Course: Electrophysiology of Heart

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Lecture 17: Heart rate variability (HRV)

Hello everyone. So, today we will start our next topic that is heart rate variability. So, in this topic we will cover heart rate variability, what is the background information, how it is done methodology, the terminology of various HRV heart rate variability analysis, how it is interpreted and clinical value of HRV analysis. So, before moving on to the main topic I would like to discuss this ECG with you. So, here this is an ECG where an 80 year old man he presented with breathlessness and ankle swelling, no history of any chest pain in the emergency and the ECG has been done. So, this is his ECG recording.

So, what are the findings of this ECG? So, first and foremost if we are supposed to calculate the ventricular rate of this ECG, since it is an irregular rate and rhythm you can see in this ECG, but no rhythm strip is given over here. So, we will calculate the ventricular rate based on our simple basic formula. So, here the ventricular rate as per the number of RR large boxes you can see, from here we can calculate the ventricular rate as approximately 38 beats per minute. That means, 300 by 9 around 9 large boxes I could count.

Now second if we are supposed to see what are the where are the P waves. So, we are not able to identify the P waves, because we are seeing the irregular fibrillatory waves present over here. So, irregular fibrillatory waves present. So, this since already ventricular rate is there. So, this is signifying atrial fibrillation.

Next we will see in the chestlets V 2 and V 3 we could see deep or prominent S waves and in case of V 5 and V 6 we could see the notched M shepherd R wave. So, deep prominent S wave V 2, V 3 and at V 5 and V 6 we are getting notched M shepherd R wave. So, this is signifying left bundle branch block and if we see about the axis deviations we will we go for the quadrant approach. In the quadrant approach we have the lead 1 and AVF. So, this is a positive deflection and AVF is having a negative deflection which says it is a left axis deviation.

So, this ECG is of atrial fibrillation with left bundle branch block. Now moving on to

the main topic that is heart rate variability. Heart rate variability refers to the beat to beat variations or the alterations in the heart rate. Our heart rate is not constant it should not be constant rather because whenever we are at rest suppose my heart rate is 70 beats per minute. Whenever I am talking I am walking I am doing some exercise I am standing I am sitting I am lying down there should be variation of heart rate because finally, it is the tug of war between the sympathetic domain and the parasympathetic domain.

That means the sympathetic the two branches of the autonomic nervous system. That means sympathetic nervous system and the parasympathetic nervous system which gives your heart rate. The balance between the sympathetic and the parasympathetic drives to the myocardium gives rise to your heart rate variability. And heart rate variability analysis is actually a non-invasive method of detecting early autonomic dysfunction in an individual. And this is usually determined with the help of RR intervals.

RR intervals are nothing but the regularity of the heart beats. And this is usually determined from the ECG recording and measured in milliseconds. So in this diagram we can see this is the interval tachogram and this is the RR interval which is interpolated. So we can see this RR interval this interval this is if it is this duration of RR interval RR 1 is definitely less than the duration of RR 2. Then RR 3 duration then we have RR 4 duration again that is of less compared to RR 3.

So we have varying heart rate variability or varying durations of the varying interval of RR intervals. So this is the interval tachogram. And if we interpolate this RR tachogram we can we will get a wave like pattern. So this we will discuss further in slides. So the basic thing is heart rate variability is big mainly because of various factors.

As I told you it is mainly due to the tug of war between the sympathetic nervous system and the parasympathetic nervous system which give rise variation in the heart rate. And this because of this variation actually the person is normal. Had there been no variation or the heart rate variability is constant or monotonous which means it is pathological which means any one domain either sympathetic or parasympathetic is predominant in that person. So you can see heart rate is 83, 76, 70, 83, 76, 78 there is variations in the heart rate and so the RR interval is also varying. So this illustration showing an unhealthy heart rate variability because the interval is constant.

We have 1 second interval, 1 second interval, 1 second interval, 1 second interval which is actually not normal. Even with the physiological phenomenon of respiratory sinus arrhythmia which we had already studied we know heart rate increases when we inspire and heart rate decreases when we expire. Even the simple mechanism is causing changes or variation in the heart rate. So obviously when the person will stand, sit or do

exercise or do some other activities in the daily routine there has to be some heart rate variability. If the heart rate variability is constant it is actually unhealthy heart rate variability.

So this is the next diagram which is showing a healthy heart rate variability that means higher heart rate variability is actually meaning good cardiac adaptability. Good cardiac adaptability means when we are not thrown into any challenges, external challenges or internal challenges in our body that means our body is in homeostasis. But whenever there are challenges, when we are thrown into the challenges our autonomic nervous system should act. It should act in such a way that it should not compensate the perfusion of the vital organs. So in this way there has to be heart rate variations or heart rate variability and the more the heart rate variability the more the autonomic modulation or the more regulation of autonomic nervous system is present in an individual.

The lower heart rate variability indicates poor adaptability of the cardiac autonomic function and it is generally associated with higher risk of cardiovascular events mainly sudden death. So this is the diagram which is showing the various factors which are responsible for of heart rate or the RR variations or RR intervals. Now we have first and foremost the baroreflex mechanism, cardiopulmonary reflex mechanisms, then we have thermoregulation, then we have the blood pressure oscillations, then hormonal or neuroendocrine factors, then we have other circadian rhythms. So these are all factors which give rise to the RR intervals. So here we can see the sympathetic stimulation on the intrinsic heart rate is slow whereas, the parasympathetic stimulation on the intrinsic heart rate is instantaneous and this is the net autonomic nervous system stimulation that means the balance between the sympathetic and the parasympathetic nervous system which is giving rise to the intrinsic heart rate.

So what are the factors which actually give rise to the heart rate variability? Intrinsic factors means activity, the stress both mental and physical stress, sleep apnea, then any bad habits if a person is into like smoking. Then we have intrinsic periodic rhythms like respiratory sinus arrhythmia, baroreflex regulations, also respiration is one of the factor, thermoregulations, neuroendocrine secretions that means hormonal, then we have the circadian rhythms. These are all the factors which give rise to the variations in the RR intervals or heart rate variability. So, that is why heart rate variability is also known as cycle length variability or RR variability. These are the other names of heart rate variability.

So how do we quantify heart rate variability? Now HRV is quantified depending on various factors like how much variability is there. You want to quantify based on how much variation is there. For that we use time domain and geometric analysis. If we want

to see what are the underlying rhythms present and how much power does each underlying rhythm is having. So for that we use frequency domain analysis that means the power spectral density analysis.

Then we have how much complex is this rhythm or how much complexity is there or self similarity is there. For that we use non-linear analysis. So these are the various types of analysis which are present to quantify the heart rate variability based on what you want to which parameter you want to check, which domain you want to check, you have to perform that analysis. So acquisition of ECG signal, ECG recording has done. We have obtained the ECG signal.

Then we will be digitization is done or preconditioning of this ECG signal is done. After this preconditioning we could detect the R wave peak detection that means RR intervals we will get. We will generate the RR time series and optimizations. Now generation of RR time series means n n RR is also known as n n interval sequence. So with this n n interval sequence we get time domain analysis and non-linear analysis.

And when we do this interpolation of this n n interval sequence and resampling of this sequence we get frequency domain analysis. So RR time series and optimization is obtained from the R wave peak detections and we get non-linear analysis and time domain analysis. And frequency domain analysis is obtained from the interpolation and resampling of n n interval sequence. So from that we get frequency domain analysis. So acquisition of the ECG signals like preconditioning of the ECG signal is based on various factors like what is the filter you are using, what is the sampling frequency, what is the duration of the recording needed.

So for the filter we use band pass filters of 0.5 hertz to 35 hertz. Now filter is mainly used to eliminate any unwanted noises. So sampling frequency should be more than 120 hertz. Duration whether you want to do short term HRV for that 5 minutes recording is needed if you want to do long term HRV for that at least 24 hour HRV is needed for long term recording.

So this is how the acquisition of the ECG signal is done. Now history of HRV what we have learnt so far is the methodology of the HRV. Now how HRV has come into existence? Now initially in the 18th century Von Heller the scientist noticed that heart beat is not regular. That means regularity of heart beat is not there means he could see there is variations in the heart rate. Then Hahn and Lee in 1965 could detect the beat to beat interval changes in the fetal distress.

Further Ewing this is very important name because this based on this person we have

the autonomic scoring. He developed a number of simple bedside test of short term RR differences to detect autonomic neuropathy in diabetic patients. Not only this later on Axlelot introduced power spectral analysis. This power spectral density analysis is mainly for the frequency domain analysis which has been invented or discovered by Askelod. Then we have in 1980s late 1980s HRV confirmed strong predictor of mortality after an acute myocardial infarction.

Then in 1996 task force published the standards of measurement of HRV. Now with the standards of measurement of HRV or heart rate variability now a days at present we have various new digital multi channel ECG recorders available which could detect or which could quantify this heart rate variability. So the task force was established by the board of the European society of cardiology and the electrophysiology group. What are the specific goals of this task force? Now they wanted to know the variation first and foremost the variation of this heart rate. The nomenclature they want to do they develop the definition and terminology of various variation.

They want to quantify heart rate variability. They want to study the physiological as well as pathophysiological correlates. Currently appropriate clinical applications to be described and also in future research is possible or not. They wanted to identify certain various areas. So the challenges of this heart rate variability comes as I told you our body is always in a state of homeostasis still we are under stress.

But whenever we are under stress our body should try to overcome that challenge and it should not it should overcome the challenge in such a way that the blood flow or the perfusion of the vital organs are not compensated. So the challenges occur the problem occurs when the systems involved in this homeostasis they do not shut off when not needed or they do not become active when they are needed. When my autonomic nervous system sympathetic nervous system is needed at that time it is not working and when my sympathetic nervous system is not needed suppose I am at rest if it if get if that time sympathetic nervous system gets activated then it is problematic. So the balance between the sympathetic nervous system and parasympathetic nervous system is usually disturbed in these cases and that could lead to the autonomic dysfunction which could be due to the chronic conditions or stress related health problems. Also when the body does not return to the state of rest after an emergency state that is why whenever we perform the autonomic test autonomic function test always we keep an entity of the post recovery period.

So we want to see after the stress test or after the provocative test whether the person autonomic nervous system is coming back to normal or at the rest level because if it does not come back then again it poses a challenge to the autonomic nervous system. So the

meaning of the depressed HRV what does it indicates? Now whenever the ability of the autonomic nervous system regulatory function is low there is depressed HRV. Whenever the ability to keep the body in homeostasis is dysregulated whenever the body is not able to cope with the internal and the external stresses there is depressed HRV. Whenever there is a lower resistance to disease or recovery in proper time is not occurring then there is that means it is the HRV is depressed. So higher HRV and lower HRV means nothing but in case of higher HRV the person as I told you is physiologically less stressed that means there is good cardiac adaptability to stresses but in case of lower HRV the person is physiologically more stressed that means the his autonomic nervous system is very much tired to react to the challenges.

Now the terminology of HRV parameters as I told you there is the generation of the RR time series and optimization occurs after the R wave peak detections then we get n n interval sequence which give rise to time domain analysis, non-linear analysis and then we have the interpolation of the n n sequence interval sequence and we get the frequency domain analysis. Now later on the time domain analysis is further classified into statistical analysis and the geometrical analysis. Before moving on to the statistical analysis, geometric analysis are very much complex. Geometrical analysis they are usually obtained from the histogram plot of RR intervals when all the n n intervals or the RR intervals are plotted in a histogram from there we usually do the geometrical analysis like for example, of geometrical analysis is HRV triangular index. HRV triangular index was a very popular geometrical index which is done but the main important thing is to make sure all the n n intervals are plotted in the histogram the recording should be very long.

So, at least we need a like for example, 20 minutes recording minimum 20 minutes maximum can be 24 hour recording but minimum we need 20 minutes recording for this geometrical analysis. So, for this long term HRV can be done but short term for short term HRV which is 5 minute duration geometrical analysis are usually not done. So, for that we use the statistical analysis which are easy to apply and they are applied directly to the RR interval series. So, these methods are as I told you the statistical methods we have simple statistics as well as complex statistics. Now simple statistics like that means mean then we have the standard deviations of the RR intervals this statistics we say and the current geometric methods are inappropriate to evaluate short term recordings.

So, we will see what are the statistical methods the simple time domain measures we have mean RR interval mean heart rate minimum RR interval maximum RR interval and difference between the RR minimum RR interval and the maximum RR interval. Now these all are usually measured in terms of milliseconds. Now mean suppose the mean RR interval is 1000 milliseconds the mean heart rate will be suppose 60000 divided by 1000.

So, 60 beats per minute minimum RR interval say suppose 700 milliseconds maximum RR interval is 1200 milliseconds. So, the difference between these two RR minimum and RR maximum is 500 milliseconds in this way these are the simple time domain measures which uses usually simple calculations.

Then we have the complex time domain measures we have SDNN SDANN standard deviation NNN index RMSD NNN 50 and NNN 50 percentage. In this the very important are SDNN we have to remember RMSD and NNN 50 we usually concentrate on this three. So, SDNN that is the standard deviation of the RR intervals which reflects generally the overall autonomic nervous system activity that means includes both the sympathetic domain the parasympathetic domain the cyclical variations and the hormonal variations which are occurring. So, reflects all the cyclic components responsible for the variability in the period of recording the actual values of SDNN depend on the length of the recording the longer the recording the higher is the SDNN.

So, it depends on the length of the recording. So, longer recording gives rise to higher values of SDNN then SDANN that is A stands for average the standard deviation of the averages of NN intervals in all 5 minute segments of the entire recording which means this recording to get this index SDANN we need at least 5 minute recording or the recording should be more than equal to 5 minute. If the recording is less than 5 minute we would not be able to get this index then we have SDNN index mean of the standard deviations of all RR intervals for all 5 minute segments in the entire 24 hour recording. Then we have standard deviation of the successive RR interval differences then we have RM SSD that means root mean square of successive differences in RR intervals. This RM SSD this measures the high frequency variations mainly high frequency variations in heart rate and obviously, in the short term HRV this correlates with the vaguely mediated activity of the heart generally. Then we have NN 50 the number of successive differences between RR intervals greater than 50 milliseconds.

So, what are the number of successive differences between RR intervals which are greater than 50 milliseconds that will constitute NN 50. So, these are the time domain measures or the time domain analysis. Now, the frequency domain methods the most common power spectral estimation of HRV analysis is the frequency domain analysis or power spectral density analysis which is mainly dependent on the fast Fourier transform algorithm. Now, power spectral density estimates this estimation this provides the basic information of how the power of the signal is distributed as a function of frequency. How the power of the signal is distributed or distribute as a function of frequency and we get the wave generally after the interpolation RR interpolations the power spectral that is the frequency domain analysis which we get.

We get the decomposition of this RR series and with this decomposition of RR series is further this is it is this RR series is decomposed into various sine and cosine waves. And this sine and cosine waves are nothing but the various components and it quantifies the sympathetic as well as the parasympathetic domain or the influences on the heart. And as I told you fast Fourier transform algorithm is the basis of this frequency domain analysis or the power spectral density analysis. Now, this frequency domain measures this extracts this is mainly done on the fast Fourier transform algorithm or the autoregressive modeling. As you can see the wave pattern this is one wave pattern this is one wave pattern and this is one wave pattern.

So, and also this is another wave pattern. So, four wave patterns are we can see which means there is decomposition of single series into various sines and cosine waves. And this sines and cosine waves are actually they are having the frequency they are having the multiple frequency compared to that of the fundamental frequency. So, decomposition of a given signal into series of sine and cosine waves which are having frequencies that are multiples of the fundamental frequency because that is of the reciprocal of the time length of the input data record that why I want to do. So, this is one wave you can say this is wave a and wave b and this is wave c we get wave c and finally, it is decomposed into wave a and wave b. And in this way we get various parameters of frequency domain analysis and the frequency that these are the multiples of the fundamental frequencies.

So, frequency domain methods what we get we are the absolute measures we have total power T p this ranges between 0 to 0.4 hertz ultra low frequency this is the band below 0.003 hertz very low frequency this is the band which is 0.003 to 0.04 hertz low frequency and high frequency low frequency band ranges between 0.

04 to 0.15 hertz and high frequency band ranges from 0.15 hertz to 0.4 hertz. Now, each power each parameter or this frequency these are having significance the of cardiac autonomic control like for example, total power usually estimates the overall autonomic activity it is similar to that of the SDNN of time domain analysis. Then ultra low frequency is of not much use very low frequency is very used also reflect usually they reflect signals low frequency mainly contributes both sympathetic nervous system as well as parasympathetic nervous system. But predominantly sympathetic nervous system and high frequency band which is 0.

15 to 0.4 that is mainly because of the respiratory sinus arrhythmia and which is vaguely mediated that is the parasympathetic nervous system contribution is there. So, this is the absolute measures now this unit is measured in terms of hertz we also have normalized unit normalized unit that means, N u we have normalized unit. Now, normalized units

means the ratio of the absolute measure of a particular frequency to the total power. So, if I want to see check for the normalized unit of low frequency. So, L f divided by total power here total power includes total power and usually the very low frequency is excluded in this case.

So, this is the normalized unit of the percentage of power we can calculate we can check the parameter in normalized unit also or in case of hertz also anyway both are going to reflect the parasympathetic domain or sympathetic domain or total autonomic overall autonomic activity in the same fashion. Now non-linear methods of HRV these are now a days in popular demand it is based on the fractal analysis and chaos theory. So, these methods include Poincare plot we have detrended fluctuation analysis DFA we have Shannon entropy we have fractal dimensions. So, most commonly we will study Poincare plot analysis in non-linear methods for HRV analysis. So, this non-linear methods as I told you these are mainly based on the R R intervals all when all the R R intervals are plotted in two dimensions.

And based on the chaos theory and fractal analysis this non-linear methods for HRV analysis is done this all Shannon entropy fractal dimensions other entropies these are usually done with the help of convoluted neural networks support vector machines these are the entities of artificial intelligence. So, that is why non-linear analysis is mainly for the complexities. So, in this summary we could see the HRV tachogram this is the Poincare plot analysis which we will discuss later this is the power spectral analysis and this is the geometrical analysis from the histograms. So, these are the references Thank you.