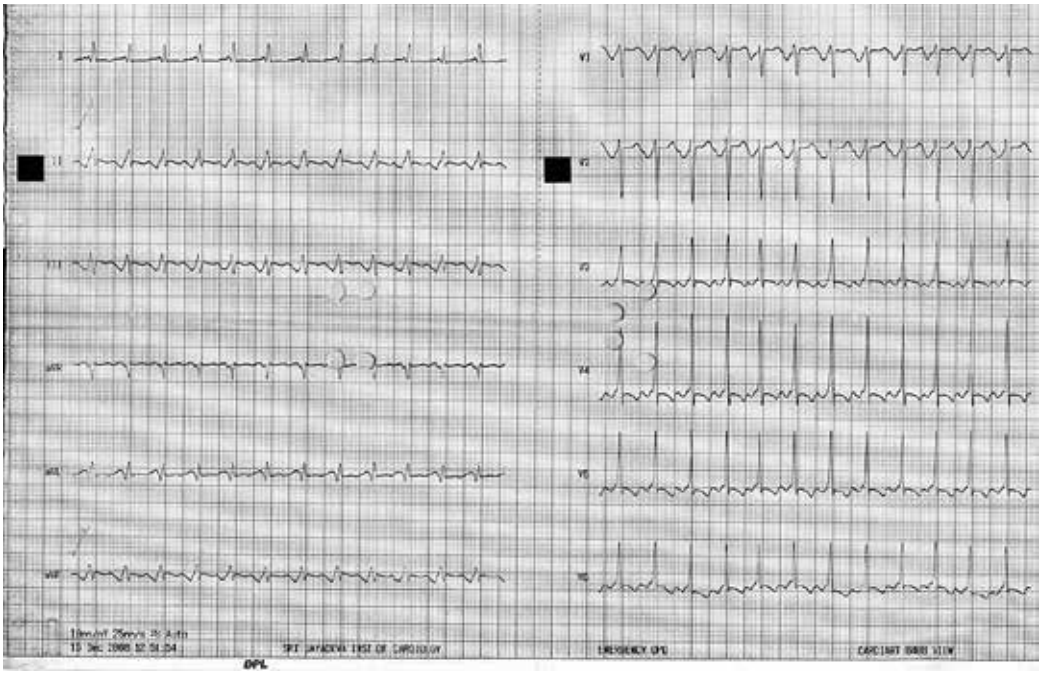


***Figure 3**

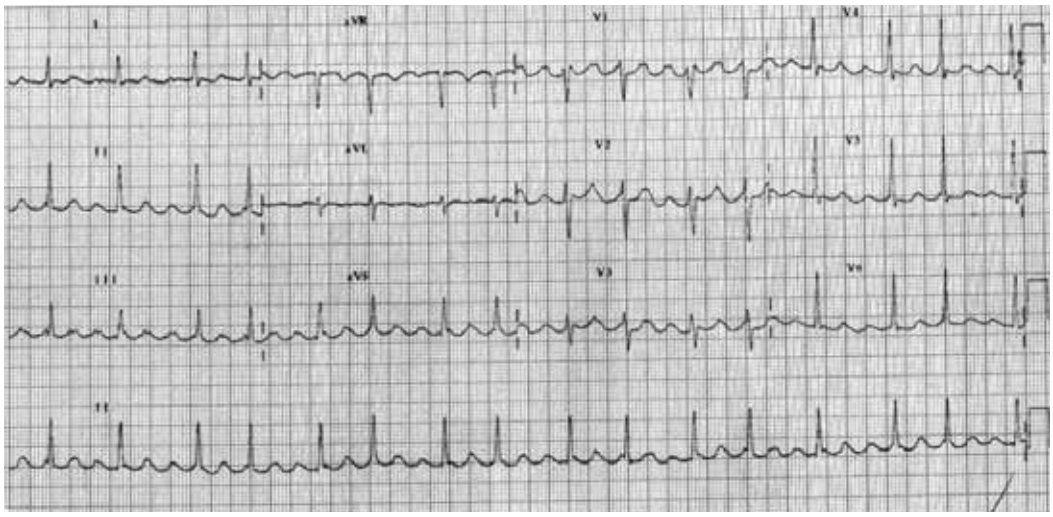
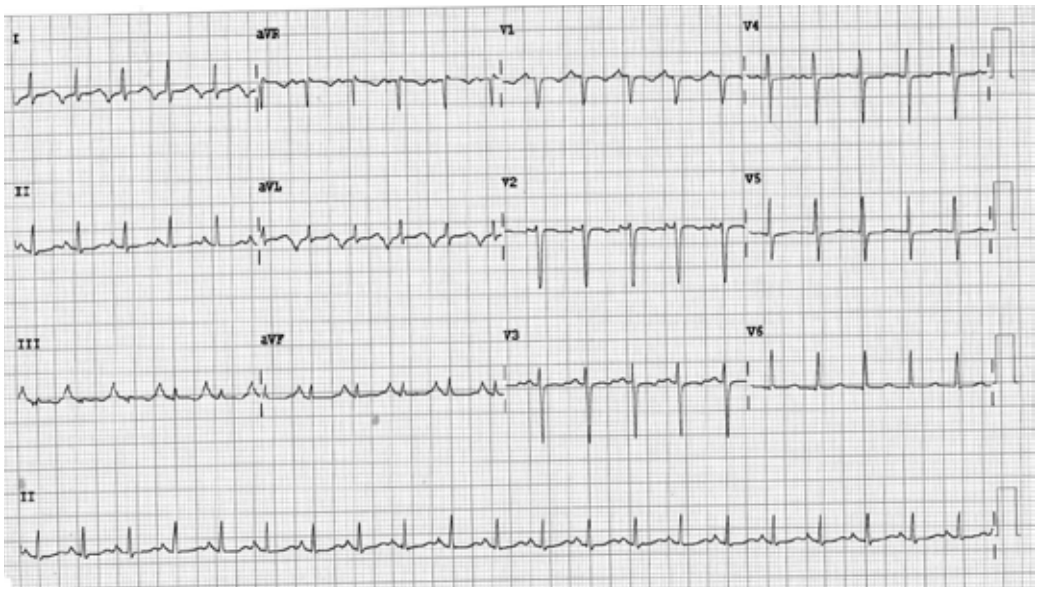


*Figure 4



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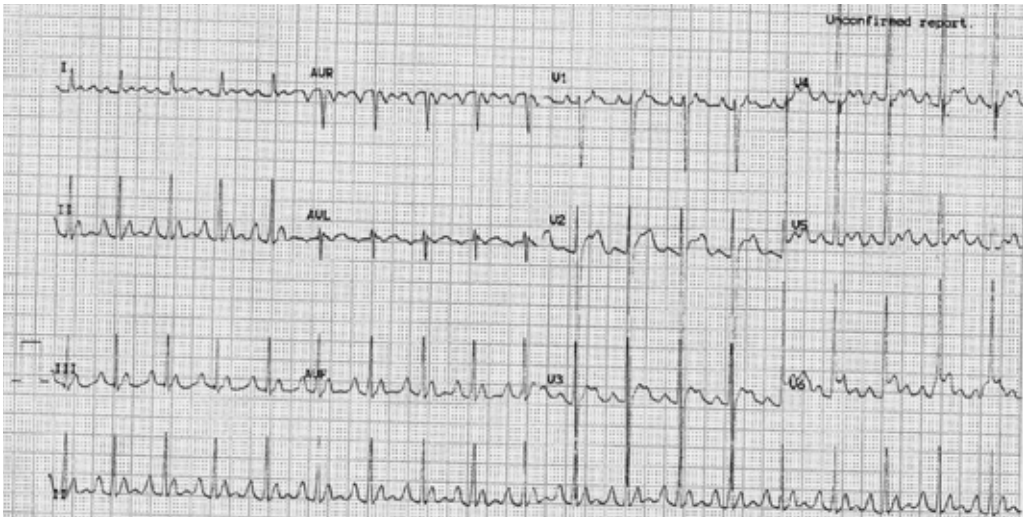

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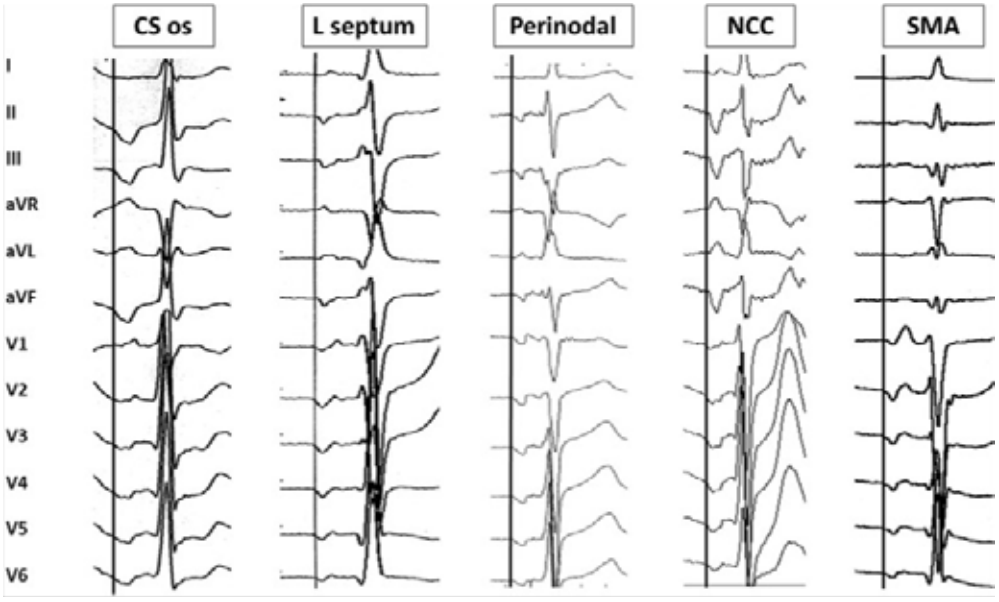

***Figure 7 (courtesy Kistler PM, et al. P-Wave Morphology in Focal Atrial Tachycardia - JACC Clin Electrophysiol - 2021)**

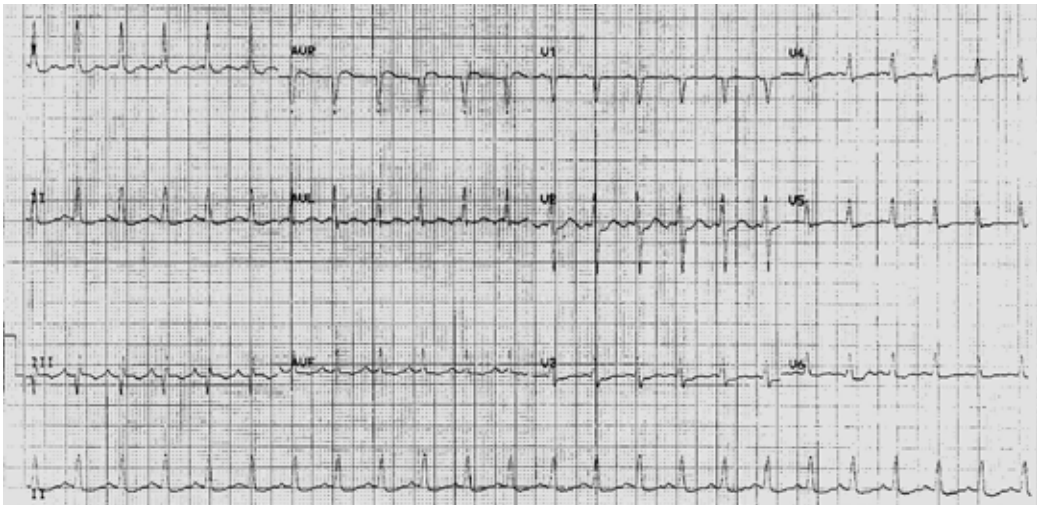

***Figure 8 – Superior Mitral Annulus (SMA) origin Atrial Tachycardia**

P wave Morphology in Paraseptal/Midline Origin ATs

The paraseptal or midline region includes following locations, in right atrium, right septum, perinodal region, coronary sinus ostium and septal tricuspid annulus regions. In left atrium, superior mitral annulus, left septum and non-coronary cusp regions. P wave morphology of ATs origination from these sites generally shows isoelectric/positive or biphasic [-/+] configuration in V1 with an overlap between these sites **(Figure 7).**

Multifocal atrial tachycardia

Multifocal AT is defined as a rapid, irregular rhythm with at least three distinct morphologies of P waves with distinct isoelectric lines between P waves on the surface ECG. The PP, PR and RR intervals are variable **(Figure 11)**.

Macro-reentrant atrial tachycardia[MART]

Atrial flutter is defined according to the ECG appearance i.e. continuous regular electrical activity, most commonly a saw-tooth pattern. ECGs with flutter-like appearances are mostly due to macro- re-entrant atrial circuits but micro-re-entry is also possible. However, MRATs with a significant part of the activation of the circuit in protected areas may display a focal AT pattern, with discrete P waves.

Atrioventricular junctional arrhythmias

Atrioventricular nodal re-entrant tachycardia (AVNRT)

In the typical form of AVNRT (also called slow-fast AVNRT), retrograde P waves are constantly related to the QRS and, in the majority of cases, are indiscernible or very close to the QRS complex. Thus, P waves are either masked by the QRS

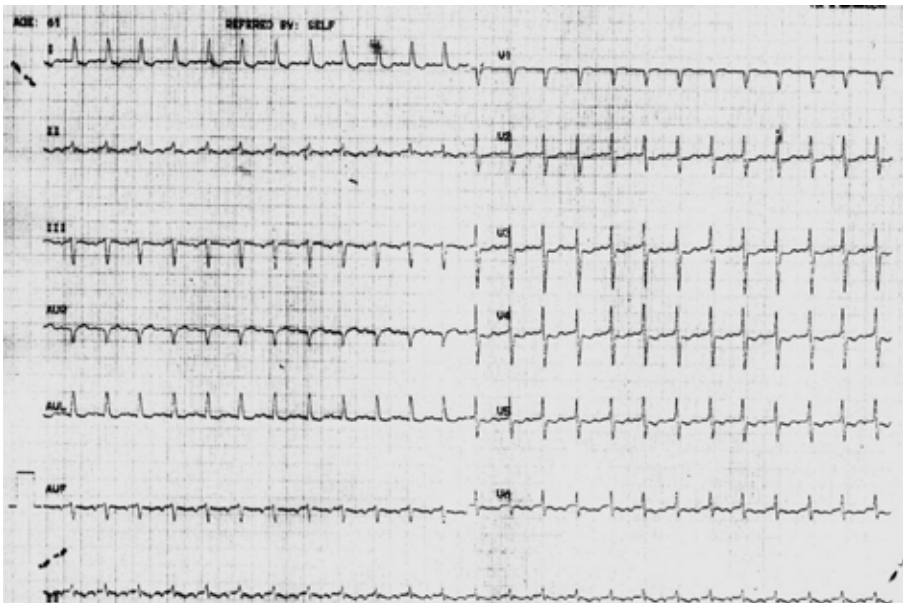

***Figure 9 – Non-Coronary Cusp Origin Atrial Tachycardia**

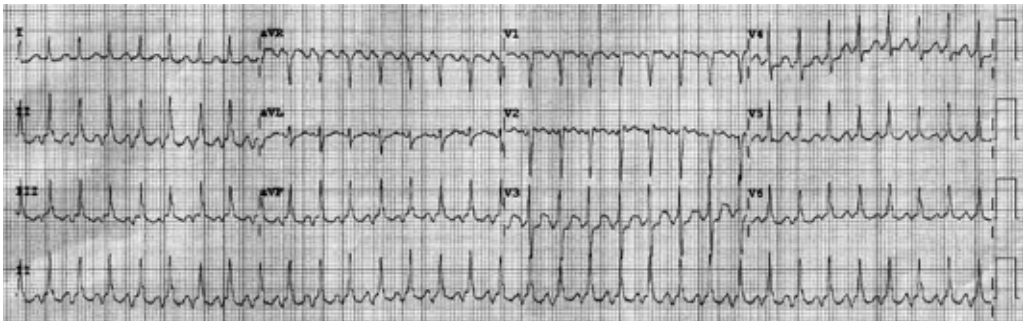

***Figure 10 – Coronary Sinus Ostium (CS)origin Atrial Tachycardia. (D/D includes Atypical AVNRT and PJRT)**

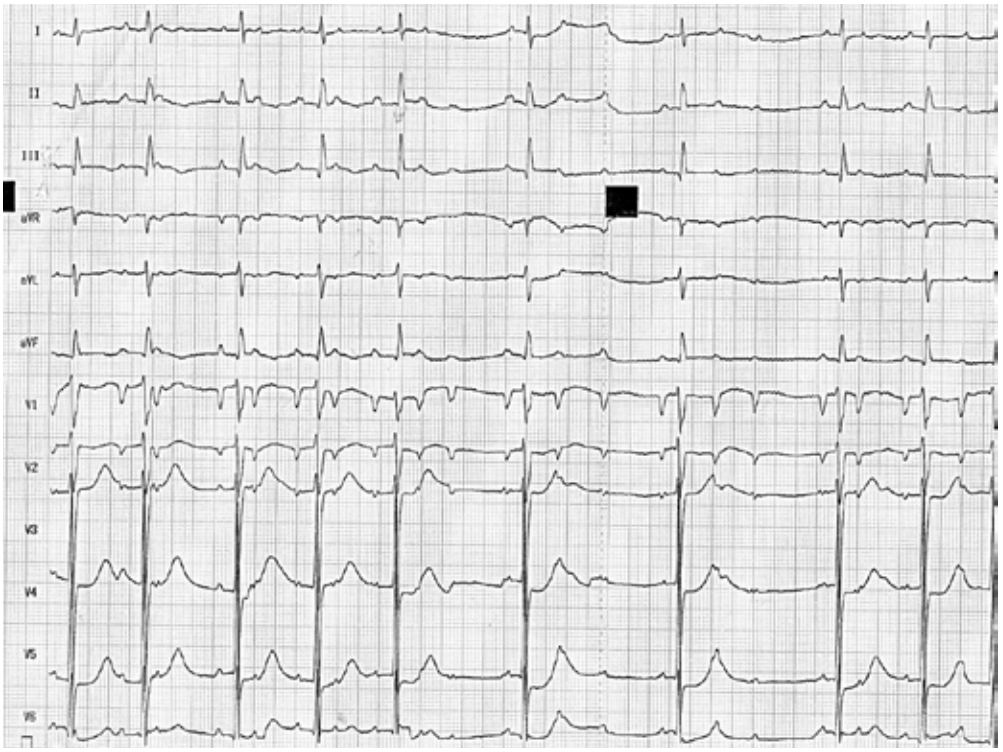

***Figure 11**

Macro-reentrant Atrial Tachycardia/Atrial Flutter

- Constant regular P-wave/flutter wave morphology.
- Rate typically >250bpm
- Mechanism: Macro-reentry

Cavotricuspid Isthmus Dependent

Right Atrial reentry dependent on conduction through the cavotricuspid isthmus

Typical Atrial Flutter

Counterclockwise Atrial Flutter

ECG Flutter waves*

- Negative in II, III, avF
- Positive in V1

Clockwise Atrial Flutter

(Reverse typical Flutter)

ECG Flutter waves*

- Positive in II, III, avF
- Negative in V1

V1 typically opposite in polarity to inferior leads

Non-Cavotricuspid Isthmus Dependent ("Atypical Atrial Flutter")

- Reentry that is not dependent on conduction through the cavotricuspid isthmus.
- The circuit is usually defined by atrial scars from prior heart surgery, ablation, or idiopathic.

Right Atrial

Example: Reentry around healed surgical incision in the free wall of the right atrium after repair of congenital heart disease. **(Figure 13)**

Left Atrial

- Perimitral Flutter
- Left Atrial roof dependent flutter
- Others

(Figure 14)

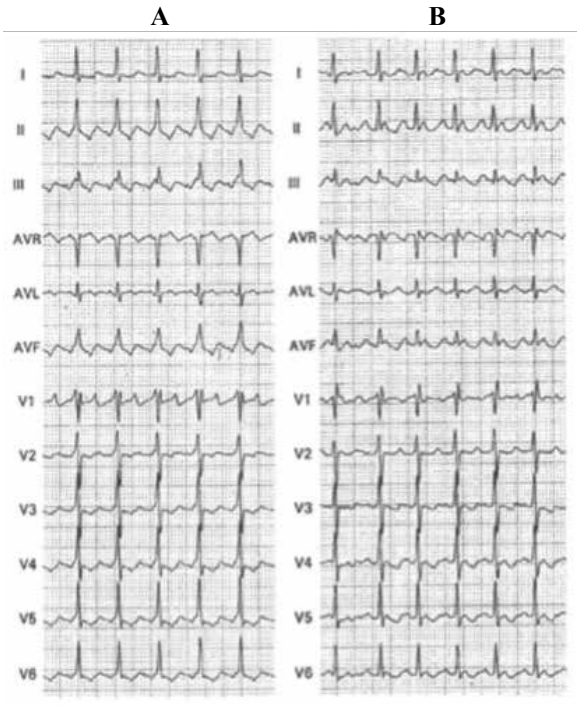

***Figure 12 – Counter clockwise (A) and Clockwise (B) Atrial Flutter with 2:1 AV conduction.**

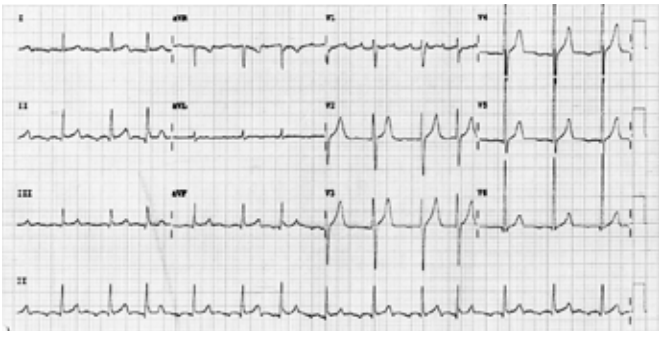

***Figure 13 – Post ASD surgical closure Atypical Flutter with varying AV conduction.**

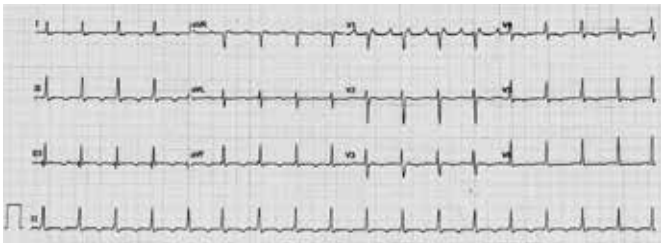

***Figure 14 – Post Mitral Valve Surgery Atypical left atrial flutter with 2:1 AV conduction.**

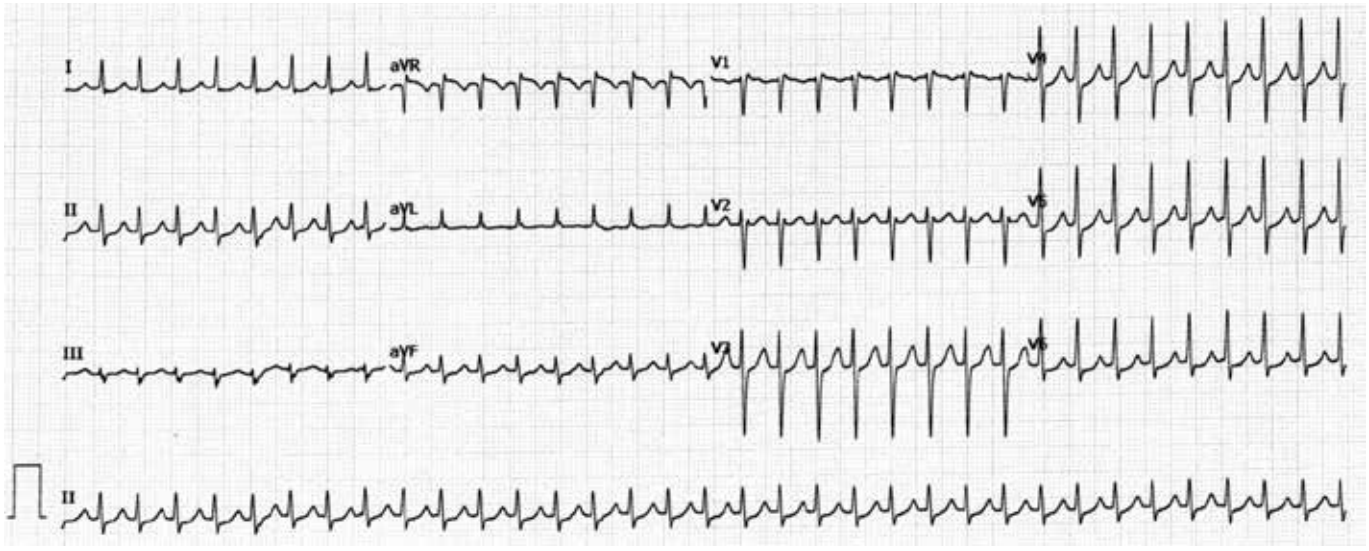

***Figure 15**

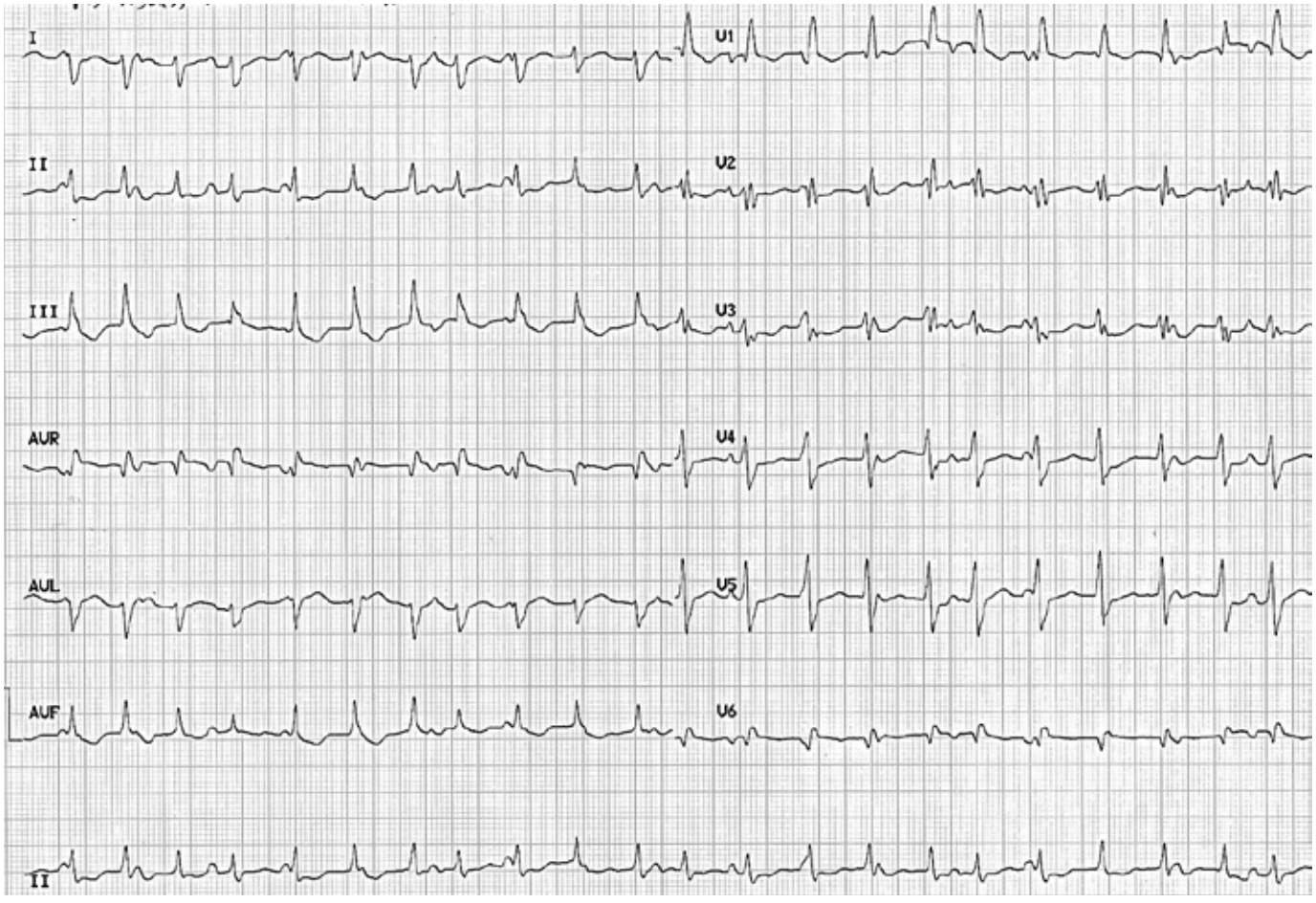

***Figure 16**

complex or seen as a small terminal P' wave that is not present during sinus rhythm (pseudo R deflection in lead V1 and a pseudo S wave in the inferior leads, a notch in lead aVL, and a pseudo R in aVR) **(Figure 15)**.

In the atypical form of AVNRT (fat-slow or slow -slow AVNRT), P waves are clearly visible before the QRS, i.e., RP>PR interval, denoting a long RP tachycardia, and are negative or shallow in leads II, III, aVF, and V6, but positive in V1.

Non-re-entrant junctional tachycardias

Junctional ectopic tachycardia (JET), or focal junctional

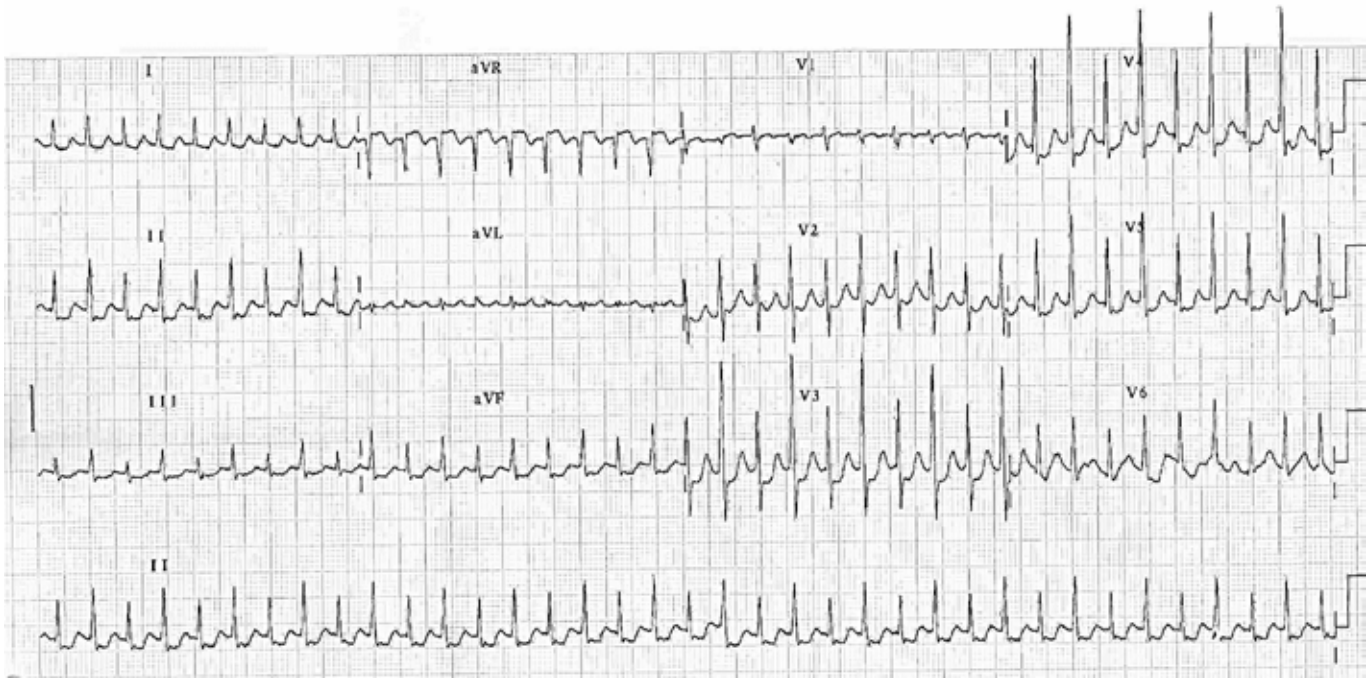

***Figure 17**

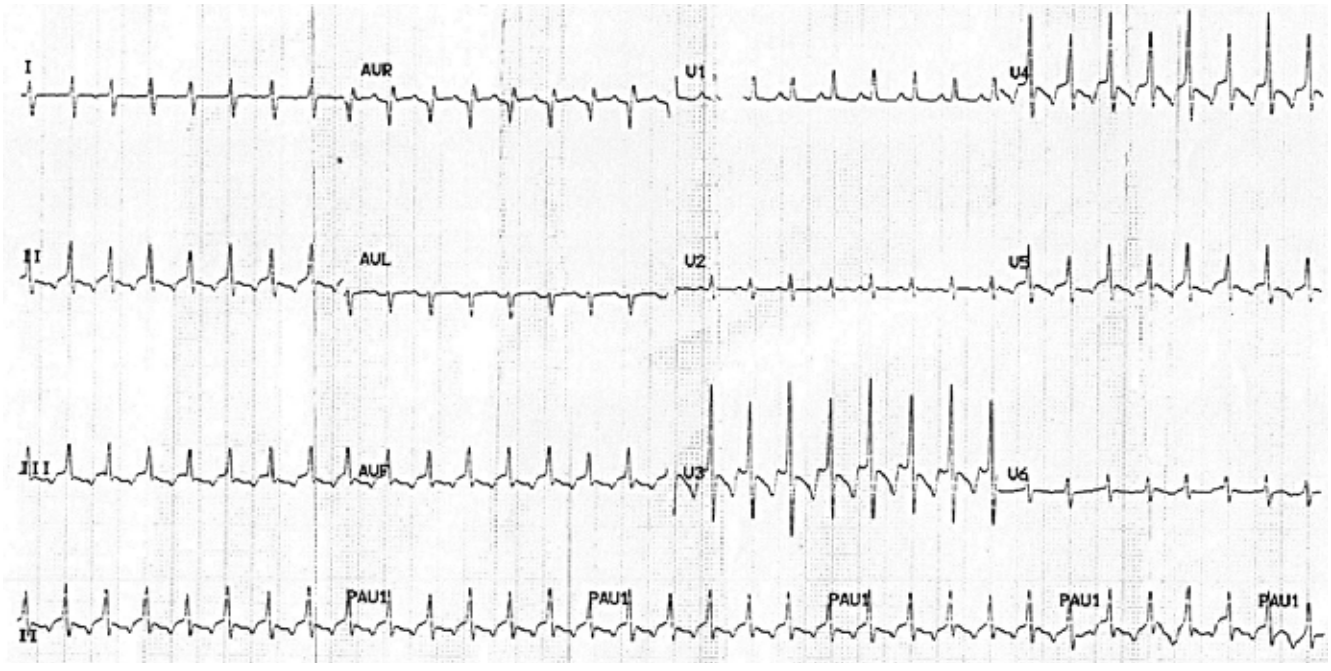

***Figure 18**

tachycardia is an uncommon arrhythmia that arises from abnormal automaticity at the AV Node or proximal His bundle. Focal junctional tachycardia in children may be seen as a congenital arrhythmia or, more often, early after infant open-heart surgery. The usual ECG finding in JET is a narrow QRS tachycardia with a short RP interval or AV dissociation. Occasionally, the tachycardia might be irregular and resemble AF **(Figure 16)**.

Atrio ventricular reentrant arrhythmias [AVRT] AVRTs use an anatomically defined re-entrant circuit that consists of two limbs: first, the AV Node-His purkinje system, and second, an accessory pathway also called the bypass tract. The two limbs are characterized by differences in refractoriness and conduction times, with critically timed premature atrial or ventricular beats initiating re-entrant tachycardia.

Orthodromic AVRT accounts for >90% of AVRTs and for 20 - 30% of all sustained SVTs[1]. The re-entrant impulse conducts from the atrium to the ventricle through the AV Node-His purkinje system, which is the anterograde limb of the re-entrant circuit, whereas the accessory pathway conducts from the ventricle to the atrium, and serves as the retrograde limb of the re-entrant circuit. Retrograde P wave [negative in inferior leads and positive in V_1] has constant relationship with R wave and falls usually first half of the ST segment and cause ST depression **(Figure 17)**.

Antidromic atrioventricular re-entrant tachycardia

Antidromic AVRT occurs in 3 - 8% of patients with WPW syndrome and re-entrant impulse conducts from atrium to the ventricle through an accessory pathway and either AV Node - His purkinje system or another accessory pathway conducts impulse from the ventricle to atria and serve as retrograde limb of the circuit. ECG shows wide QRS complex fully pre-excited tachycardia and the retrograde P wave usually inscribed within the ST-T segment.

Permanent junctional reciprocating tachycardia [PJRT]

PJRT is a rare form of AV reciprocating tachycardia using a concealed and decremental accessory pathway which is usually located in posteroseptal region. PJRT is a long RP tachycardia due to the slow conduction properties of the accessory pathway, and is characterized by deeply inverted retrograde P waves in leads II, III, and aVF due to the retrograde atrial activation **(Figure 18)**.

Clinical importance of P-wave Morphology analysis

In the in the current era of high-density 3D electro-anatomical mapping with multi electrode catheter, that P wave morphology analysis may be overlooked for AT localization.

P wave morphology-based algorithm to localize the site of origin of ATs[3]. (Figure 19)

However, P wave analysis is rapid and practical and avoids widespread mapping but rather focuses on a region of interest. This is particularly important in focal arrhythmias where sometimes ectopy or tachycardia is limited. For example, non-pulmonary vein triggers in patients with AF, just a single beat is available before the onset of AF to identify the site. Also recognizing the P wave morphology from common sites of AT origin will help us to do conventional ablation without using advanced 3D technology in resource limited practice.

Conclusion

ECG interpretation and P Wave morphology analysis could help the physician to identify the type of SVT. It also helps to differentiate focal and macro reentrant AT from the other SVTs and to manage and to treat correctly these patients. The P wave morphology analysis could be a very helpful tool in directing mapping during electrophysiological study.

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Electrocardiography Interpretation In Patients Undergoing Conduction System Pacing

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Introduction

The field of conduction system pacing has witnessed tremendous growth in the last decade. By capturing either His bundle or left bundle branch fibers, CSP provides synchronized activation of the left ventricle avoiding long term right ventricular (RV) pacing related complication.[1] His bundle pacing (HBP) has been shown to be associated with inherent limitations in the form of high pacing threshold, lead instability, inability to correct distal conduction system disease and premature battery depletion. Left bundle branch pacing (LBBP) has been suggested as an alternative modality to overcome the limitations of HBP by direct capture of LBB fibers on the left ventricular (LV) subendocardium.[2] LBBP has been shown to be an excellent alternative for biventricular pacing in patients with heart failure, low LV ejection fraction and wide QRS morphology.[3] It is essential to confirm conduction system capture to provide effective resynchronization therapy and new diagnostic criteria are still being developed. Electrocardiography (ECG) plays an important role for confirming the capture of conduction system both at the time of implantation and during follow-up.

His bundle pacing

His bundle pacing is performed using continuous recording of intracardiac electrograms and 12-lead ECG by targeting the site with largest His deflection. Direct capture of his purkinje system (HPS) results in homogenous depolarization of the ventricle rather than the delayed myocardial depolarization resulting from right ventricular pacing. This will be reflected in the 12-lead ECG with QRS mimicking the native morphology. Transition in QRS morphology is the most important feature to look for in ECG as the pacing output is gradually reduced. The basic principle behind the QRS morphology transition is the capture of two different substrate (conduction system and septal myocardium) by the pacing lead. Septal myocardium and conduction system has different conduction velocity, capture threshold and refractory period. Three different transition patterns can be demonstrated – selective capture to loss of capture, non-selective to selective to loss of capture, non-selective to myocardial capture to loss of capture. In patients with wide QRS morphology, another transition pattern from QRS morphology with correction to without correction could be demonstrated (Figure-1)

ECG patterns in HBP

The pacing lead can be deployed in the atrial or ventricular aspect of the His bundle (HB). During Selective HBP (S-HBP), ventricular activation occurs entirely through HPS and hence there will be a delay between the pacing artefact and the onset of QRS morphology. The duration of the delay corresponds to the native HV interval (onset of His signal

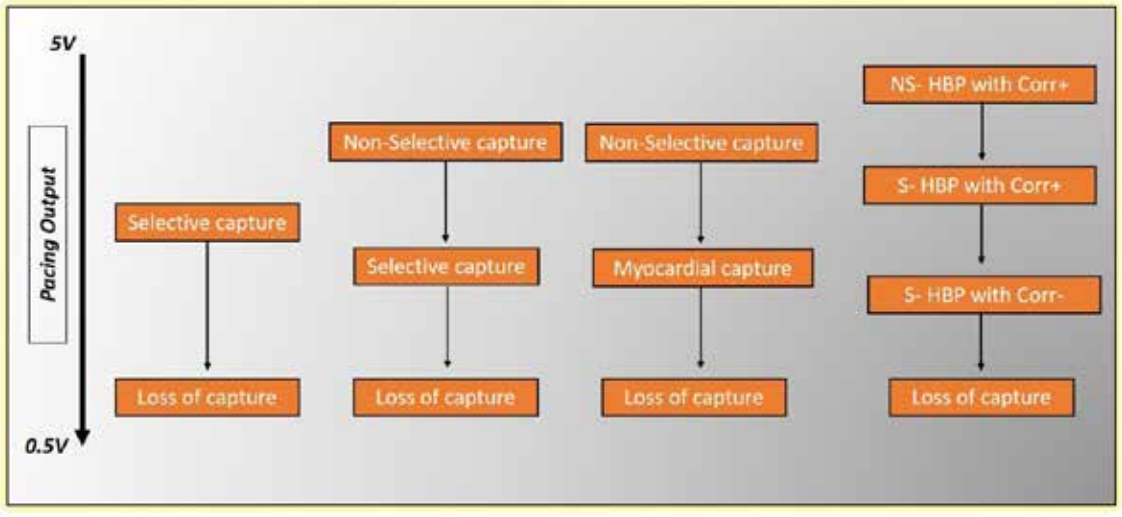

Figure 1: Output dependent capture transition in patients undergoing conduction system pacing. Four different transition patterns are noted in patients undergoing his bundle pacing with either narrow or wide baseline QRS morphology

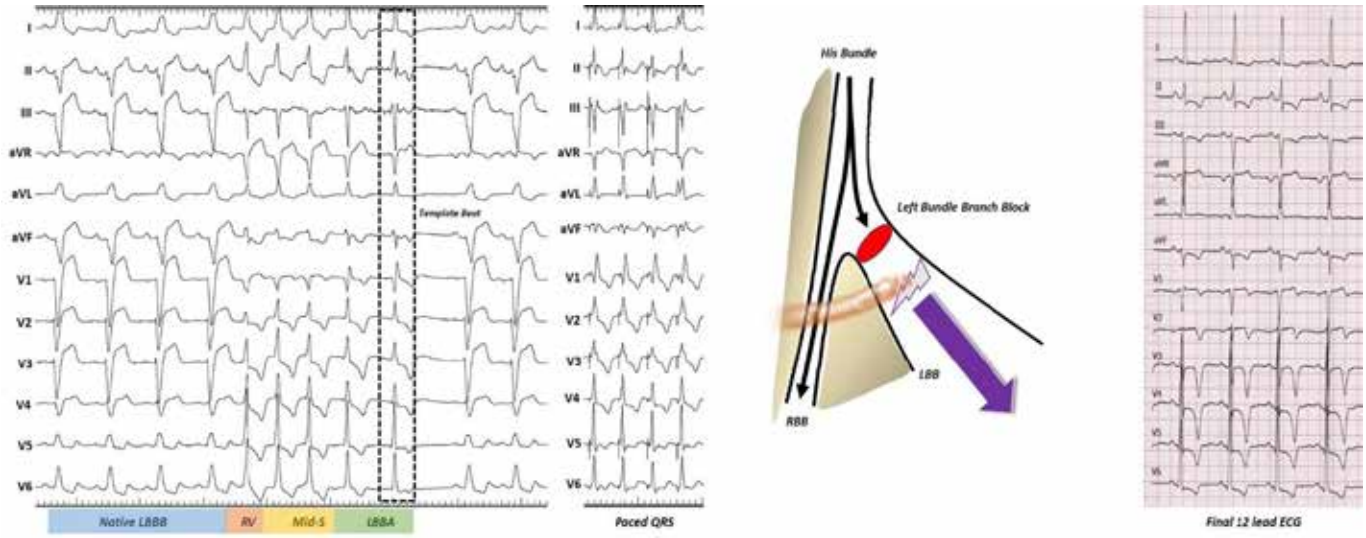

Figure 2: Premature ventricular complex guided left bundle branch pacing. Note the change in QRS morphology from QS to qR as the lead traverses from right side to left side of the septum. Final 12-lead ECG showing narrow paced QRS duration with T-wave memory.

to the onset of QRS). Intracardiac electrogram will show distinct isoelectric interval between the pacing artefact and the local ventricular electrogram. The QRS morphology will be identical to the intrinsic rhythm. Non-selective HBP (NS-HBP) usually occurs when the pacing lead is positioned at the ventricular aspect of the HB with myocardial tissue surrounding it. Ventricular activation occurs through HPS and surrounding myocardial capture. Hence ECG will show pseudo delta wave resembling pre-excitation pattern due to local myocardial capture, the amplitude and duration of the wave depends on the density and mass of the surrounding myocardial tissue and HV interval. In addition to the pseudo delta wave, increase in amplitude of R-wave in leads I, II and V6 will be seen due to simultaneous activation of local myocardial tissues and HPS. Studies have shown that there is no difference in clinical outcomes in patients with S-HBP and NS-HBP.[4] However, NS-HBP is associated with better sensed R-wave amplitude and has the advantage of providing backup myocardial capture if there is a loss of HB capture during follow-up.

The fibers inside the HB are longitudinally dissociated and are predestined to either left bundle or right bundle branch. Hence pacing distal to site of the block in the HB will correct bundle branch block in 60-90% of the patients[5-7]. Conduction disease may be localized at different levels and the correction can be total or partial. Though the myocardial only capture is expected to generate wide QRS morphology, it may be relatively narrow. Differentiating myocardial only capture from NS-HBP may be difficult sometimes. Transition in QRS morphology during decrementing pacing output, sudden prolongation of stimulus to retrograde P-wave, R-wave peak time of <90ms in lead-V6, absent notches, slurs or plateaus in lead I, V1, V4, V5 and V6 might favor NS-HBP rather than myocardial capture. A QRS duration of <130ms is never observed in myocardial only capture.

Left bundle branch pacing

LBBP is defined as direct capture of left bundle branch fibers with simultaneous activation of all of its fascicles.[8] The pacing lead is positioned deep inside the proximal interventricular septum 1-1.5cm below the HB along an imaginary line connecting distal His signal to RV apex. Pre-excitation of left bundle branch results in right bundle branch delay (RBBD) pattern in the surface ECG. Presence of qR/rSR' in lead-V1 is considered as the hallmark of LBBP though it is seen in 23-44% of patients with LV septal pacing (LVSP).[9] Continuous monitoring of 12-lead ECG and intracardiac electrograms are required for successful lead deployment. Premature ventricular complexes (PVC) of changing morphology will be generated as the lead traverses from right to left side of the septum during rapid deployment(figure-2). A PVC with RBBD pattern labelled as template/fixation beat[10,11] will confirm LBB area capture. Further, a PVC with 'M' pattern in lead-V1 labelled as "M-beat" is a sensitive marker for selective LBB capture. In a retrospective study by Ponnusamy et al,[12] template beat was observed in 90.4% patients (n=190) and M-beat in 32.8% (n=69). The mean QRS duration of M-beat was 129±13ms and the morphology mimicked the selectively capture beat. M-beat predicted selective LBB capture with specificity of 96.7% and sensitivity of 66.04%

Site of pacing

Analyzing the 12-lead ECG will help in identifying the site of deployment of pacing lead in the left conduction system. The paced QRS morphology differs based on the location of the lead in the main trunk of left bundle, left anterior fascicle or in the left posterior fascicle (table-1). RBBD is a hallmark of left conduction system capture and is seen in all patients irrespective of the lead location within the conduction system. In patients with left main trunk pacing the paced QRS morphology will be similar to native rhythm but for the RBBD

Table 1: Paced QRS morphology depending on the site of the pacing lead. LAFP – left anterior fascicular pacing; LPFP – left posterior fascicular pacing.

LBB Trunk	LAFP	LPFP
RBBB Pattern	RBBB Pattern	RBBB Pattern
Normal axis	Right axis	Left axis
S in I, aVL similar to that in Sinus rhythm	Dominant S in I, aVL	Dominant R in I, aVL
R in II, III, aVF similar to that in SR	Dominant R in II, III, aVF	Dominant S in II, III, aVF

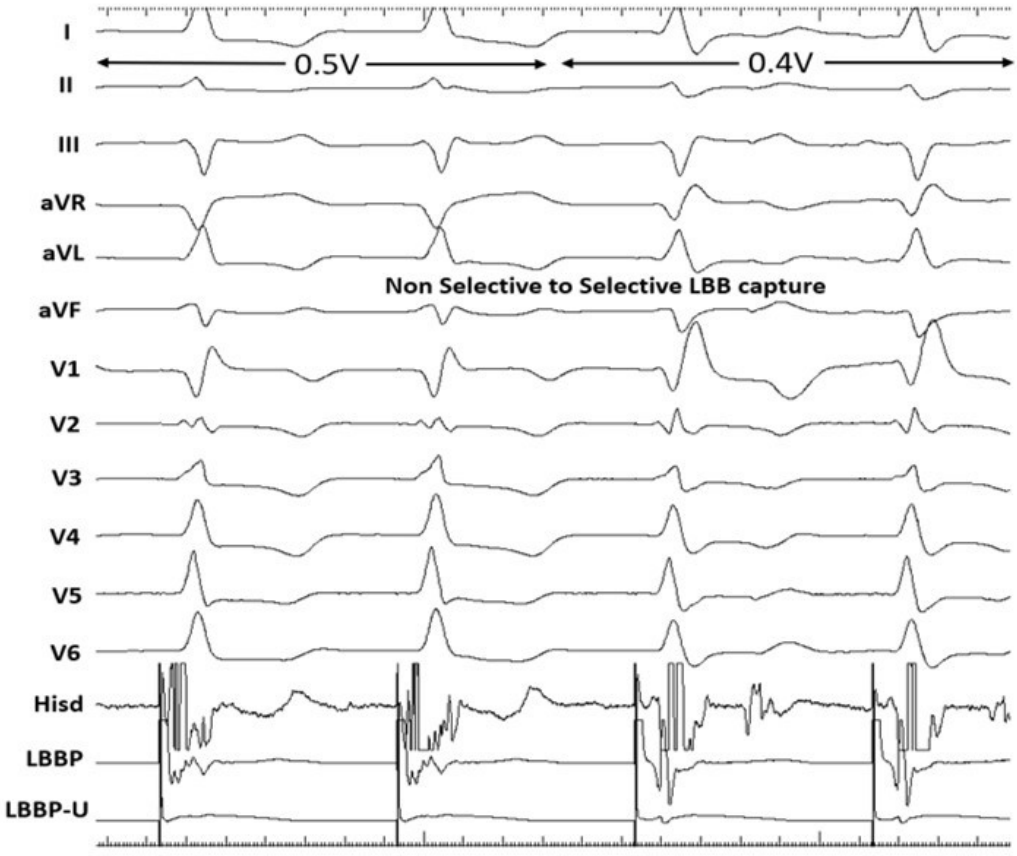

Figure 3: Output dependent capture transition during left bundle branch pacing. Note the change in QRS morphology and pacing lead electrogram as the pattern of capture changes from non-selective to selective.

pattern. With left posterior fascicular pacing, RBBD pattern will be seen along with left axis deviation, dominant R-wave in leads I and aVL and deep S-wave in leads II, III and aVF. In patients with left anterior fascicular pacing, RBBD pattern will be associated with right axis deviation, dominant R-wave in leads II, III and aVF and deep S-wave in leads I and aVL.

Output dependent QRS morphology transition

Transition in QRS morphology with gradual reduction in pacing output helps in confirming LBB capture. Su et al[13] observed output dependent transition in 74% of the cases during implantation. Transition can be either from non-selective to selective capture or from non-selective to LV septal capture. Non-selective to selective capture (figure-3) is characterized by distinct interval between the pacing artefact and the local electrogram along with change in paced QRS morphology (qR to 'M' pattern in lead-V1, increase in S-wave amplitude in lead-V6 by >50%, rounded configuration of terminal R' component in lead-aVR). The distinct iso-electric interval can be better appreciated in the LBB lead electrogram than in the surface ECG and the duration is equal to the interval between LB potential to the onset of QRS. Non-selective to septal transition is characterized by loss of R-wave in lead-V1, prolongation of global QRS duration, appearance of pseudo-delta wave in lead V3-V5 and decrease in S-wave in lead-I and V6. There will be sudden prolongation of R-wave peak time as measured in lead-V6 (from the pacing artefact to the peak of R-wave) by >10ms as the pattern change from non-selective to septal capture. If both septal myocardium and LBB has similar capture threshold and refractory period, QRS transition may not be seen. Output dependent change in QRS morphology is transient sometimes and may not be noted at the end of the procedure.

Programmed deep septal stimulation

Programmed stimulation from the pacing lead tip will help in confirming the capture of LBB both at the time of implantation and during follow-up (figure-4). The refractory period of myocardium and HPS depends on the preceding cycle length. Myocardial refractoriness is influenced by the cumulative effect of the several preceding cycle lengths and HPS refractoriness by the immediately preceding cycle length. Three different responses can be noted based on the QRS morphology[14] (a) Myocardial response – as the coupling interval of the premature beat is gradually reduced, there will be a loss of LBB capture resulting in capture of septal myocardium only. The changes that can be noted include change in QRS axis, reduction in amplitude of 'R' wave in lead-V1, higher amplitudes in mid-precordial leads, increase in global QRS duration and notching of R-wave. (b) Selective LBB capture response – characterized by RBB delay pattern with distinct iso-electric interval between pacing artefact and onset of QRS. Surface ECG will show appearance of 'M' pattern in lead-V1, increase in amplitude and duration of S-wave in lead-V6 and rounded appearance of terminal R'-wave in lead aVR as the pattern change from non-selective to selective capture. (c) Non-diagnostic response – seen in patients with nearly similar refractory period of myocardium and LBB, characterized progressive minor change in QRS morphology not suggestive of myocardial or selective LBB capture response. Marek et al[14] showed myocardial or selective LBB capture response in 79.7% of patients. Non-diagnostic response was noted in 20% of patients. Selective response was noted more often when the premature beats were introduced during sinus rhythm and myocardial response when the premature beats were introduced during basic drive train. Programmed deep septal stimulation helps in confirmation of conduction system capture when other criteria are equivocal.

Lead V6 R-wave peak time

The V6 R-wave peak time (RWPT) indicates the duration it takes for the depolarization wavefront to the reach the epicardial surface of the LV lateral wall. As the conduction velocity of the HPS is faster than the myocardium, V6RWPT will be shorter during HBP as compared to RV pacing and shorter during LBBP as compared to LV septal pacing (LVSP). The V6 RWPT is measured using digital calipers at sweep speed of 150-200 mm/s from the onset of pacing artefact to the peak of R-wave. The normal value of intrinsicoid deflection time in lead-V6 is 50-60ms. The normal duration of LBB potential to QRS onset is 25-35ms. Hence, V6RWPT of <75ms has 100% specificity for confirming LBB capture. A V6RWPT of <83ms has sensitivity and specificity of 84.7% and 96.3% respectively for capture confirmation. In a multicenter retrospective study by Vijayaraman et al[3], RWPT <90ms was used as an arbitrary cut-off to account for the delay in the conduction system due to cardiomyopathy.

As there is restoration of normal activation of the left ventricle, the paced V6RWPT does not exceed the native V6RWPT by more than 10ms. Similarly, the pacing artefact to

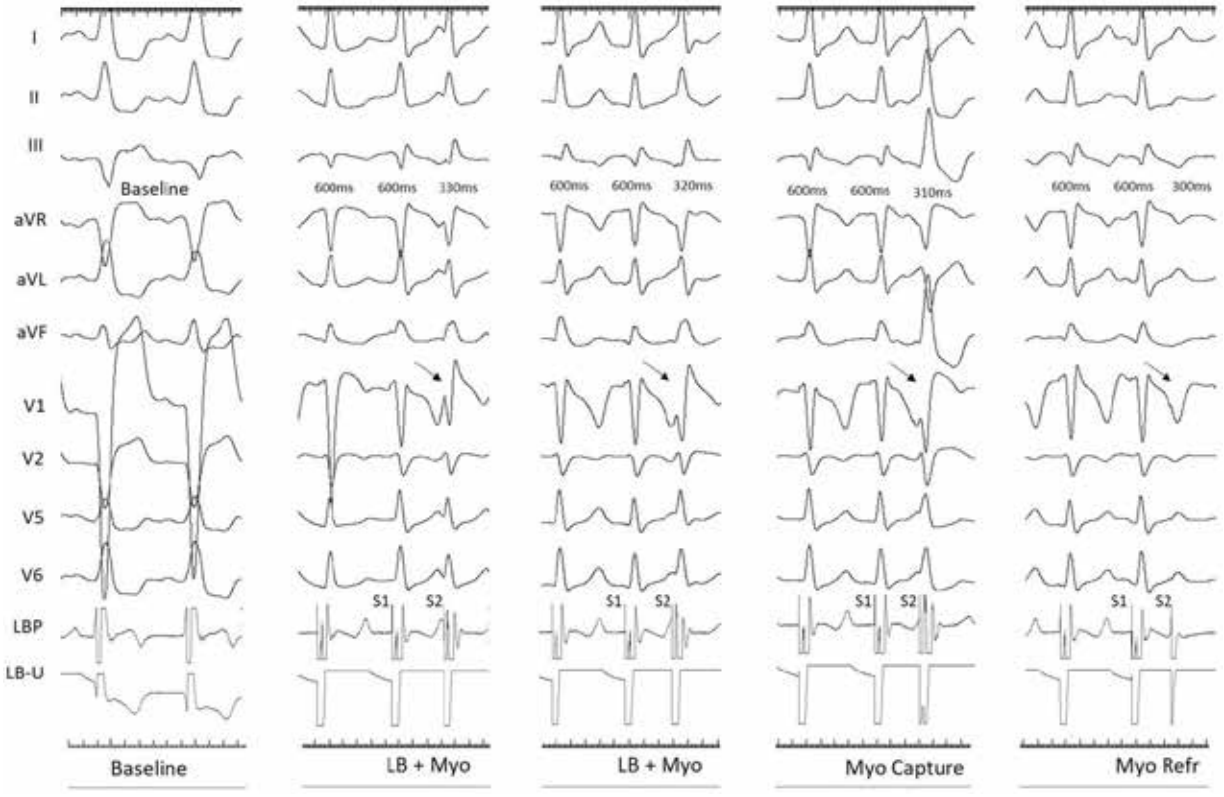

Figure 4: Programmed deep septal stimulation. Note the change in QRS morphology due to loss of conduction system capture when the coupling interval was reduced from 320ms to 310ms.

Table 2: Differentiating LBBP from LVSP based on ECG criteria. LBBP – left bundle branch pacing; LVSP – left ventricular septal pacing; LBBB- left bundle branch block; NS – non selective; RWPT – R wave peak time.

Parameters	LBBP	LVSP
Paced QRS (V1)	qR in ~100%	qR in 44%
	Absent terminal S-wave	Terminal S-wave in 60%
RWPT (V6) – differential pacing	Short and constant	Different at different output
RWPT (V6) – absolute value	<75ms in non-LBBB	Prolonged
	<85ms in LBBB	
LB potential	++	+/-
Capture transition	NS to Selective	No transition
	NS to Septal	
V6-V1 interpeak interval	>33ms	<33ms
Physiology based ECG criteria	Native RWPT=paced RWPT	>10ms difference
Programmed deep septal stimulation	Change in QRS morphology, axis	No change

RWPT equals the LBB potential to RWPT in lead V6. These criteria have high sensitivity and specificity for differentiating LBB capture from LV septal capture.[15] The optimal cut-off for V6RWPT in patients with non-LBBB morphology is 83ms (sensitivity 84.7%; specificity 96.3%) and with baseline LBBB morphology is 101ms (sensitivity 90.4%; specificity 78.9%) for differentiating LVSP from LBBP.

V6-V1 interpeak interval

Tha pattern of LV and RV activation differs during non-selective, selective LBB capture and LV septal capture. On the surface ECG, the intrinsicoid deflection in lead-V1 reflects RV activation delay and lead-V6 reflects LV activation delay. Hence the difference between these two intrinsicoid deflection will help in differentiating LBB capture from LV septal capture. During transition from non-selective to selective capture, the RV activation is delayed with unchanged LV activation pattern due to loss of myocardial capture. On the contrary the LV activation is delayed with unchanged RV activation pattern during transition from non-selective to septal capture transition due to loss of conduction system capture. Marek et al[16] showed that the V6-V1 interpeak interval would be shortest during LVSP, intermediate during non-selective LBB capture and longest during selective LBB capture. An optimal cut-off of 33ms has 71.8% sensitivity and 90% specificity to differentiate nonselective LBB capture from LVSP and 44ms has 100% specificity for confirming selective LBB capture. Similarly, the R-wave amplitude and duration in lead-V1 would increase during non-selective to selective capture transition. A cut-off of ≥15ms differentiate LBB capture from LV septal capture with a sensitivity of 95.6% and specificity of 59.4%.

How to differentiate LBBP from LVSP?

Differentiating LBBP from LVSP is important to ensure physiological activation of the ventricle. Though several studies have proposed criteria for confirming LBB capture, these are not tested in large scale studies. There is a significant overlap of both QRS duration as well as morphology as nearly 40% of patients with LVSP will also have RBBD pattern. A short and constant V6 RWPT, output dependent capture transition, V6-V1 interpeak interval and programmed deep septal stimulation will help in differentiating LBBP from LVSP (table-2). However, there are no long-term studies comparing the hemodynamic benefits of LBBP over LVSP.

Conclusion

Understanding paced QRS morphology is very important to confirm conduction system capture during implantation. The paced QRS morphology differs based on site of the pacing lead location within the conduction system. The difference in the refractoriness and capture threshold of HPS and myocardium can be exploited for the diagnosis of HPS capture. Careful analysis of 12-lead ECG along with pacing parameters are warranted during follow-up to ensure consistent conduction system capture

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Importance of Lead V1

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Abstract

The importance of lead V1 is generally not recognised although one always refer to it while reading an ECG. This brief article helps to recollect the various ways in which lead V1 helps us in the understanding of the heart,

Introduction

Generally, lead II is considered the most looked at and may be the most important lead by some. However, lead V1 has its fair share of importance as it lies on the right side of the heart and it looks at it from above downwards (Fig 1) a perspective done only by another lead avR. Another aspect is that it lies just anterior to the right atrium and right ventricle (Fig 2) and has the left atrium to its left and posteriorly. Thus, it can clearly depict the atrial waveforms

Atrial enlargement

Atrial enlargement could result from the enlargement of either the right atrium or the left atrium or a combined enlargement of both the right and the left. The components of the P wave from the right atrium and the left atrium can be clearly demarcated and the relative sizes of each chamber assessed.

The beginning half of the P wave is caused by the right atrium and the latter part by the left atrium

Rhythm Abnormalities

The P wave in lead V1 helps us to determine the rhythm of the heart, particularly in atrial flutter where it can detect the type of atrial flutter – a positive flutter wave in V1 along with a negative flutter wave in Lead II indicates **typical atrial flutter**.

Importance of the QRS in Lead V1

The QRS morphology in lead V1 helps us in identifying the bundle branch blocks. In Left bundle branch block the V1 shows a rQS pattern as shown in figure 5 & 6:

Brugada Pattern

Lead V1 helps in the diagnosis of Brugada syndrome by drawing attention to the Right ventricular infarct-like pattern in V1. Its diagnosis in more complete by looking at V2 as well and by completing procainamide or flecainide challenge test.

Arrhythmogenic Right ventricular Dysplasia (ARVD)

ARVD an inherited cardiomyopathy presenting with localised patches of fibro fatty replacement of right ventricular and occasionally of the left ventricle. It can predispose to lethal ventricular arrhythmias and is characterised in the ECG by late signals in lead V1 after the QRS that is called an Epsilon wave.

Myocardial Infarction

Posterior myocardial infarction can be hinted by noticing a flat ST depression in lead V1 and a positive T wave. It becomes more certain with tall broad R (>30 ms) in lead V2 and confirmed by ST elevation in posterior leads V7 to V9.

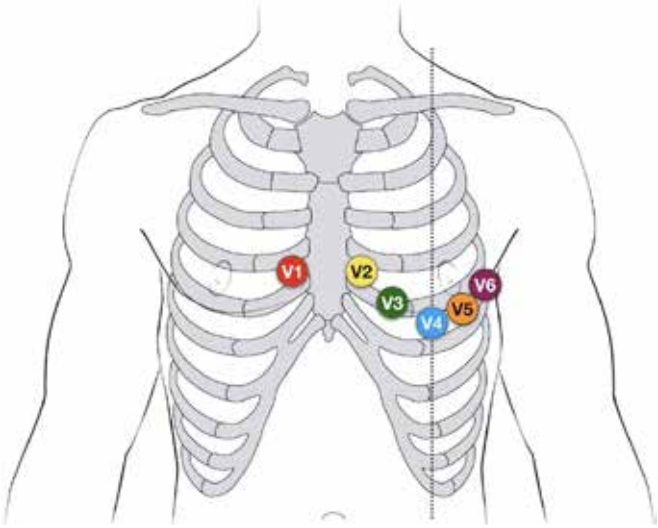


Figure 1: Note the position of lead V1, well right of the heart

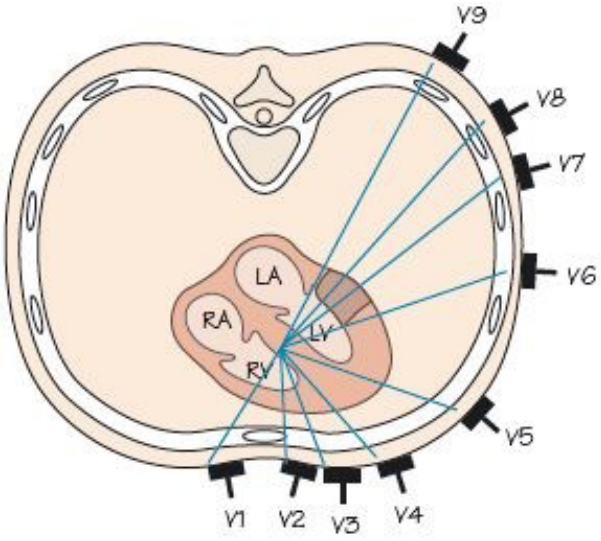
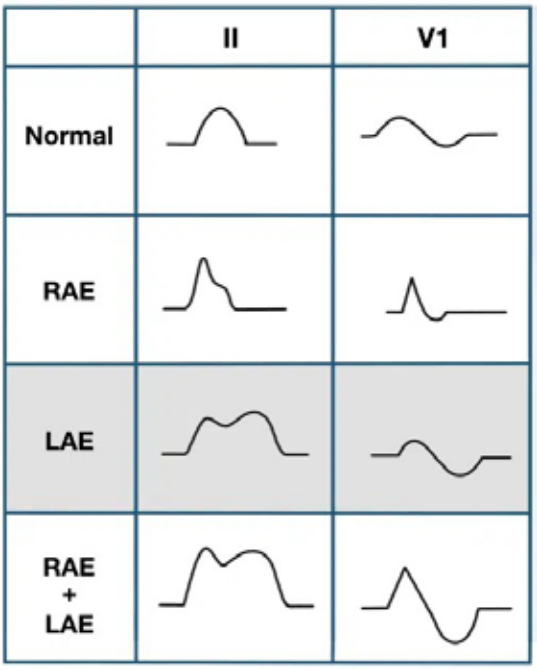


Figure 2: Note lead V1 – and its relation to the right ventricle



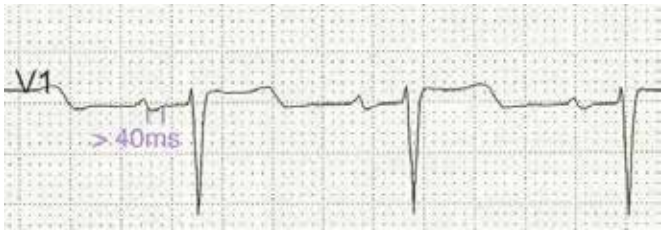


Figure 3: Cartoon depicting the components of the right and left atrium that combine to form the P wave in Lead II and in V1

The initial positive wave is from the right atrium. The amplitude of this increases in right atrial enlargement. The latter part of the P wave is contributed by the left atrium and is negative in V1. Its depth increases in left atrial enlargement to>0.1 mV and width to >40 ms

ECG strip of V1 to show the **left atrial enlargement**

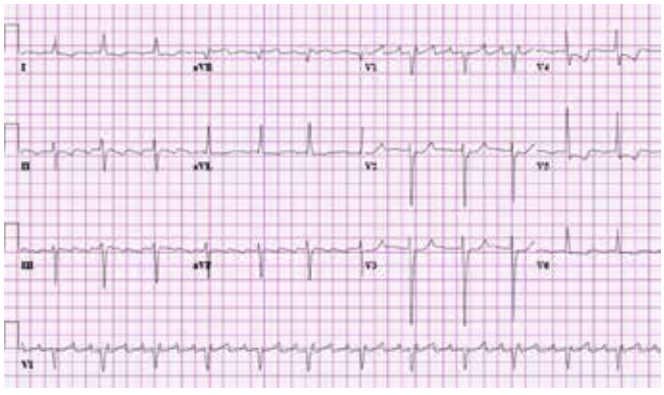
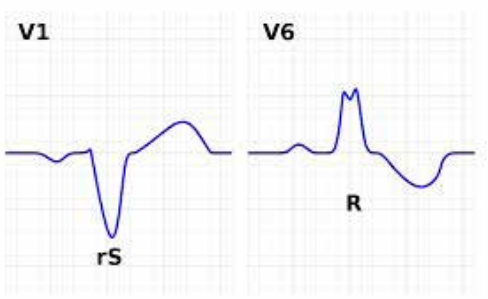


Figure 4: ECG showing a positive flutter wave in V1 and negative saw teeth patytern in Lead II indicating Typical Atrial Flutter



Right Bundle branch has a rSR' pattern in V1

Figure 5: ECG of Left Bundle Branch showing rQS in V1 and Notched R in V6 (Courtesy: Wikipedia)

Figure 6: ECG of Right Bundle Branch block showing rSR in V1 and qR with a slurred S in V6. (Courtesy: Wikipedia)

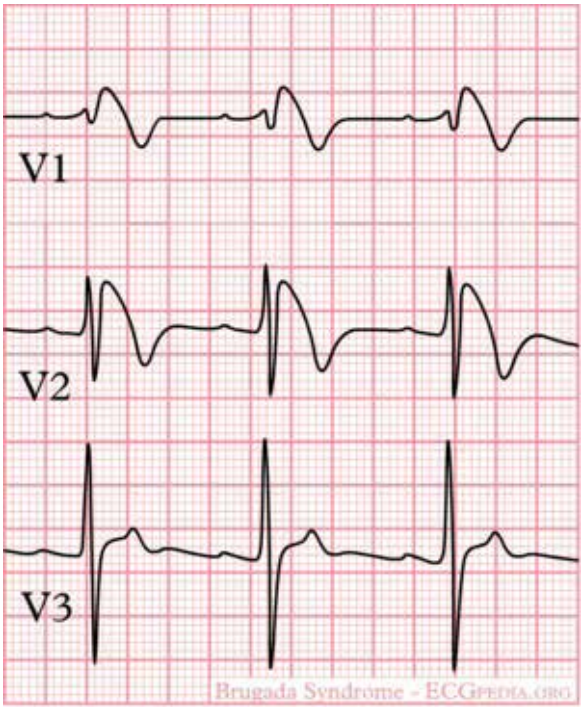
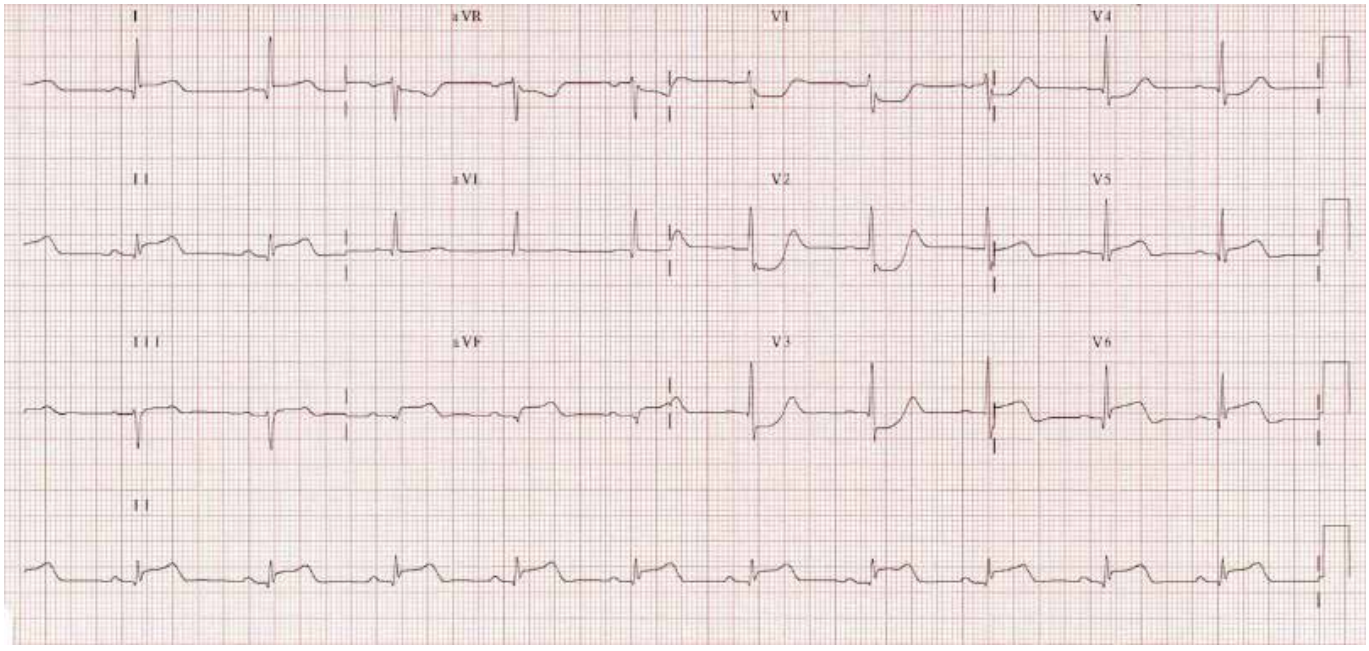


Figure 7: Brugada syndrome also known as Sudden unexpected Nocturnal Death Syndrome is a Sodium Chanellopathy with autosomal dominant inheritance causing sudden death in sleep. ECG shown here is of the Type I Brugada with a coved ST. Types II & III have a saddle back shaped ST, with Type III having negligible J point elevation.



Right ventricular MI can be suspected when ST elevation of V1 is more than that in V2, but confirmed when ST elevation in V4R is maximum.

Figure 9: ECG of posterior wall MI with flat ST depression in V1 and V2, tall broad R in V2 and ST elevation in V6

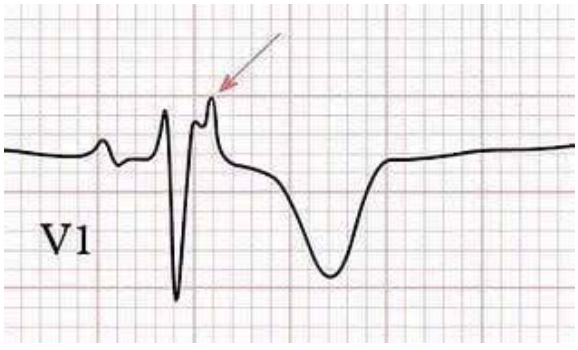


Figure 8: Late signals after QRS – the Epsilon wave of Arrythmogenic right ventricular Dysplasia

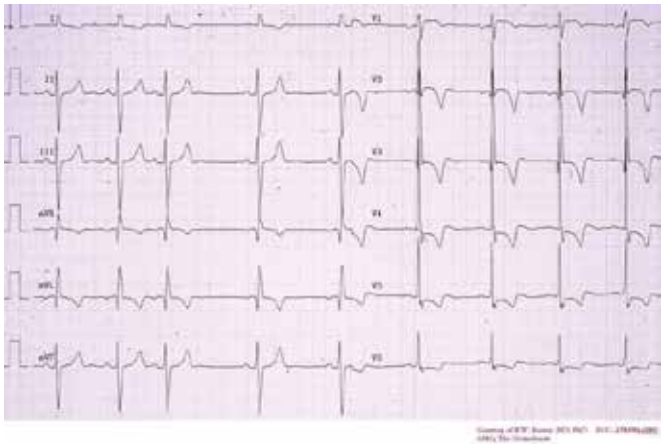


Figure 10: ECG of a right ventricular MI with ST elevation in V1

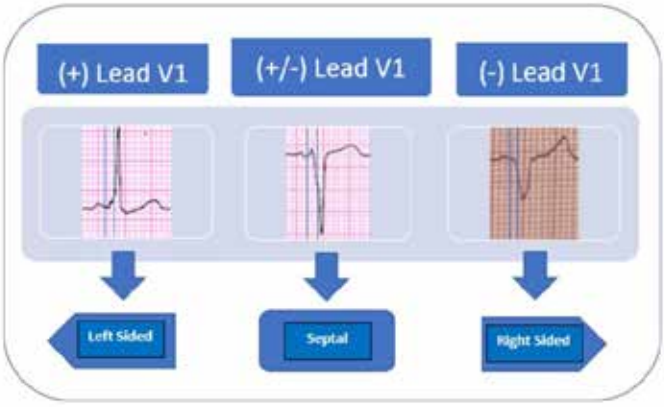


Figure 11: In V1 if the R wave to S wave ratio is more than 1, the accessory pathway is located in the left, if less than 1, it is Pulmonary Hypertension, Right ventricular Hypertrophy and Pulmonary embolism

Pre-excitation

In cases of pre-excitation a study of the R wave in lead V1 can indicate if the accessory pathway is right or left sided

The ECG in V1 shows tall R wave of qR type in severe pulmonary hypertension, rR in right ventricular hypertrophy and rsR in pulmonary embolism.

The lead V1 of the 12 lead ECG is thus a warehouse of information if that is sought by a keen patient observer.

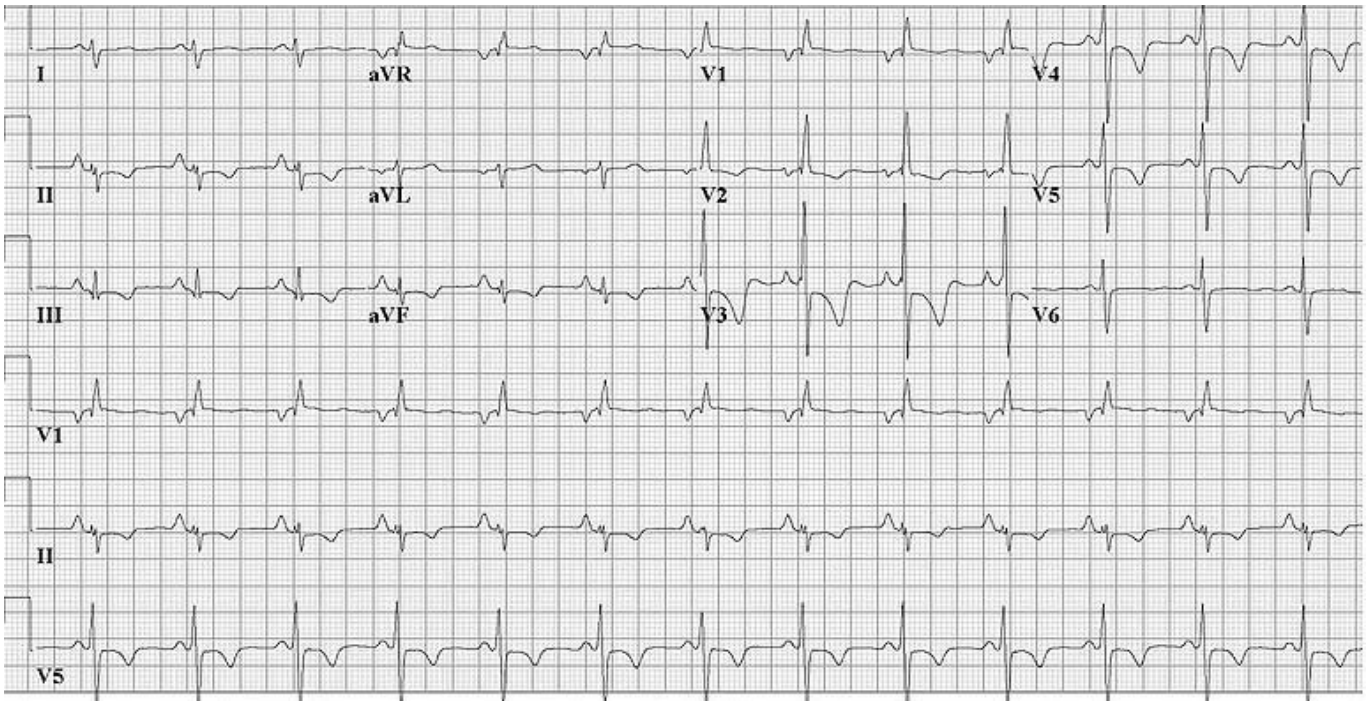


Figure 12: Right ventricular hypertrophy in a patient with pulmonary hypertension showing qR pattern in V1

Reading Material

1. Mirvis DM, GoldbergerAL, Electrocardiography, Braunwald's Heart Disease, 11th Edition, Philadelphia, PA, Elsevier Saunders, 2019

INDIAN SOCIETY OF ELECTROCARDIOLOGY

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Health Harmony, 2-Dattani Chambers, S V Road, Malad (W), Mumbai 400064
Mobile : 91-98200 51849 • e-mail : drketanmehta@yahoo.com • www.iseindia.org

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of _____

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Thanking you,

Yours sincerely

Signature of the A pplicant

Proposed by (the Member of the S ociety)

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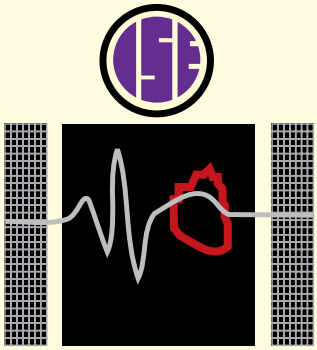

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