PACEMAKER ESSENTIALS COURSE

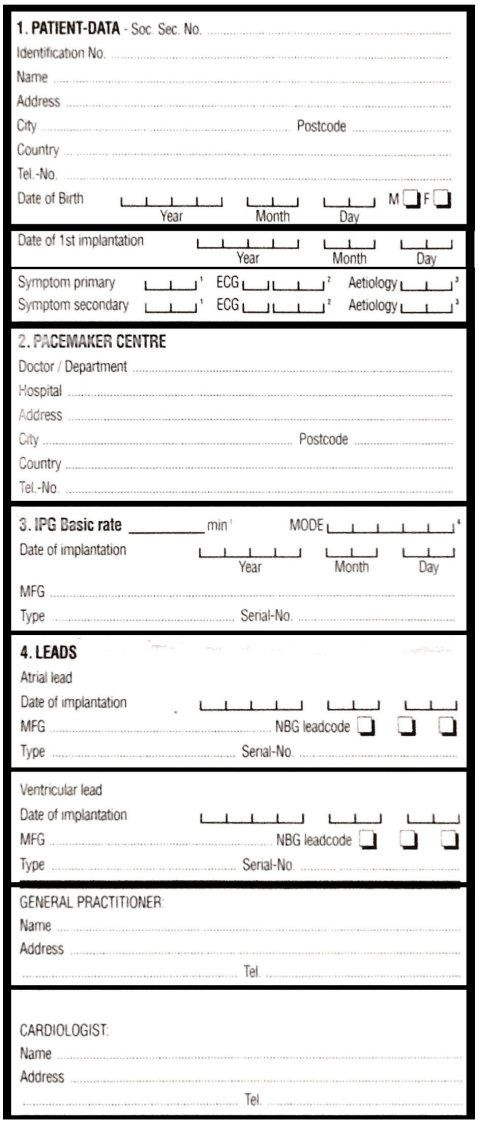
Hi, it's Kristian here. I've created this document myself to make the course a little more comprehensive if you find you've been left thirsting for more knowledge! The information here can add value at any point during the course but it will be best enjoyed after you have viewed the video lessons. It includes a breakdown of a pacemaker ID card, information about pacemaker timing cycles (in plain English) and a glossary of some terms that you may not be overly familiar with. At the very end, there are just a few more things, extra bits and bobs that I need to clarify before the course is complete.

ID Card Stripped Back

Many times when you meet a patient with a pacemaker, they can only provide you with their pacemaker identification card as an insight into their device. Although the information it contains is by no means comprehensive, it is a good starting point for developing a broader understanding of a patient's device and the disease process it was implanted to treat.

So I thought I would provide you with an example of a typical ID card, as many of you may not have seen one before, and point out the information it provides.

European Pacemaker Patient Identification Card



1. PATIENT-DATA - Soc. Sec. No. ....
Identification No. ....
Name ....
Address ....
City .... Postcode ....
Country ....
Tel.-No. ....
Date of Birth Year Month Day M F

Date of 1st implantation Year Month Day

Symptom primary ECG Aetiology
Symptom secondary ECG Aetiology

2. PACEMAKER CENTRE
Doctor / Department ....
Hospital ....
Address ....
City .... Postcode ....
Country ....
Tel.-No. ....

3. IPG Basic rate ________ min⁻¹ MODE
Date of implantation Year Month Day
MFG ....
Type .... Serial-No. ....

4. LEADS
Atrial lead
Date of implantation
MFG .... NBG leadcode
Type .... Serial-No. ....

Ventricular lead
Date of implantation
MFG .... NBG leadcode
Type .... Serial-No. ....

GENERAL PRACTITIONER
Name ....
Address ....
.... Tel. ....

CARDIOLOGIST
Name ....
Address ....
.... Tel. ....

← Patient Details
← Date of 1st Implantation
← Implantation Codes
← Implanting Dr / Centre Details
← Pacemaker Can Details and Initial Pacing Mode
← Atrial Lead Deatils
← Ventricular Lead Deatils
← General Practitioner Details
← Cardiologist Details

Naked Timing Cycles

AV INTERVAL = *Atrioventricular interval.*

Purpose = In place to synchronize the heart's atrial contraction and ventricular contraction, by increasing cardiac output through a more physiological heart beat.

The AV interval is broken down into either the PAV or the SAV, depending on whether the atrial event is paced or sensed.

PAV = *Paced AV delay.*

This is the length of time between an atrial output pulse (A pacing) and the pacemaker's delivery of the next paced ventricular output pulse (V pace).

SAV = *Sensed AV Delay.*

This is the length of time between an atrial sensed event (atrial depolarization) and the pacemaker's delivery of a paced ventricular output pulse (V pace).

How it works = The SAV and the PAV are programmable and are usually between 150-220 ms, but can be extended to much longer durations. They are in place to synchronize the heart's atrial and ventricular contractions.

A pacemaker starts the PAV as soon as it delivers an atrial output pulse. However, the SAV starts a little later (roughly half way through the P wave), as this is when the pacemaker senses an atrial depolarization. For this reason the PAV is normally a little longer than the SAV (20 ms or so) so that the PR interval on the ECG remains the same during both paced and sensed atrial events.

Adjustable? Yes, both the PAV and the SAV can be lengthened to discourage ventricular pacing. This works by delaying when the pacemaker paces the ventricles following an atrial event. This gives the heart longer for the electrical signal to pass through the AV node and trigger a natural ventricular depolarization, which would cause a VS (ventricular-sensed event), halting the AV interval and causing the pacemaker to inhibit ventricular pacing. Alternatively, if we want to pace (for instance in biventricular pacing), we can shorten the PAV and SAV to ensure that pacing occurs before intrinsic ventricular depolarization.

Further reading: The link between ventricular pacing atrial fibrillation/heart failure hospitalizations.

V-BLANKING = *Ventricular blanking.*

Purpose = To prevent crosstalk.

How it works = The very first part of the AV interval includes a V-blanking period. During the V-blanking period, the ventricular channel ignores any sensed events. This prevents the ventricular lead from sensing the atrial output pulse (which is more likely in a unipolar atrial output pulse) and interpreting it as a genuine ventricular depolarization. If it did sense the atrial output pulse as a ventricular event, it would inhibit pacing. This could happen on every cycle... Imagine if the patient was pacemaker-dependent—this could be catastrophic.

Adjustable? Yes, V-blanking can be lengthened if crosstalk is occurring. However this will increase the risk of genuine ventricular events that occur early on in the AV interval being ignored.

Further reading: Crosstalk sensing window and ventricular safety pacing.

PVARP = *Post-ventricular atrial refractory period.*

Purpose = To prevent pacemaker-mediated tachycardia.

How it works = The PVARP starts immediately after a paced or sensed ventricular event. During the PVARP any sensed atrial activity does not start an AV interval and therefore does not trigger subsequent ventricular pacing. This protects against a pacemaker-tachycardia.

Pacemaker-mediated tachycardias occur when the ventricular depolarization conducts backwards up through the AV node (retrograde conduction) triggering an atrial-sensed event. This retrograde P wave is sensed by the pacemaker starting the AV interval, resulting in a ventricular-paced event. This would could result in another retrograde P wave and the process would continue/repeat over and over. Ultimately without the PVARP retrograde, P waves could start a re-entrant tachycardia mediated by the pacemaker inappropriately increasing the patient's heart rate.

The atrial events during the PVARP are counted but not tracked. If they were not counted, an atrial tachycardia could potentially be ignored by the pacemaker and prevent appropriate automatic mode switching (where the pacemaker changes to a VVI/VDI mode during an atrial tachyarrhythmia to improve pacemaker function).

Adjustable? Yes, the PVARP can be lengthened to prevent pacemaker-mediated tachycardias occurring because of retrograde P waves that take longer to travel back up through the AV node and therefore fall outside the PVARP. This will restrict how much range you have on your upper pacing limit/max track rate. In other words, if you extend your PVARP, you may not be able to increase your upper pacing limit as high as you might like. Alternatively you can decrease your PVARP to allow for a higher upper pacing limit—maybe over 180 bpm!

Further reading: Automatic mode switch

PVAB = *Post-ventricular blanking period.*

The first short portion of the PVARP.

Purpose = To prevent inappropriate automatic mode switch and inaccurate atrial arrhythmia diagnostics. Functions by preventing the ventricular output pulse (which more likely in a unipolar ventricular output pulse) and far-field R-wave sensing in the atria. During the PVAB, any atrial events are ignored altogether; this prevents inaccurate diagnostics and inappropriate automatic mode switch events. Far-field R-wave sensing is where the ventricular depolarization is sensed on the atrial lead. Atrial leads are usually set up to be quite sensitive due to the smaller signal amplitudes generated in the atria. This makes them susceptible to detecting the “large” depolarizations of the ventricles. As this is so likely this period is totally blanked Far-field R-wave sensing could cause the atrial event counter to increase and potentially cause inappropriate automatic mode switching; this is more likely during a natural sinus tachycardia when a patient exerts him or herself.

Adjustable? Yes, lengthening the PVAB may help prevent inappropriate automatic mode switch if far-field R-wave sensing persists. On the downside, this may prevent appropriate automatic mode switch in the presence of a genuine atrial tachyarrhythmia. Shortening the PVAB would increase the device sensitivity to genuine atrial tachyarrhythmia but may lead to far-field R-wave sensing that was not previously a problem, and in turn increase the risk of inappropriate automatic mode switch.

Further reading: pre-VAB

LRL = *Lower rate limit the base rate timing cycle.*

When you program the pacemakers base rate, this is converted into beats per millisecond and this programs the LRL. For example, base rate 60 bpm = 1 beat every 1000 ms; so the LRL = 1000 ms.

Purpose = To set the minimum heart rate

How it works = After every sensed or paced ventricular depolarization, the LRL timing cycle begins. If 1000 ms passes and another ventricular depolarization has not occurred, the pacemaker will deliver an output pulse to trigger a ventricular depolarization. If a ventricular depolarization does occur during this period, the LRL timing cycle is reset.

Adjustable? = Yes, it can be increased by decreasing base rate, or decreased by increasing base rate.

Further reading: Hysteresis and search hysteresis

VA or AEI = *the ventricular atrial timing cycle*

—the interval from a ventricular paced or sensed event to an atrial paced event. Calculated by LRL: PAV = VA. If the LRL is 1000 ms and the PAV is 200 ms, then the VA interval will be 800 ms.

Purpose = Ensures that the PAV interval can be maintained during base rate pacing.

How it works = Consider a pacemaker set to 60 bpm with a PAV of 200 ms.

After a paced/sensed ventricular event, the LRL timing cycle begins to time out 1000 ms. If after 1000 ms the ventricles have not depolarized again, then the pacemaker will deliver a ventricular output pulse to make this happen.

When would the pacemaker have to pace the atria to allow for a PAV of 200 ms before the ventricles were paced? After 800 ms—this would mean that when the PAV completed (200 ms), the ventricles would be paced at exactly 1000 ms (60 bpm).

The VA interval is cancelled by a sensed atrial depolarization.

Adjustable? No. It is dictated by other programming settings (LRL and PAV).

Further reading: Sleep rate

VRP = *Ventricular refractory period*

Purpose = To prevent the pacemaker from pacing below the base rate.

How it works = The ventricular refractory period prevents the ventricular channel from sensing its paced ventricular event. This includes sensing its own output pulse, the evoked depolarization (QRS) and depolarization (T wave). The pacemaker starts the LRL timing cycle after any paced or sensed ventricular event; a sensed event will rest this timing cycle. Oversensing of evoked ventricular activity will cause this timing cycle to be reset inappropriately, which could lead to the pacemaker pacing slower than the programmed base rate. For example, in a pacemaker set to 60 bpm, the longest duration between genuine ventricular depolarization should be 1000 ms. However, without the ventricular refractory period, the pacemaker senses or paces the ventricle and the LRL timing cycle begins; after 300 ms the ventricular channel senses the evoked QRS and restarts the LRL (which will start to count to 1000 ms once more before pacing the ventricles). This means that the interval between genuine ventricular events is 1300 ms. This is the equivalent of 46 bpm—significantly slower than the programmed base rate. Ventricular events that occur in the refractory period are still counted for diagnostic purposes, making the device more sensitive to detecting genuine tachycardias.

Adjustable? Yes, the VRP can be lengthened to prevent sensed T waves from resetting the LRL timing cycle, which occurs if they fall outside of the VRP. This is an option if changing the pacemaker's ventricular sensitivity causes it to struggle to prevent T-wave oversensing (remember, we don't really want to see T waves at all). Though T waves sensed in the VRP will still be counted as additional ventricular events for diagnostic purposes.

Further reading: T wave oversensing

PVVB = *Post-ventricular ventricular blanking*

Purpose = Improve device diagnostics

How it Works = The first part of the VRP is completely blanked and protects against counting of the output pulse and evoked QRS. These events are both large in amplitude on the electrogram and therefore impossible to filter out by decreasing ventricular lead sensitivity (unlike T waves, which are often much smaller). Adjusting ventricular sensitivity will not prevent them from being counted as additional ventricular events; they have to be totally blanked or diagnostics will be heavily affected. The entire VRP is not totally blanked to allow the device to record genuine arrhythmias, for example VT.

Adjustable? Yes, PVVB can be lengthened if it is not long enough in duration to "mask" the evoked QRS. This can sometimes occur if the tissue being paced (activation site) is a little too sluggish to depolarize or "pass on" the signal to its neighbouring cells; the evoked QRS can come a little after the initial output pulse and fall outside the PVVB. Lengthening the PVVB can make your pacemaker less sensitive to genuine arrhythmias.

Further reading: Pacemaker latency

URL = *Upper Rate Limit*

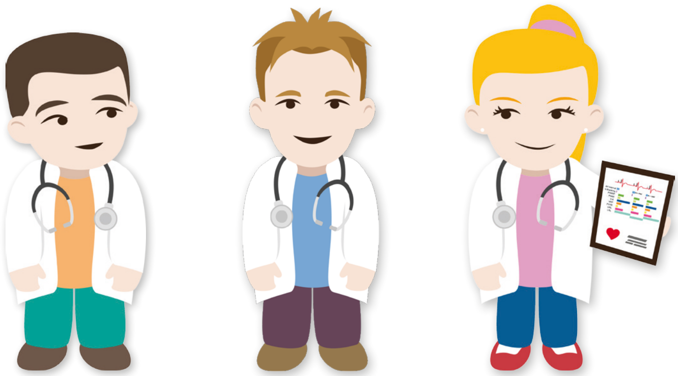
(sometimes referred to as MTR = max track rate or VTL = ventricular tracking rate)

Purpose = The upper rate limit allows us some control over the maximum paced ventricular heart rate. In a patient with heart block, we have the unique opportunity to limit heart rates during an atrial arrhythmia through pacemaker programming. The upper rate limit is one algorithm that provides us with this luxury. If the upper rate limit is programmed to 120 bpm; this is the fastest the pacemaker will ever pace the ventricles. Any atrial rate of up to 120 bpm will be tracked by the pacemaker and trigger a contraction (a 1:1 relationship). If the atrial rate increases, lets say to 130 bpm, the pacemaker would not track every atrial contraction and the paced ventricular rate would never exceed 120 bpm.

How it works = It works by initiating a "no-pace zone" in the ventricles after each sensed or paced event. If the upper rate limit on the pacemaker is 120 bpm, this equates to a maximum of one ventricular depolarization every 500 ms. After a ventricular event, the pacemaker starts the timer and will never pace the ventricles again until 500 ms have passed. Even if a sensed atrial depolarization has occurred, the AV delay has timed out and the pacemaker is due to pace the ventricles; it will wait until 500 ms has passed before delivering the pacing stimulus. When the atrial rate exceeds the upper rate limit, upper rate behaviour will occur.

Adjustable? Yes. You can increase or decrease the upper rate limit. The out-of-the-box setting tends to be around 130 bpm, which is obviously of little use to an active 30 year old. In that case, you could increase the upper rate limit to approximately 170 bpm to allow naturally occurring sinus tachycardias (during exercise) to be tracked to the ventricles. Unfortunately, AV delays, PVARPs and some of the other necessary timing cycles will define a limit on the upper rate limit. This makes pacing in 2nd and 3rd degree heart block more of a challenge in very young patients or competitive athletes, both of whom can have very fast but physiological sinus tachycardias.

Further reading: Upper rate behaviour.



Glossary of *Some* Terms

Asynchronous pacing: This is where a pacemaker is set up to pace at set intervals regardless of any intrinsic activity. For example VOO, an asynchronous pacing mode, set to 60 bpm will delivery an output pulse every 1 second regardless of anything the heart is doing–*pacing is not inhibited.*

Bipolar pacing / sensing: A pacemaker configuration that uses two electrodes on the lead. These are the lead tip electrode and the lead ring electrode.

Capture: When the output pulse is successful in causing the tissue to depolarize. In direct contrast to failure to capture, where the output pulse is unsuccessful in triggering depolarization.

Channel: The lead and computer wizardry within the pacemaker that is dedicated to a particular chamber of the heart (e.g. the atrial channel refers to the atrial lead, sensing and pacing).

Excitable: Tissue that is ready to depolarize given the right conditions. Analogy: an un-flushed toilet that is in a position to flush. Opposite to *refractory.*

Fused: Describes a QRS that is a combined result of pacing and intrinsic activation. This occurs if the pacemaker delivers a pacing output pulse at around the same time that the intrinsic electrical activity passes through the AV node and reaches the ventricles.

Intrinsic beat / complex / P wave QRS: An electrical event initiated by the heart's natural conduction system. In direct contrast to a *paced beat / complex / P wave QRS.*

Inhibited / pacemaker inhibition: Where the pacemaker refrains from pacing if it senses intrinsic activity.

Output pulse: The electrical energy delivered by the pacemaker to pace the heart.

Oversensing: When a pacemaker channel senses something other than what it is meant to. In the ventricular channel this could be any of the following: T waves, atrial output pulses or electrical artefact.

Paced beat / complex / P wave QRS: An electrical event initiated by the pacemaker's output pulse. In direct contrast to an *intrinsic beat / complex / P wave QRS.*

Refractory: Tissue that cannot be activated under any condition. Analogy: a flushed toilet that cannot be flushed again until it has been refilled. Opposite to *excitable*.

Settings: How a pacemaker is programmed.

Stimulus: Another word for the output pulse.

Unipolar pacing / sensing: A pacemaker configuration that uses one electrode as a lead and the pacemaker can as the other.

Zoo: Where animals are kept.

i's dotted and t's crossed.

Please be mindful that many of these rules do not apply to implantable cardioverter defibrillators (ICD's). While ICDs do have bradycardia capabilities for which the information presented in many of these lessons will hold true, the additional tachycardia therapies work in an entirely new way.

Lessons that focus on specialist algorithms explain the concept only to the extent of pointing out that the algorithms of various manufacturers are all slightly different in their exact working criteria.

For continuity we have used the term biventricular pacemaker to describe a pacemaker that has a minimum of a right ventricular and left ventricular lead that are being used to resynchronize ventricular contractions to alleviate heart failure symptoms. These are also commonly referred to as cardiac resynchronization therapy pacemakers (CRT-Ps).

Finally, the goal of this course is to teach the main concepts of pacemaker therapy and as a result, not all of the algorithms or timing cycles currently in use are covered in this series of lessons. I have referred to the *max track rate* as the *upper rate limit timing cycle* to help avoid confusion during the video lessons and to maintain consistency with terminology used to explain the lower rate limit timing cycle when discussing base rate. Please be mindful that *upper rate limit* is often called *max track rate* and that these terms are interchangeable.

Thank you and happy pacing!
Kristian