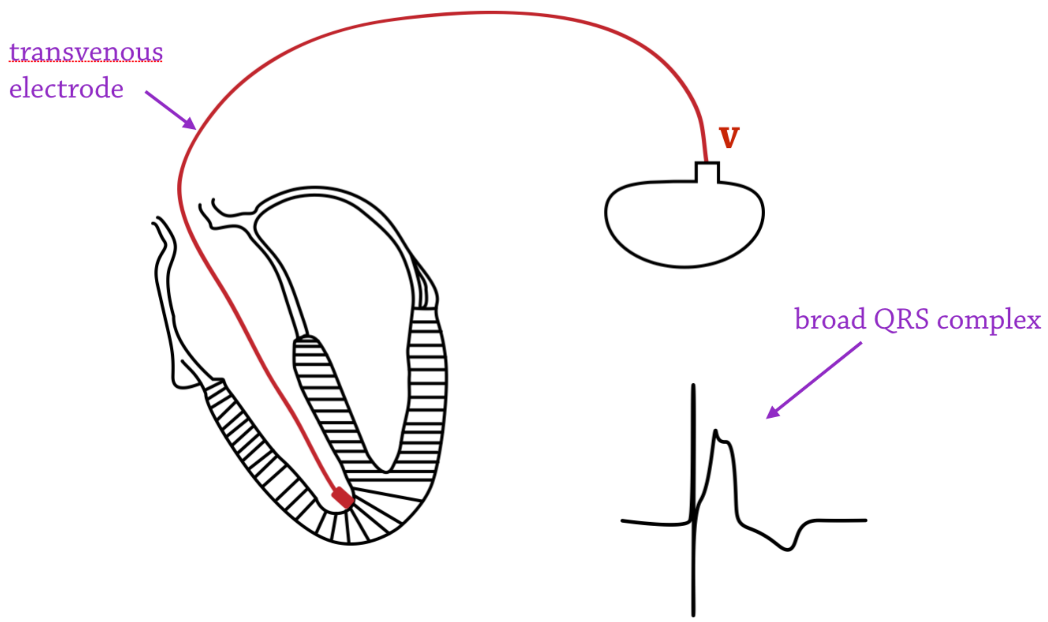
Level 10: Artificial Pacemakers

In Level 1 we learned about the characteristics of the pacemaker ECG: the vertical straight lines produced by the pacing stimulus. However, besides merely identifying a tracing as a pacemaker ECG, the doctor reading the curve should also be able to get more information out of it. This short history on pacemaker developments will teach you all you need to know.

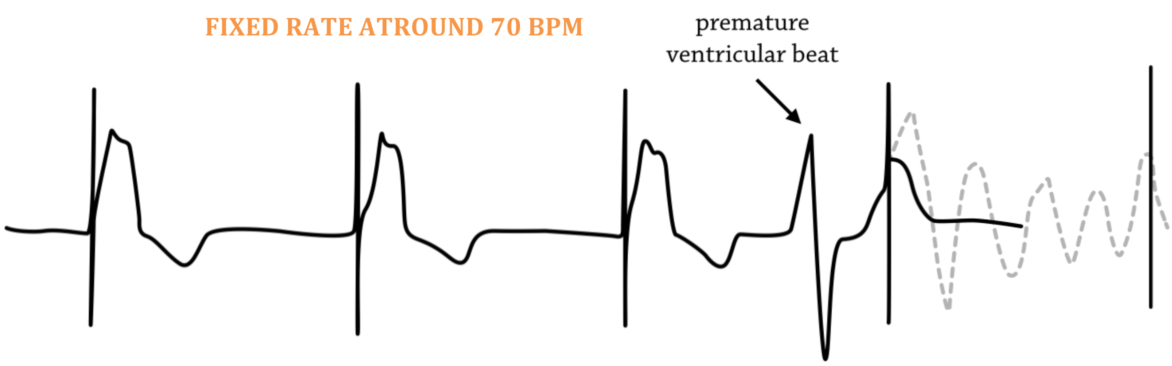
Fixed-rate pacemakers – a potentially life-threatening technology

First we'll look at the basic technology. Let's start with single-chamber pacemakers:



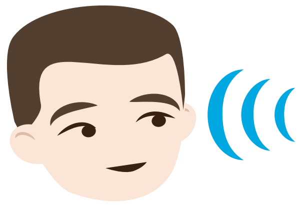
The pacing impulse is delivered by a transvenous electrode to the right side of the interventricular septum at the apex of the right ventricle. In these single chamber pacemakers there is only one electrode being connected to one cardiac chamber. In most instances this will be the ventricle, because the usual indication for a pacemaker is complete AV block. The resulting QRS complex in these pacemakers looks very similar to LBBB, because just as in LBBB, the entire ventricle is stimulated by impulses coming from the right side of the heart.

In the very early days of pacemaker therapy the pacemaker unit delivered pacing impulses at a fixed rate—e.g., 70 beats per minute:



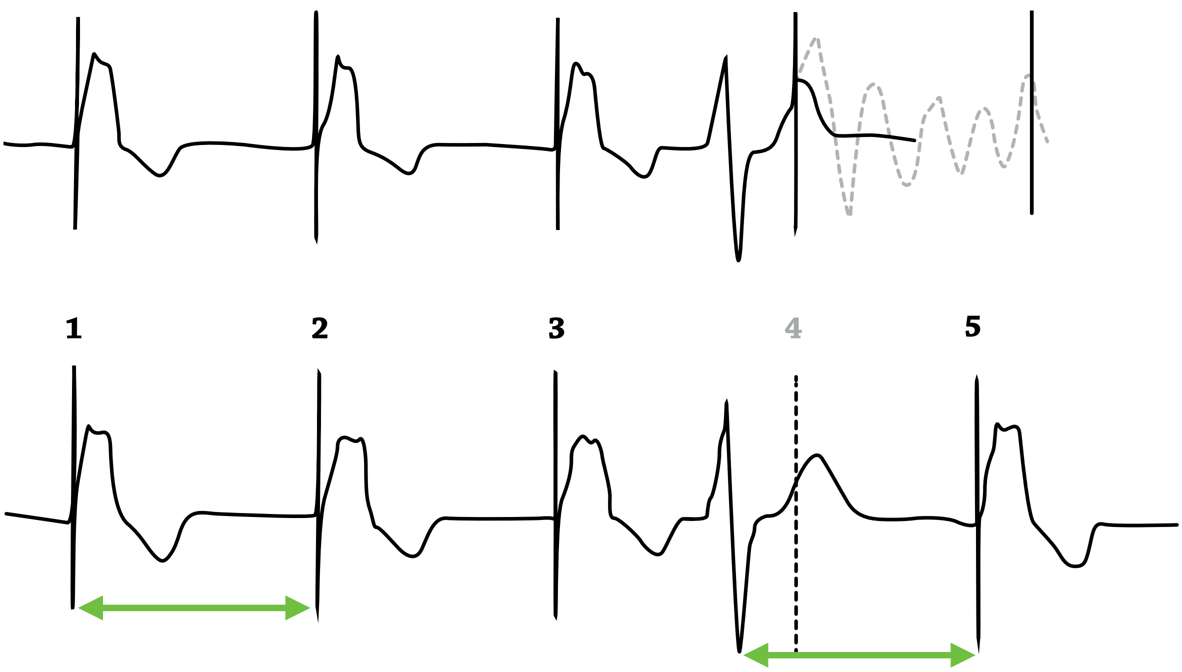
These types of pacemakers also delivered an impulse when by chance a ventricular premature beat (VPB) occurred after such a paced QRS. The pacing impulse therefore could eventually enter the heart just on the tip of the T wave (of the VPB). And we know that electrical stimulation towards the end of the refractory period (that is, on or after the tip of a T wave) can trigger ventricular fibrillation with cardiac arrest and eventually death. This was sometimes observed with these **fixed rate pacemakers**, so they **had to be taken off the market**.

Sensing solves the problem



The solution to this problem was as follows: the ventricular electrode was not only used to send an impulse into the heart (**pacing**), but also to record the electrical activity within the heart (the **sensing property of a pacemaker**).

This enabled the pacemaker unit to sense the VPB and to set the electronic "clock" responsible for the pacing interval to zero in the moment the VPB was detected. Therefore, the pacing interval started again right at this very moment.



Here pacemaker impulse number 4 was **inhibited** due to the sensing capacity of the pacemaker. Instead, pacemaker impulse number 5 was fired at a **preset pacing interval** after the VPB

Hence this type of pacemaker delivered impulses only if no spontaneous QRS occurred during a preset pacing interval, so pacing occurred only when necessary (**demand pacemaker**).

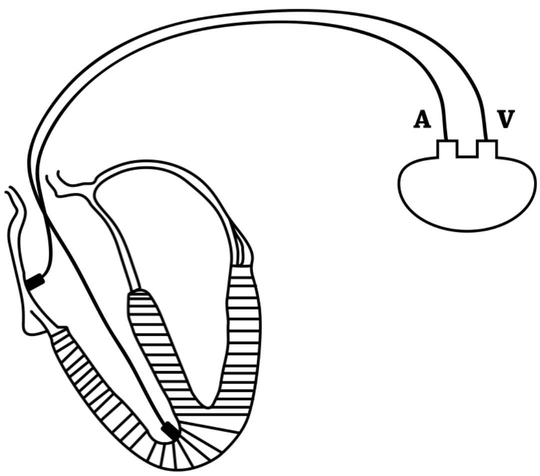
This type of pacemaker was not life-threatening, but it had the disadvantage that the pacing rate could not fall below and could not increase above a predetermined rate. The patient's heart, therefore, kept beating at, for example, 70 beats per min when he was climbing four flights of stairs or when he was sound asleep at midnight.

The introduction of rate-responsiveness

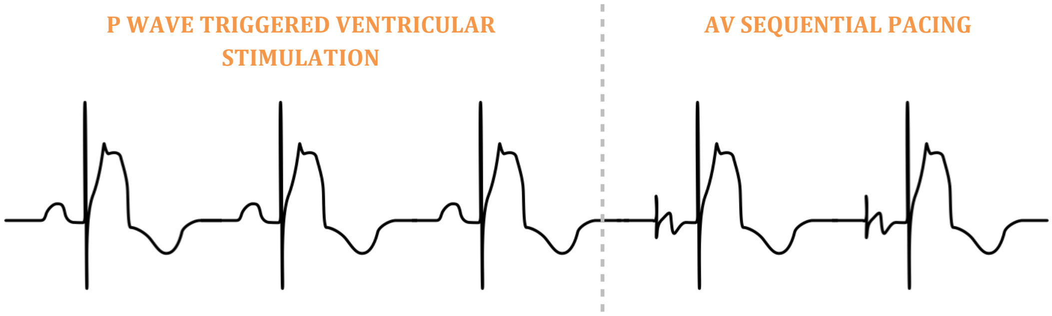
There were several attempts to solve this problem and to adapt the pacing rate to the needs of the organism. One was to integrate a Piezo element into the pacemaker unit. This element is very sensitive to movements; it changes its electrical charge with the level of vibrations, and can thus modify the pacing rate. A calibration method allows the pacemaker to pace at a low rate when the patient is quiet (sitting or sleeping) and to pace at higher rates when the patient is walking or running (and thereby shaking his pacemaker unit).

Even better: sensing atrial activity (i.e., physiologic P wave–triggered pacing)

One other method to provide "physiological" pacing is shown here:



There are two electrodes, one for the atrium and one for the ventricle. The atrial electrode (A) "senses" the electrical activity within the atria (i.e., the P wave) and sends this information to the pacemaker unit. The pacemaker then waits a couple of milliseconds to account for a physiologic PR interval before it stimulates the ventricles via the ventricular electrode (V). The ventricles, therefore, follow the rate of the patient's own P waves (i.e., the patient's sinus node activity), but the PR interval "happens" outside the heart in the pacemaker unit. This type of pacing is called **physiological pacing** or **P wave triggered ventricular stimulation**.



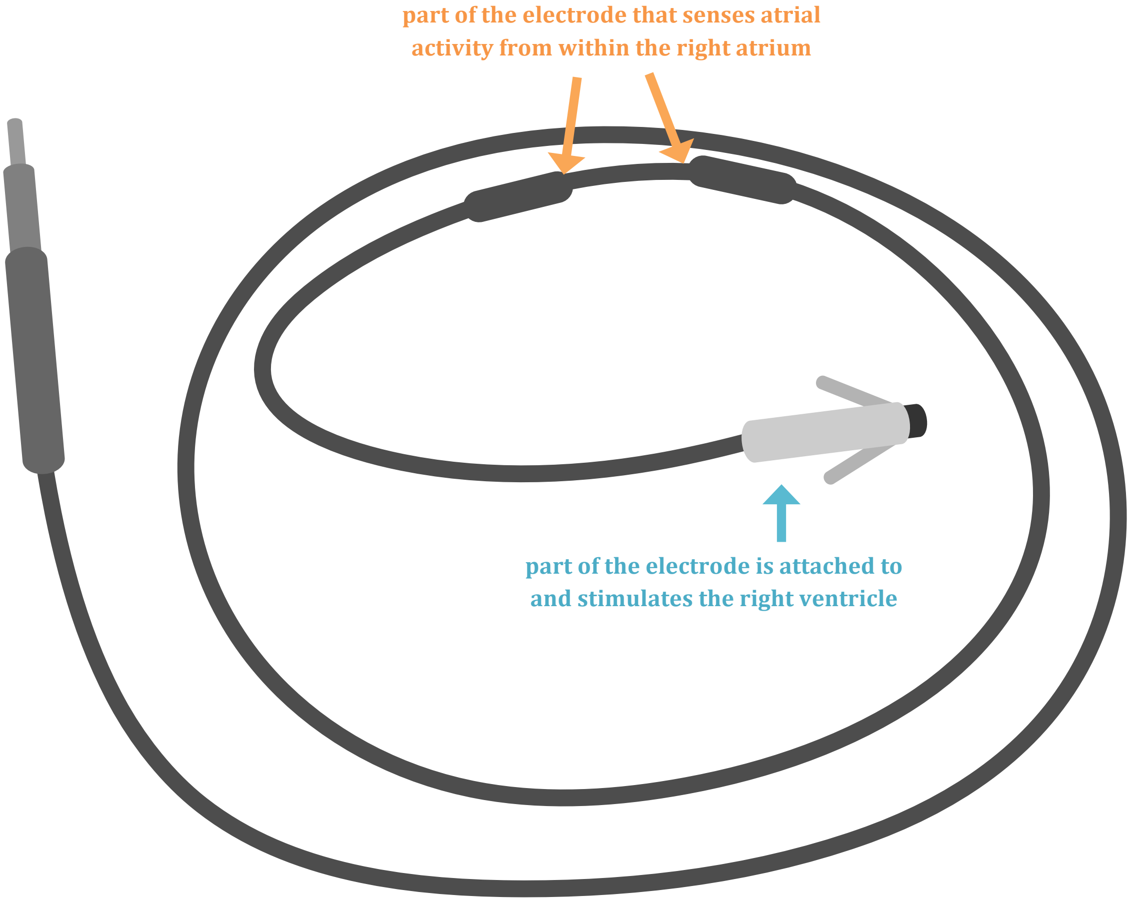
Killing two birds with one stone: the atrial lead makes atrial pacing possible

The introduction of the atrial lead was a huge innovation for two reasons. First, it enabled sensing and transmission of atrial activity to the ventricles, as we have learned above. And secondly, it was able to stimulate the atria in patients where the sinus node was not functioning properly.

When the pacemaker stimulates the atria and then the ventricles, we find tiny vertical impulses followed by P waves, and with a certain delay taller impulses followed by widened QRS complexes, the unit now paces the atria and the ventricles in a sequential manner. This type of pacing is called **A-V-sequential pacing**.

An alternative method to deliver P wave triggered pacing

If we don't need atrial pacing but want to get P wave triggered ventricular stimulation anyway, we can use another technical trick. We can implant only one electrode into the ventricle, but the part of this electrode that's passing the right atrium will contain a large sensor on its surface that is able to record P waves even though there is no direct contact to the atrial myocardial wall:



The pacemaker code

This short pacemaker history now ends with the so called **pacemaker code,** giving us information about the type of pacemaker implanted in an individual patient.

The code consists of four digits:

Digit #1: The cardiac chamber to which pacing impulses are delivered (e.g., A= atrium; V = ventricle; D = dual, atrium and ventricle)

Digit #2: The chamber from which impulses are recorded/sensed (e.g., A= atrium; V = ventricle; D = dual , atrium and ventricle)

Digit #3: The consequence of the sensed information (I = inhibition of a pacing impulse; T = triggering of a pacing impulse; D = dual, inhibition and triggering)

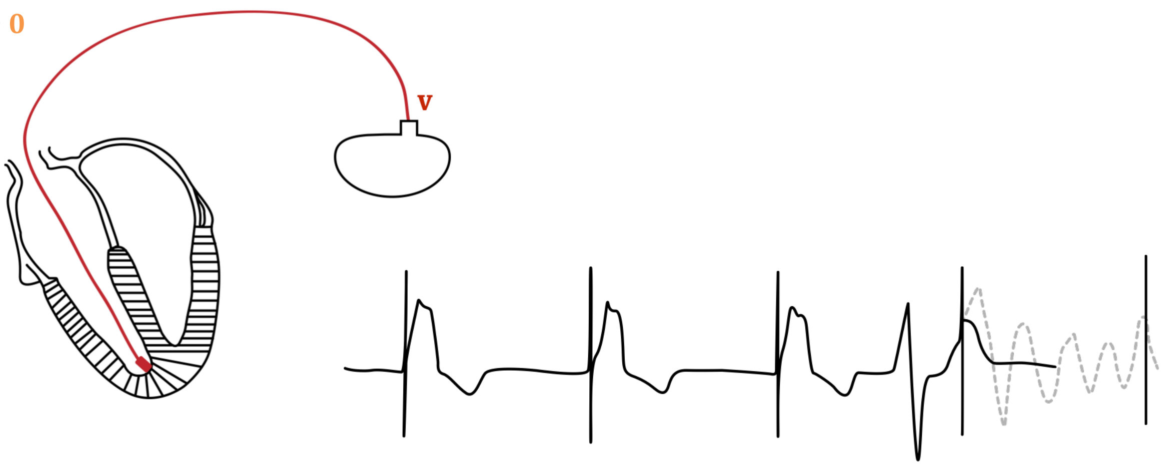
Digit #4: Rate responsiveness function (R = rate responsive), e.g. Piezo element

stimulating chamber	# 1	V	V	V	D	A
sensed chamber	# 2	0	V	D	D	A
consequences of sensing	# 3	0	i	D	D	I
rate responsiveness	# 4		(R)	(R)		

In my opinion, #3 is the least important for you to understand.

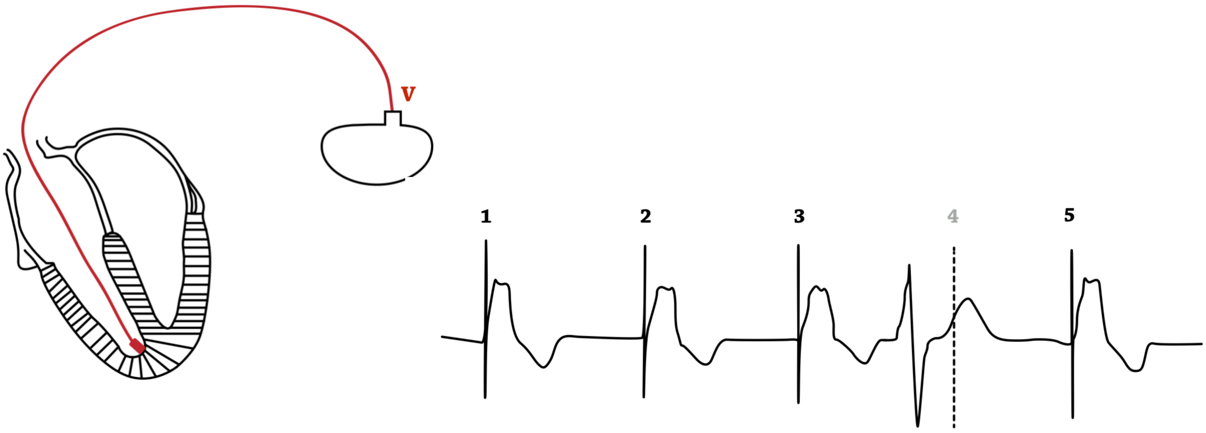
Here are a few examples:

V 0 0



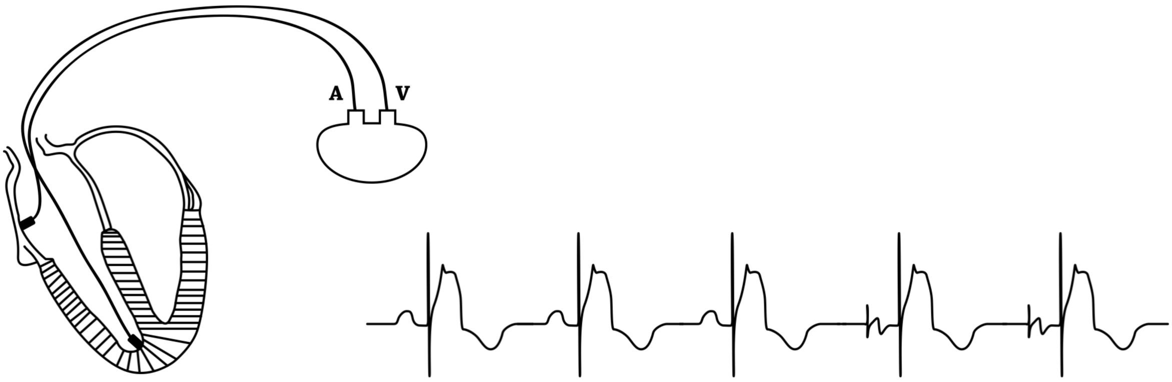
This type of pacemaker only has one electrode located in the right ventricle. It can only pace the ventricles but has no sensing properties (so digit #2 = 0). Since there is no sensing, nothing can happen after sensing (so digit #3 is also 0). This is a fixed rate pacemaker, which could trigger ventricular tachycardias and eventually death. So it has been taken off the market.

V V I



This pacemaker also only has one electrode, which is located in the ventricles. This electrode paces the right ventricle (digit #1 = V) and also senses in the ventricle (digit #2 = V). When it senses a premature beat (or any kind of ventricular depolarization) it inhibits the next planned impulse (digit #3 = I). So opposed to the V00 pacemaker, this type of pacemaker is not life-threatening. The VVI can be equipped with a rate-responsiveness function (VVI-R).

D D D

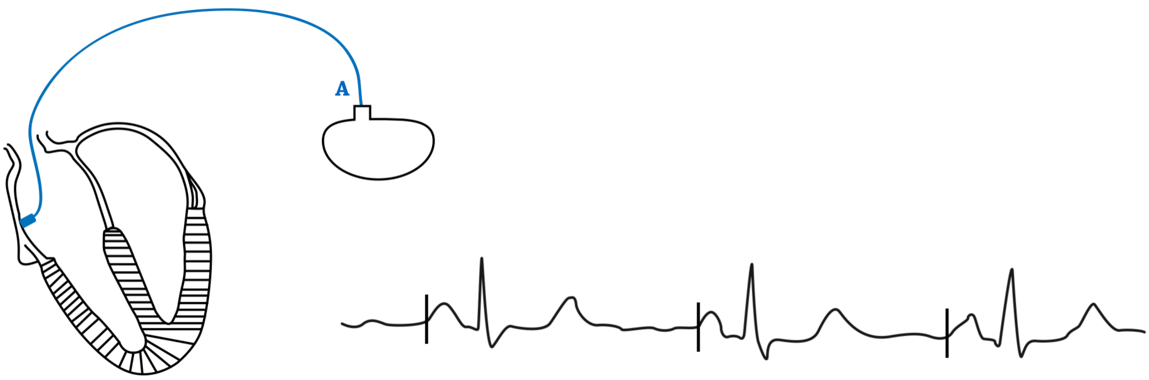


This is a dual chamber pacemaker with one electrode in the right atrium and another one in the right ventricle. This pacemaker paces both chambers (digit #1 = D) and also senses in both chambers (digit #2 = D). When a normal or premature impulse is sensed, the pacemaker inhibits the next planned pacemaker impulse and when the pacemaker doesn’t sense any activity within a certain period, it can also trigger another pacemaker impulse (digit #3 = D). This pacemaker can also be equipped with a rate-responsiveness feature (DDD-R).

VDD

The VDD pacemaker only has one electrode, which paces the ventricle (digit #1 = V) but senses both the atrium and the ventricle (digit #2 = D). When a premature beat occurs, it can inhibit the next planned impulse, and when no beat occurs, it can trigger an impulse (digit #3 = D). The VDD can be equipped with a rate-responsiveness feature (VDD-R).

AAI



The AAI has one electrode, which is located in the right atrium (digit #1 = A), where it senses and paces the atrium (digit #2 = A). When it senses a sinus beat (or any other impulse in the atria) it inhibits the next planned impulse (digit #3 = I). The AAI is implanted in patients with sinus node dysfunction with normal AV nodal function. It is only rarely used. The AAI can also be equipped with a rate-responsiveness feature (AAI-R).