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SOME CLINICAL ASPECTS OF PAIRED STIMULATION OF THE HEART

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Not very long ago use of electrical currents for clinical purposes was considered—to say the least—an unusual and not very attractive idea. This view has changed rapidly in the last few years. The results of driving the heart with repetitive electrical stimuli during Adams-Stokes attacks or for the suppression of ectopic centres responsible for ventricular tachycardia, are gratifying. Fig. 1 demonstrates the effect of artificial single stimulation on a very active ventricular focus in a patient with coronary heart disease.

Electric shocks across the heart or thorax are generally accepted in the treatment of ventricular fibrillation and atrial and ventricular tachycardia. This development helped to convince the clinician that electricity is something less than dangerous. In these conditions, electricity, applied either as one massive discharge or as repetitive single driving stimuli, has been used because of an inadequate cardiac output from a heart beating either too slow or too fast. Under these circumstances, an increase in cardiac output and improvement of myocardial contractility are primarily a consequence of the return to normal of the heart rate.

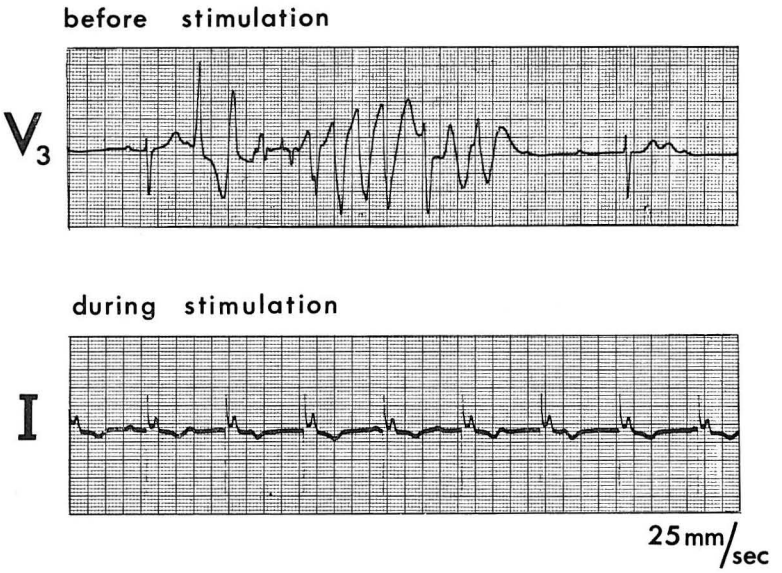

Fig. 1. Parts of the electrocardiogram of a patient with runs of ventricular premature beats before and during artificial single stimulation.

Paired stimulation has a profound direct effect on the heart muscle, by increasing myocardial contractility immediately, often in a dramatic way, under circumstances in which cardiac output is already normal. Investigation of the clinical applications of paired stimu-

lation can be done only by an investigator experienced in the electrophysiological aspects of stimulation of the myocardium in animal experiments.

The use of this method entails many risks. Some of these are caused by properties of the normal or abnormal myocardium, others by the shortcomings of the apparatus, its operators, or both. The risks may give rise, acting singly or in combination, to dangerous and fatal disorders of the heart action. Therefore elaborate precautions have to be taken against failures of the apparatus and the operator. It is essential to review some basic electrophysiological principles of electrical stimulation of heart muscle. Immediately after the absolute refractory period a small interval occurs in which the receptivity of the heart to electrical stimulation may be high, as evidenced by the occurrence of multiple premature beats or even ventricular fibrillation after a single shock delivered in this period: this is called the vulnerable period (Hoffman and Cranefield,1960). For the ventricles, this coincides approximately with the later part of the ascending limb or top of the T wave, and for the atrial muscle with the later part of the PTa segment. It can be demonstrated in normal myocardium if currents of high intensity are applied; however, these currents are not used clinically. In abnormal hearts, e.g. acute myocardial infarction, a vulnerable period may be present for much lower current intensities, such as those delivered by a normal pacemaker. In a patient with acute infarction and atrioventricular block receiving single stimulation by an intracardiac electrode, a run of premature beats was shown to occur when the stimulus was applied during the vulnerable period (Fig. 2). In a large number of experiments on the dog heart this vulnerable period for the ventricles was not found for currents with a duration of 1 msec and a strength below 10 times the diastolic threshold.

Because of the available evidence supporting the theory that the properties of the human myocardium are not much different from those of the canine heart (Durrer, Van Dam

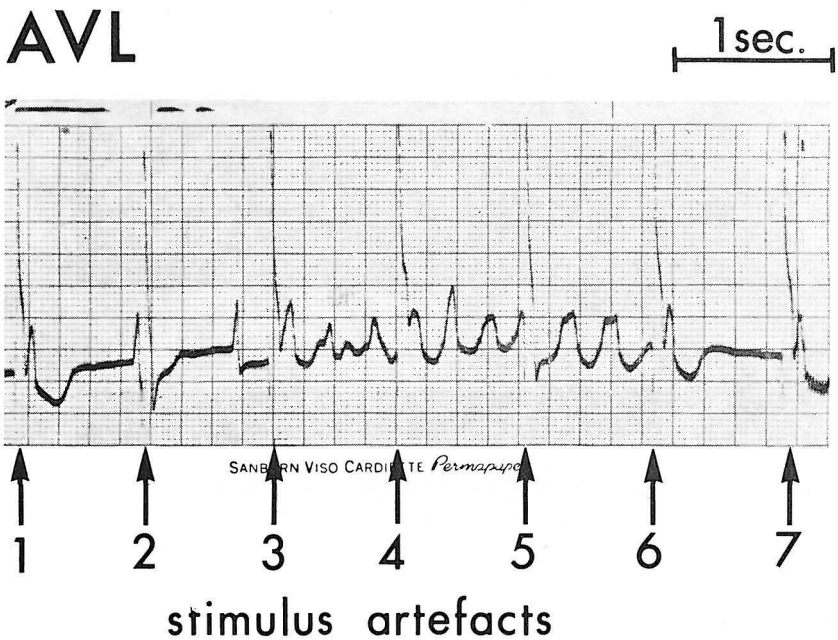

Fig. 2. Part of the electrocardiogram of a patient with an acute myocardial infarction and periods of total atrioventricular block. Artificial single stimulation was produced by means of an intracardiac electrode. The arrows indicate the stimulus artefacts: stimulus No. 3 occurs during the vulnerable period on the ascending limb of the T wave of a spontaneously occurring QRS complex. This stimulus gives rise to a short run of ventricular tachycardia, which is terminated by an artificial stimulus (No. 6). This record illustrates both the hazards and benefits of artificial stimulation.

Meijler, Arzbaecher, Müller and Freud, 1966), it is safe to apply currents with a strength of twice the diastolic threshold for a duration of 2 msec. Paired stimulation may be applied either to the atria or to the ventricles with varying consequences for the circulation.

Paired stimulation of the atria

Paired stimulation of the atria in a patient with normal atrioventricular conduction can result in an immediate slowing of the mechanical heart rate (Fig. 3). The atria are stimulated directly by currents applied via the intra-atrial electrode. Every first artificially induced atrial beat of the pair of stimuli is conducted normally to the ventricles. The second prema-

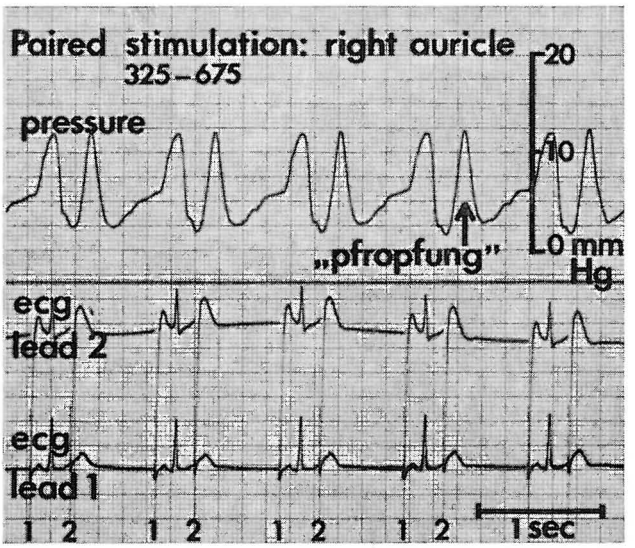

Fig. 3. Paired stimulation of the right auricle to reduce ventricular rate. The second lead (2) auricular activation falls in the refractory period of the preceding QRS complex. The mechanical effect of the second contraction is illustrated in the top tracing ("Pfropfung").

ture beat falls so early that it is blocked at the atrioventricular node. The refractory period of the atrioventricular node is longer than that of the atrial muscle. Therefore an incomplete atrioventricular dissociation is present, with capture of the ventricles by every first atrial beat and blocking of conduction to the ventricles by every second atrial beat. The frequency of the ventricles may be diminished in this way to 60/minute.

Slowing of the mechanical beats does not reduce the cardiac output, which remains constant within a wide range of frequencies; therefore the stroke volume varies inversely with the heart rate. Slowing of the heart rate by the application of paired stimuli of the atria may be used in the treatment of atrial tachycardia. Prolongation of the refractory period of the atrial muscle makes it difficult for the ectopic centre to act as a pacemaker of the atria.

The presence of a vulnerable period of atrial muscle may cause auricular tachycardia and fibrillation after paired stimulation, but this situation has not been encountered so far. A safe interval between the first and second impulse of each pair in most instances will probably be 280 msec or longer. Even in a steady state situation of paired stimulation of the atria, capture of the atria by the sinus node can take place. This is sometimes seen almost at once, after a few paired stimulation beats, probably because changes in the refractory

period in atrial and ventricular muscle occur for a large part on a beat-to-beat basis, i.e. after one beat. Reduction in rate of the ventricles by paired stimulation of the atria will probably decrease oxygen consumption of the heart per minute (Meijler and Durrer, 1965). In a failing heart with rapid rate in which the coronary flow is the limiting factor, this rate reduction could result in a longer diastolic coronary perfusion and improvement of myocardial function, but there is still no evidence to support this theory in the human heart.

Paired stimulation of the ventricles

In paired stimulation of the ventricles, the electrical stimuli are delivered directly to the ventricles. Slowing of the ventricular rate in therapy-resistant ventricular tachycardia may be achieved in this way. The commencement of paired stimulation in a patient may be the cause of disturbances of ventricular rhythm; or of spontaneous ventricular premature beats (Fig. 4). One spontaneous ventricular premature beat, disturbing the absolute fixed

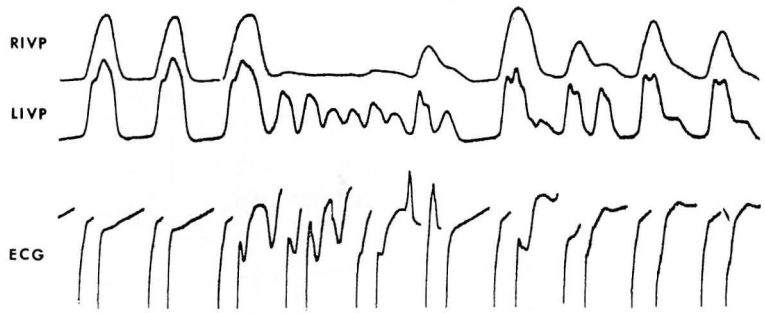

Fig. 4. A run of ventricular premature beats during paired stimulation of the ventricles. The deleterious effect of this short period of ventricular tachycardia on the circulation is shown by the pressure tracings from the right (RIVP) and left (LIVP) ventricles.

pattern of heart action during paired stimulation, gave rise to multiple ventricular premature beats, with immediate but unfavourable consequences for the circulation. The great improvement of acute low output circulatory failure in physiological experiments (Meijler and Durrer, 1965; Lopez and Petkovich, 1965) by paired stimulation has necessitated study of the influence of this procedure on post-bypass circulatory failure.

In 5 patients this method was used only in the terminal phase after all other therapeutic measures had failed. No improvement was seen in any of these patients. In one, operated on for mitral valve replacement, ventricular tachycardia occurred 60 seconds after the beginning of paired stimulation. The cardiac output probably did not increase but the paired stimulation may have caused coronary insufficiency, because the larger oxygen demand caused by paired stimulation was not met by a larger coronary flow. A low output of the heart is also present in shock due to myocardial infarction.

After thorough consideration of all aspects, it was thought acceptable to use paired stimulation in those cases of cardiac shock in which all other therapeutic measures had been without effect. In a patient with cardiac shock caused by myocardial infarction, paired stimulation was used as a last resort. Only a slight and temporary effect was noted. Shortly after the beginning of paired stimulation, a fatal attack of ventricular tachycardia occurred, arising probably in a focus near the infarcted area. The large oxygen demand (Meijler and Durrer, 1965) caused by paired stimulation may be the reason for the occurrence of this ectopic centre in this patient.

If the coronary blood flow to a portion of the heart muscle becomes insufficient during paired stimulation, an immediate threshold rise for electrical stimuli occurs, which is probably not the same for all parts of the ischaemic area of the myocardium. Thus several conditions are present which alone or in combination may be the cause of dangerous ectopic rhythms or even ventricular fibrillation.

Paired stimulation was also used in a patient with cardiac insufficiency due to rheumatic heart disease, who was not responding to treatment. For 12 days paired stimulation of the ventricles was applied continuously, but no improvement in the cardiac condition occurred (Meijler and Durrer, 1965). Paired stimulation has also been used for diagnostic purposes during cardiac catheterization, namely, reduction of the heart rate and potentiation of the beats.

In phonocardiographic studies it was found that, in a patient with a mitral insufficiency with a late systolic murmur probably due to papillary muscle dysfunction, paired stimulation resulted in a decreased intensity of the murmur. It is assumed that in this patient the potentiation of contraction caused by paired stimulation resulted in an increased strength of contraction of the papillary muscle, sufficient to diminish the reflux across the mitral valve (Meijler and Durrer, 1965).

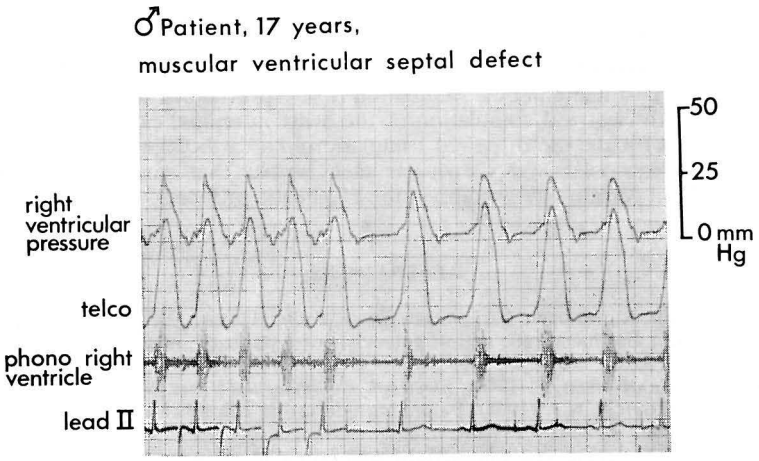

Fig. 5. Right ventricular pressure records and intraventricular phonocardiogram made during a sudden decrease of the heart rate in a patient with a muscular ventricular septal defect. The first contraction of the slower rhythm has been potentiated, diminishing the duration of the murmur.

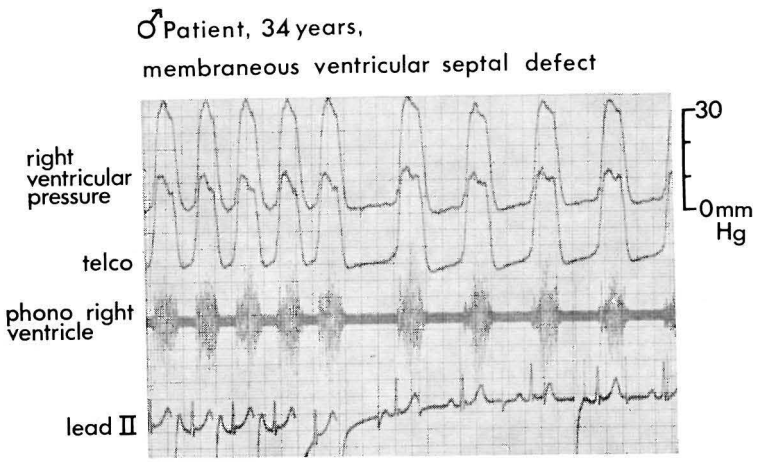

Fig. 6. Right ventricular pressure records and intraventricular phonocardiogram made during a sudden decrease of the heart rate in a patient with a membranous ventricular septal defect. The first contraction of the slower rhythm has been potentiated, increasing the intensity and duration of the murmur.

Potentiation of the beats in a patient with a muscular ventricular septal defect results in a decreased intensity and duration of the murmur, because the potentiation forces the defect to close earlier during systole. Potentiation can also be originated by a period of a high stimulation rate (Meijler, 1962). In Fig. 5 it can be seen that the first beat after the high stimulation rate period is potentiated and the shape of the murmur is changed. When the same procedure is repeated in a patient with the defect in the membranous part of the ventricular septum, the murmur during the potentiated beats increases in intensity and duration (Fig. 6).

It is thus demonstrated that a knowledge of the potentiation of cardiac muscle, of which the use of paired stimulation is a consequence, can lead to a better diagnosis. It is clear that at present paired stimulation does not have any place outside a specialized cardiological department. Investigation of paired stimulation as a clinical tool is just beginning. It is a powerful and—under certain circumstances—dangerous procedure. At present, states of acute and myocardial infarction and coronary insufficiency have to be regarded as contraindications for its use.

Apart from this, none of the apparatus available commercially is equipped with all the safeguards necessary to make paired stimulation a safe procedure. It can only be used by doctors familiar with electrical stimulation of the heart in animal experiments. At present the only indications for the use of paired stimulation in a cardiological department are the presence of supraventricular and ventricular tachycardias that cannot be controlled by other means, and, in certain circumstances, for diagnostic purposes.

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