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A mathematical model of A-V conduction in the rat heart. II. Quantification of concealed conduction

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AUTHORS' SYNOPSIS A mathematical model of A-V conduction in the rat heart has been developed which describes A-V junctional behaviour quantitatively during propagation, blocking, and concealed conduction of atrial impulses. The model enables prediction of the ventricular rhythm from atrial stimulation patterns, as well as definition of an atrial rhythm which might have caused a certain ventricular rhythm.

For reasons given in a previous study (Heethaar, Denier van der Gon, and Meijler, 1972) relations were investigated between atrial stimulation intervals and corresponding A-V conduction times. The results were summarized in a mathematical model which described the aforementioned relations accurately in case of rat hearts *in vitro* as well as *in vivo*. In essence, that model is based on the finding that when a fixed stimulus rate is changed into another fixed rate there is an exponential course of the A-V conduction times to the new steady state value. This result was generalized in such a way that a conduction time g_n following the n-th stimulus interval τ_n should equal the steady state conduction time $g_{n,\infty}$ apart from an amount equal to the first term of the exponential decay from g_{n-1} to the conduction time $g_{n,\infty}$:

$$g_n = g_{n,\infty} + (g_{n-1} - g_{n,\infty})\, e^{-\lambda\tau_n} \qquad (1)$$

$g_{n,\infty}$ denotes the conduction time in case of fixed rate stimulation with interval τ_n and $1/\lambda$ a time constant independent of the stimulus intervals and typical for the preparation.

With the help of this recurrent relation and the empirically determined function $g_{n,\infty} = g(\tau_n)$, A-V conduction times following any series of stimulation intervals can be computed, subject to the condition that $g_{n,\infty}$ exists for these intervals. This implies that no blocking of an atrial impulse is allowed to occur in case of fixed rate stimulation with any of these intervals. Nodal escapes limited the range for the long intervals. Thus the model is of use for intervals from 130 to 250 ms. The A-V conduction times varied from 75 ms for the short to 60 ms for the long intervals.

In the present study, we examined conduction times after very short stimulation intervals as well as the influence of blocked atrial impulses on the conduction times of subsequent beats. It appears that the model can be extended in such a way that it is applicable here, too.

Methods

Isolated perfused rat hearts were used for these experiments. The experimental set-up together with the stimulating and recording procedures were the same as described previously (Heethaar *et al.*, 1972). In that paper it has also been argued that measured changes in conduction times between atrial stimuli and ventricular responses almost completely result from changes in conduction time in the A-V node. The influence of intra-atrial and intraventricular conduction is also dealt with in this study.

Results

A-V conduction after long stimulation intervals ($\tau > 130$ ms)

The conduction time g_n after long stimulation intervals is in general given by the equation (1) mentioned in the introduction. By rearranging the terms in this equation it can be written as:

$$g_n = \rho(\tau_n) + g_{n-1}\, e^{-\lambda\tau_n} \qquad (2)$$

where $\rho(\tau_n) = g_{n,\infty}(1 - e^{-\lambda\tau_n})$, a function dependent only on the stimulation interval. As the first extension of the model, an algebraic expression of the function ρ is looked for. In Fig. 1 $\rho(\tau)$ is shown derived from a typical experiment (dashed line). The continuous line represents the function $A_0 \exp(-\lambda\tau) + C$ where A_0 and C are constants, independent of the stimulation intervals and $1/\lambda$ the aforementioned time constant.

It can be seen that the correspondence of both curves is fair (deviations are less than 0·2 ms and within the limit of accuracy). From this kind of experiment we concluded that ρ can be written as:

$$\rho(\tau) = A_0\, e^{-\lambda\tau} + C$$

A-V conduction after short stimulation intervals (>90 ms) and after one or more in the A-V junction blocked impulses

For conduction times in general equation (2) can be written as:

$$g_n = (A_0 + g_{n-1})\, e^{-\lambda\tau_n} + C \qquad (3)$$

For the short intervals this equation can be used also, but deviations between measured and computed conduction times were found. Therefore a term B $\exp(-\mu\tau)$ is added to (3) accounting for these deviations.

In this term $1/\mu$ ($\simeq 8$ ms) is a time constant short compared with $1/\lambda$ ($\simeq 120$ ms). Then equation (3) becomes

$$g_n = Be^{-\mu\tau_n} + Ae^{-\lambda\tau_n} + C \qquad (4)$$

where $A = A_0 + g_{n-1}$.

In Fig. 2 A-V conduction times g_b are shown of impulses generated after 16 basic stimuli at interval τ_0, an interval τ_a, and a test interval τ_b. When the stimulus after the τ_a interval was blocked in the A-V junction, the curves 1–6 are obtained. If no blocking occurred the curves 7–10 are found.

The dots represent the experimental results, while the continuous lines represent the computed A-V conduction times with help of the equation (4). For each curve three measured points are used to calculate A, B, and C. The time constant μ is estimated from one curve and used for all other curves. In Fig. 3 the results of the computation of A and C are plotted together with the conduction time g_a of the atrial extrasystole and the difference A-g_a. From this it can be concluded that C and A-g_a are constants in agreement with equation (3). For the blocked a-pulses no conduction times exist. For reasons mentioned later, for these pulses a new variable

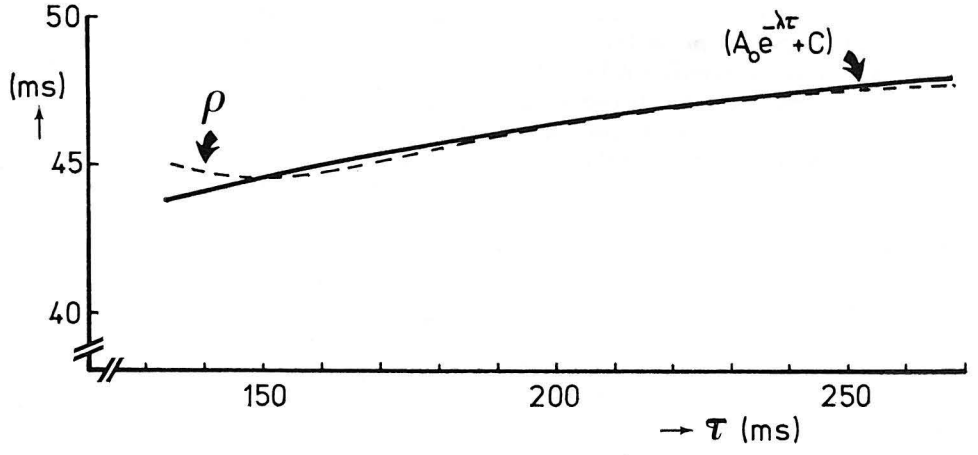

FIG. 1 *Plot of the function together with the function A_0 exp $(-\lambda\tau) + C$, showing the equivalence of these functions for the long intervals. ($A_0 = -18{\cdot}7$ ms $1/\lambda = 117$ ms, and $\rho = 49{\cdot}3$ msec).*

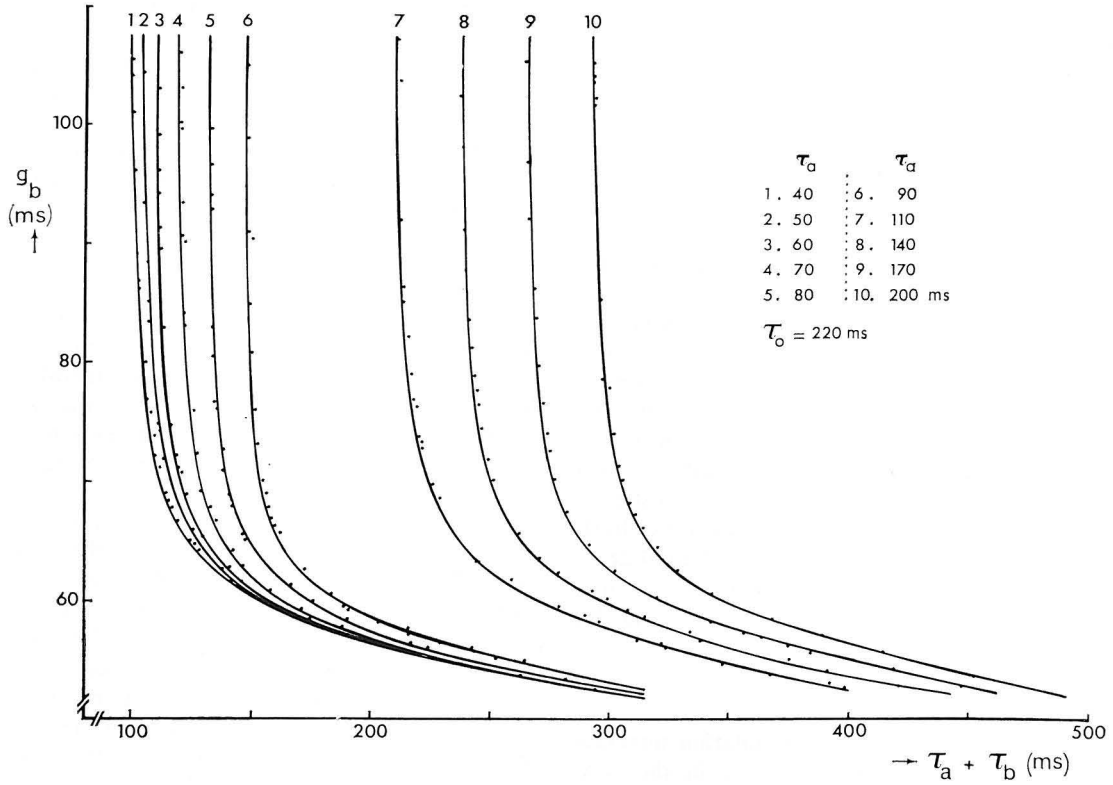

FIG. 2 *Course of computed conduction times of atrial extrasystoles* (continuous lines) *and measured conduction times* (filled circles) *after 16 basic stimuli and a blocked impulse* (curves 1–6) *and after 16 basic stimuli and a conducted one* (curves 7–10).

x – playing the role of a fictive conduction time – is defined so that $A_0 = A - x$. The x-values for the different a-pulses are also plotted in Fig. 3.

From the experimental results of Fig. 2 it follows that the shortest interval τ_b between two atrial stimuli, of which the second is conducted to the ventricles, depends strongly on the previous stimulation interval.

In this study this shortest interval between two atrial stimuli will be called the refractory time of the A-V node. In Fig. 4 a plot is given of this refractory time τ_{ref} versus τ_a.

From this result it follows that after a blocked a-pulse τ_{ref} is short relative to τ_{ref} after a conducted impulse. In Fig. 5 the constant B is plotted on a semilogarithmic scale versus τ_{ref}.

From this it can be concluded that:

$$B = B_0 e^{\mu_0 \tau_{ref}}$$

where B_0 and μ_0 are constants independent of τ_a and τ_b. It is found that the numerical value of μ_0 may be chosen equal to the value of μ mentioned in equation (4) and μ_0 will be called μ from now on. From the aforementioned results it follows that for conducted impulses equation (3) can be changed in:

$$g_b = A_0 e^{-\lambda \tau_b} + B_0 e^{-\mu(\tau_b - \tau_{ref})} + C + g_a e^{-\lambda \tau_b} \quad (5)$$

where A_0, B_0, C, λ, and μ are constants, independent of the stimulation intervals. Equation (5) can be written as:

$$g_b = \phi(\tau_b, \tau_{ref}) + g_a e^{-\lambda \tau_b} \quad (6)$$

where $\phi(\tau_b, \tau_{ref}) = A_0 e^{-\lambda \tau_b} + B_0 e^{-\mu(\tau_b - \tau_{ref})} + C$. For the blocked a-impulses equation (4) can be written as:

$$g_b = (A - x) e^{-\lambda \tau_b} + B_0 e^{-\mu(\tau_b - \tau_{ref})} + C + x e^{-\lambda \tau_b} \quad (7)$$

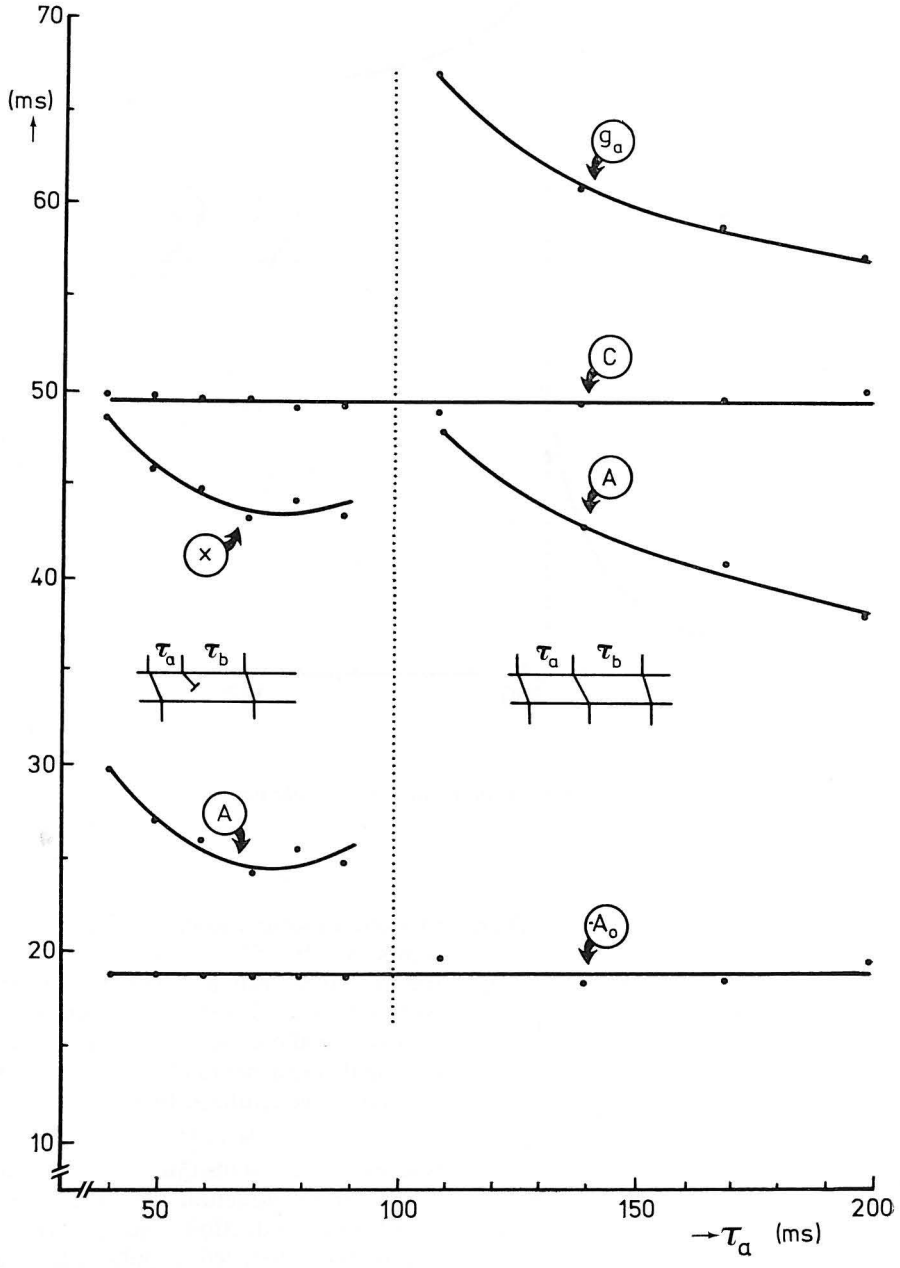

FIG. 3 *Plot of the coefficients* A *and* C *and* g_a, A_0, *and* x *versus* τ_a.

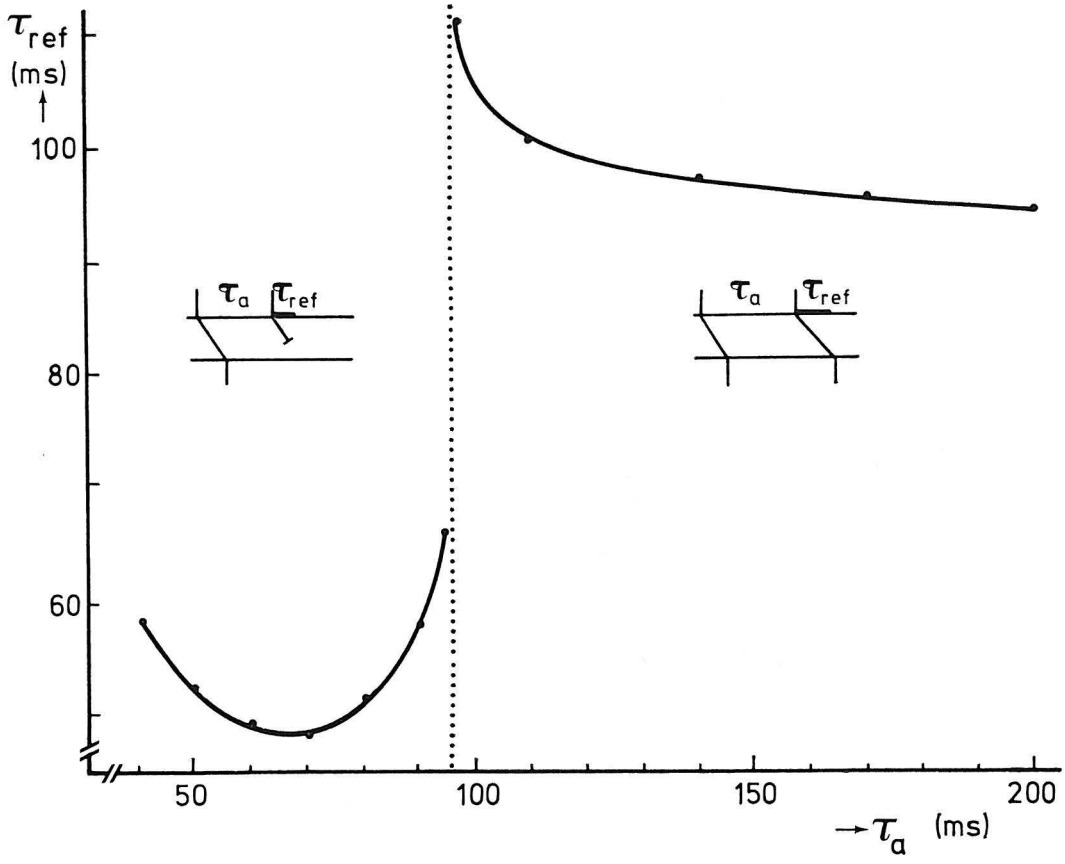

FIG. 4 *Course of the refractory time following an atrial extrasystole generated at various intervals after 16 basic stimuli.*

where x is defined before as $x = A - A_0$. Then equation (7) becomes:

$$g_b = \phi(\tau_b, \tau_{ref}) + x\, e^{-\lambda\tau_b} \qquad (8)$$

where $\phi(\tau_b, \tau_{ref})$ is the function defined above. Comparing equations (6) and (8) it can be concluded that: the effect of a blocked impulse on the A-V conduction time of a subsequent one is equivalent to the effect of a conducted impulse with a very short conduction time.

In Fig. 6 a plot is given of ϕ as a function of τ and τ_{ref}. In the vertical plane A the function ρ has been plotted versus the stimulation interval. A projection of relevant points of the function ϕ is shown demonstrating the equivalence of ϕ and ρ for the long intervals.

A relevant point is that the P-R intervals after blocked impulses can be calculated from the constants A_0, B_0, C, λ, and μ, the measured refractory time and a conduction time g_b. The constants are determined when no blocking occurs and the conduction time has to be used for the determination of x. As will be shown eq (8) may be generalized to:

$$g_n = \phi(\tau_n, \tau_{ref}) + a_{n-1}\, e^{-\lambda\tau_n} \qquad (9)$$

where $\phi(\tau_n, \tau_{ref})$ is the function defined above and a_{n-1} is the conduction time g_{n-1} preceding g_n, or a fictive conduction time x_{n-1} when there are one or more blocked impulses after each other preceding g_n. In Fig. 7 conduction times are shown of impulses generated after 16 basic stimuli and two extra conducted impulses (curve 4), after 16 basic stimuli and one blocked

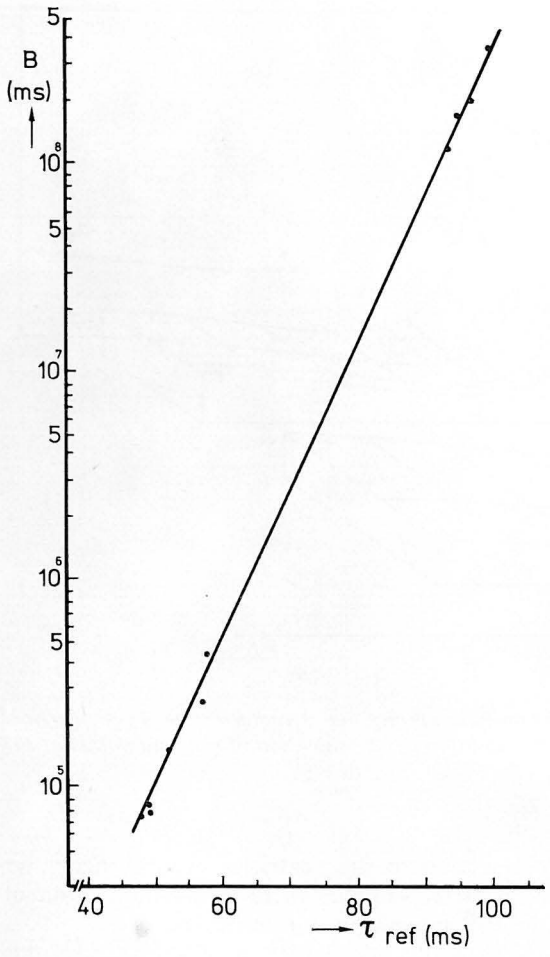

FIG. 5 *Plot of the coefficient* B *versus the refractory time.*

impulse and one conducted impulse (curves 2 and 3) and after 16 basic stimuli followed by two blocked impulses (curve 1). The time constant $1/\lambda$ has been determined from a frequency step (Heethaar *et al.*, 1972). The other constants are determined from curve 4. With the help of these constants the curves 1, 2, and 3 are computed (triangles) from the refractory times and measured points P_1, P_2, and P_3. From this it can be concluded that there is a reasonable correspondence between the experimental and theoretical results.

Ventricular intervals after an atrial extrasystole

When the heart is stimulated with a pulse sequence followed by an atrial extrasystole the A-V conduction time of this extrasystole increases when the stimulation interval τ_{ex} decreases as is shown previously. From this conduction time g_{ex}, the stimulating interval τ_{ex} and the conduction time of the last atrial impulse of the pulse sequence g_{1a} the ventricular interval can be calculated using the formula:

$$RR_{ex} = \tau_{ex} + g_{ex} - g_{1a}$$

In Fig. 8 a plot is given of RR_{ex} versus τ_{ex} of a particular experiment. From our experiments done with isolated rat hearts only shapes of curves as shown in Fig. 8 were measured.

'A-V alternans'

When the right atrial appendage is stimulated alternately with a short interval τ_a and a long interval τ_b, then after the long interval there is a short conduction time g_b compared with the conduction time g_a after τ_a. That means that the ventricular interval RR_a after τ_a: $RR_a = \tau_a + (g_a - g_b)$ can be equal to the ventricular interval RR_b after τ_b: $RR_b = \tau_b - (g_a - g_b)$. In Fig. 9 this is shown.

The stimulation intervals are $\tau_a = 128$ ms and $\tau_b = 169$ ms, which results in conduction times of $g_a = 95$ ms and $g_b = 75$ ms. This phenomenon can be called a form of A-V alternans. That means that a regular ventricular rhythm may exist and can be caused by an alternating atrial rhythm.

Intra-atrial and intraventricular conduction

In the experiments reported in this paper the heart has been stimulated at the right atrial appendage and the responses have been detected by epicardial electrodes on the left ventricle. The time delay between stimulus and corresponding ventricular response is not only originated in the A-V node but also by the specialized conduction system and the atrial and ventricular myocardial tissue.

In our previous paper (Heethaar *et al.*, 1972) it has been demonstrated that for stimulation intervals >120 ms the influence of conduction through the atrial and ventricular myocardium may be disregarded because it is relatively small compared with the total delay between atrial

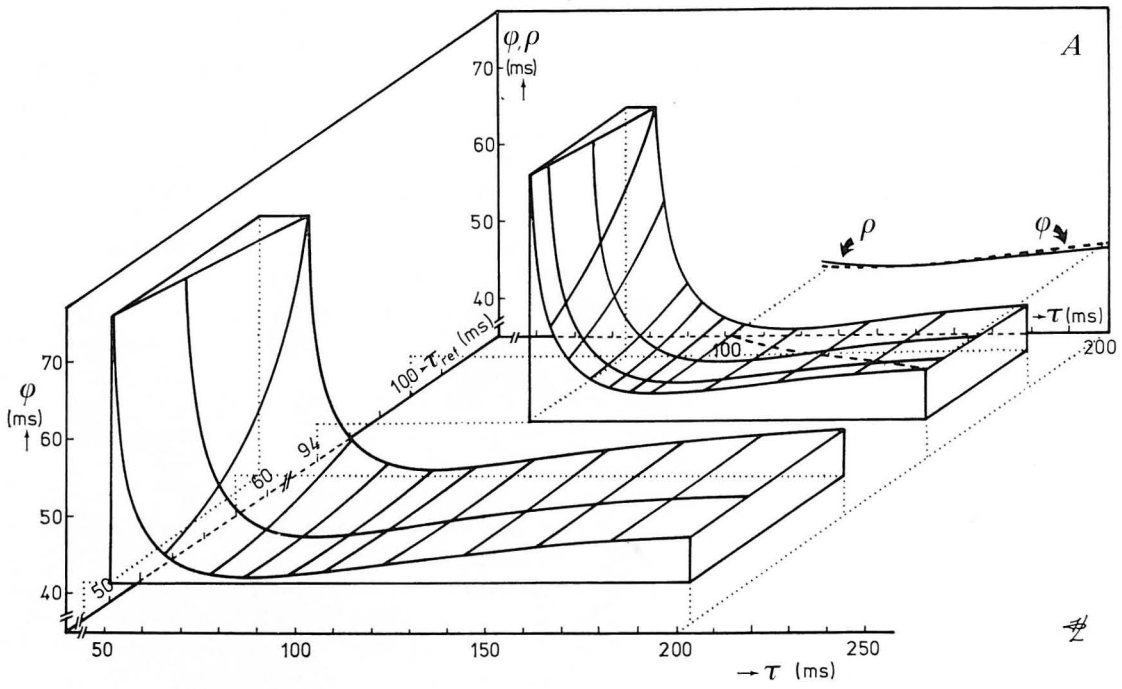

FIG. 6 *Plot of the function ø versus the atrial stimulation interval and the refractory time. In the vertical plane A the function ρ has been plotted versus the stimulation interval. A projection of relevant points of the function ø is shown for comparing ρ and ø.*

stimulus and ventricular response and independent of stimulation rate. Changes in stimulation interval from 120 to 250 ms caused no significant changes (<0·3 ms) in atrial conduction time and did not change the shape of the QRS-complex. At stimulation intervals <120 ms there is a slight prolongation of intra-arterial conduction time, but always less than 2 ms. The influence of conduction through the ventricular myocardium is difficult to estimate. But at all stimulation intervals there are no remarkable systematic changes of electrical activation of the ventricular myocardium – that is, no increase in QRS-duration or change in QRS-morphology. Thus the measured changes in conduction time between atrial stimulation and ventricular response do occur almost complete in the A-V junction.

Wenckebach phenomenon

When the atrium is being stimulated at a slightly higher rate than the maximum rate at which 1:1 conduction to the ventricles occurs, then after each atrial stimulus there is a prolongation of the P-R interval until blocking occurs.

The model developed here shows also this phenomenon. Suppose that the Wenckebach periodicity consists of four beats. After the blocked impulse there is a short refractory period and for the conduction time g_1 can be written:

$$g_1 = \phi(\tau_0, \tau_{\mathrm{ref}_0}) + x\, e^{-\lambda\tau_0}$$

where τ_0 is the stimulation interval and x again a very short fictive conduction time. Figure 10 shows in principle what will happen (all curves in this figure are taken from Fig. 6). In Fig. 10a the function $\phi(\tau, \tau_{\mathrm{ref}_0})$ is shown for the situation after the blocked impulse. After the first conducted stimulus there is a considerable increment of $\tau_{\mathrm{ref}'}$ which results in a change of the function $\phi(\tau, \tau_{\mathrm{ref}})$ as shown in Fig. 10b. The conduction time g_2 following g_1 can be found from:

$$g_2 = \phi(\tau_0, \tau_{\mathrm{ref}_1}) + g_1\, e^{-\lambda\tau_0}$$

As $g_1 > x$ and $\phi(\tau_0, \tau_{\mathrm{ref}_1}) > \phi(\tau_0, \tau_{\mathrm{ref}})$ g_2 is greater

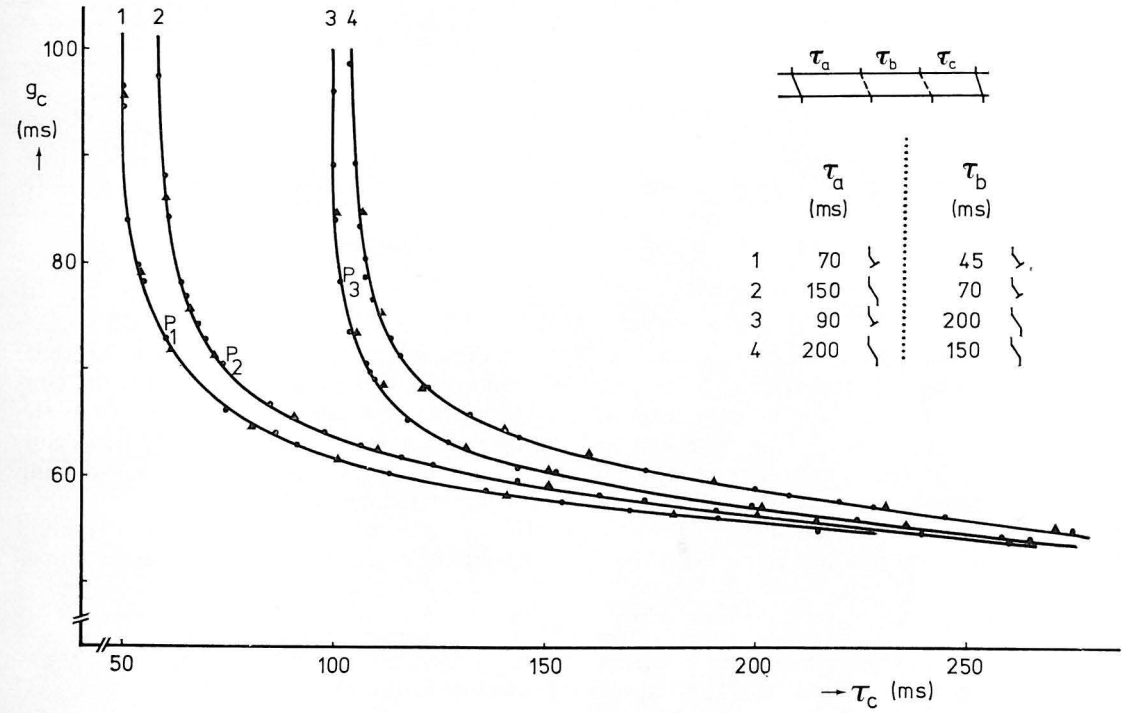

FIG. 7 *Computed* (triangles) *and measured conduction times* (filled circles) *after different stimulation patterns.*

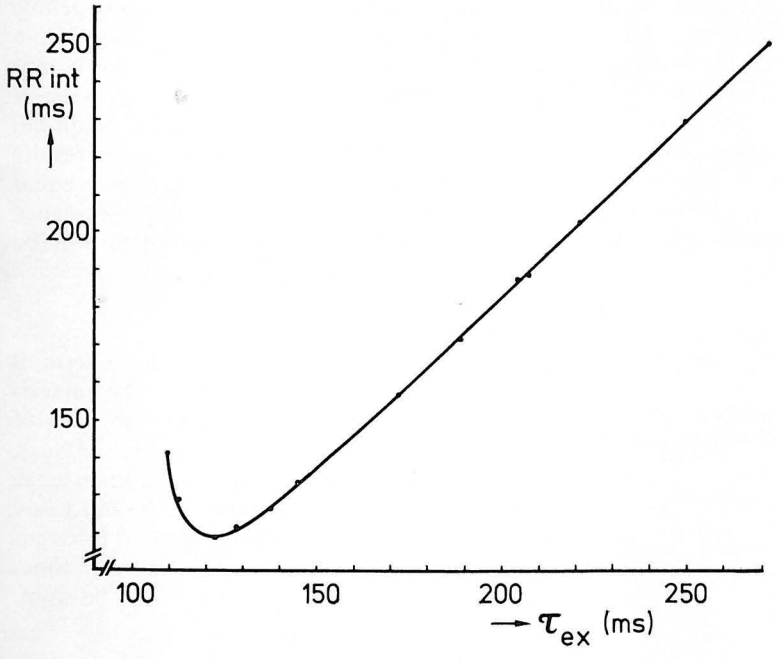

FIG. 8 *Plot of the ventricular intervals after an atrial extrasystole initiated at different intervals after 16 basic stimuli.*

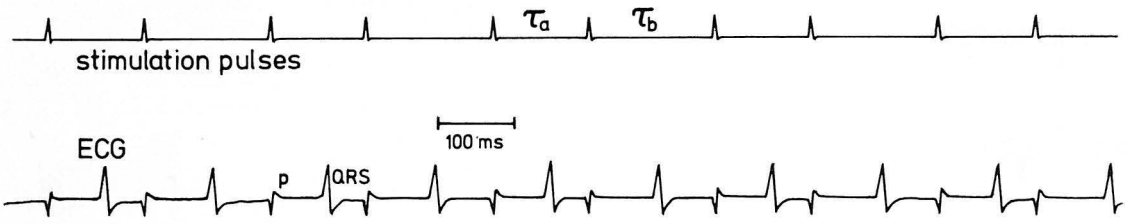

FIG. 9 *ECG recording during alternately stimulation of the right atrial appendage.*

than g_1. This results in a longer τ_{ref_2} after g_2. The corresponding function $\phi(\tau, \tau_{ref_2})$ is shown in Fig. 10c. Also for g_3 it can be demonstrated that $g_3 > g_2$ and $\tau_{ref_3} > \tau_{ref_2}$. This results in an increasing τ_{ref}. In Fig. 10d τ_{ref_3} is shown. As $\tau_{ref_3} > \tau_0$ the stimulus impulse is blocked in the A-V node. After this the situation of Fig. 10a is created and g_5 will be equal to g_1, etc.

Concealed conduction

One aspect of concealed conduction is the influence of an in the A-V node blocked impulse on the conduction of a subsequent one (Langendorf, 1948). In Fig. 11a three impulses are shown from which 1a is the last one of a series of 16 basic stimuli, a is a blocked impulse, and b a propagated one. In Fig. 11b the blocked impulse is absent, which results in a shorter conduction time of the b-impulse. In Fig. 11c the interval τ_a has been increased to τ'_a, so that the a-impulse is conducted to the ventricles. However, the interval $\tau'_a + \tau'_b$ has been kept constant. The increase Δ of the conduction time of the b-impulse in the presence of the blocked or propagated a-impulse can be calculated with the model:

$$g_{b,1} = \phi(\tau_b, \tau_{ref_1}) + x\, e^{-\lambda\tau_b}$$
$$g_{b,2} = \phi(\tau_a + \tau_b, \tau_{ref_2}) + g_{1a}\, e^{-\lambda(\tau_a+\tau_b)}$$
$$g_{b,3} = \phi(\tau'_b, \tau_{ref_3}) + g_a\, e^{-\lambda\tau'_b}$$

Thus the increase Δ_1 $(= g_{b,1} - g_{b,2})$ of the conduction time g_b after a blocked impulse is:

$$\Delta_1 = \phi(\tau_b, \tau_{ref_1}) - \phi(\tau_a + \tau_b, \tau_{ref_2}) + (x - g_{1a}\, e^{-\lambda\tau_a})\, e^{-\lambda\tau_b}$$

and the increase Δ_2 $(= g_{b,3} - g_{b,2})$ of the conduction time g_b after a propagated impulse is:

$$\Delta_2 = \phi(\tau'_b, \tau_{ref_3}) - \phi(\tau'_a + \tau'_b, \tau_{ref_2}) + (g_a - g_{1a}\, e^{-\lambda\tau'_a})\, e^{-\lambda\tau'_b}$$

From these two results we have to conclude that: the influence of a blocked impulse on the conduction time of a subsequent one as well as the influence of a propagated impulse on the conduction time of a subsequent one are satisfying the same mathematical formulation.

In Fig. 12 the parameters Δ_1 and Δ_2 are plotted as functions of τ_a and τ_b in case the basic stimulation interval is 220 ms.

Discussion

Evaluation of results

Function ρ

As the first extension of the mathematical model an algebraic expression of $\rho(\tau)$ was looked for. An approximation with help of exponential terms was preferred for reasons of homogenity of the model. It was found that the very simple form $Ae^{-\lambda_0\tau} + C$ permitted a reasonable approximation of $\rho(\tau)$. The value of λ previously found (see equation 1) appeared to lie within the range of values of λ_0 which gave good results and for reasons of simplicity λ_0 was chosen equal to λ. Up till now, no physiological evidence strengthens this choice. This problem will be dealt with in a subsequent article.

Time constant μ_0

As a second extension of the model a term B exp $(-\mu_0\tau)$ is added to equation (3). The numerical value of μ_0 is estimated from one curve of the experimental results shown in Fig. 2. Next, with the help of equation (4) and the knowledge of the value of λ, the constants A, B, and C are computed. A semilogarithmic plot of B versus the corresponding measured refractory times shows that the following relation can be used:

$$B = B_0\, e^{-\mu_0\tau}$$

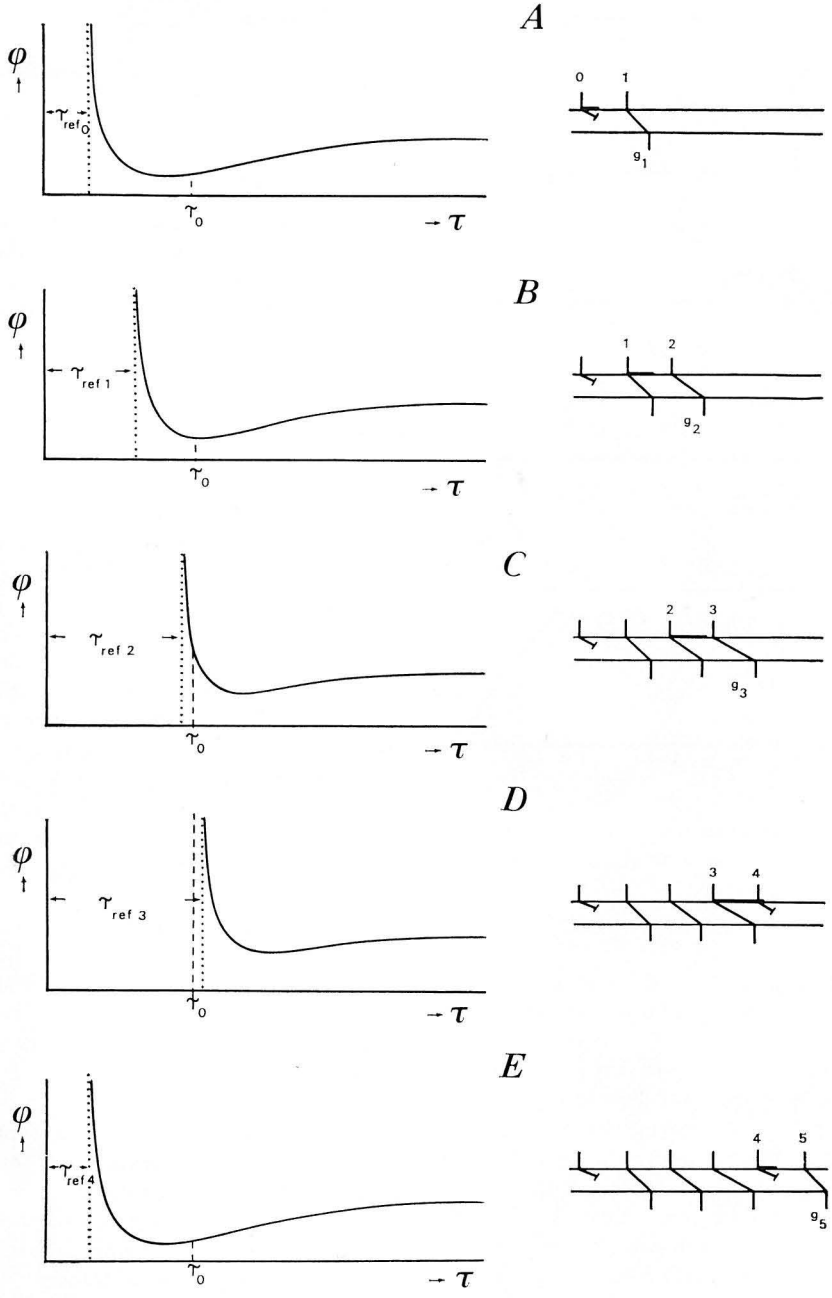

FIG. 10 *Plots of the function ø at different moments in the Wenckebach periodicity.*

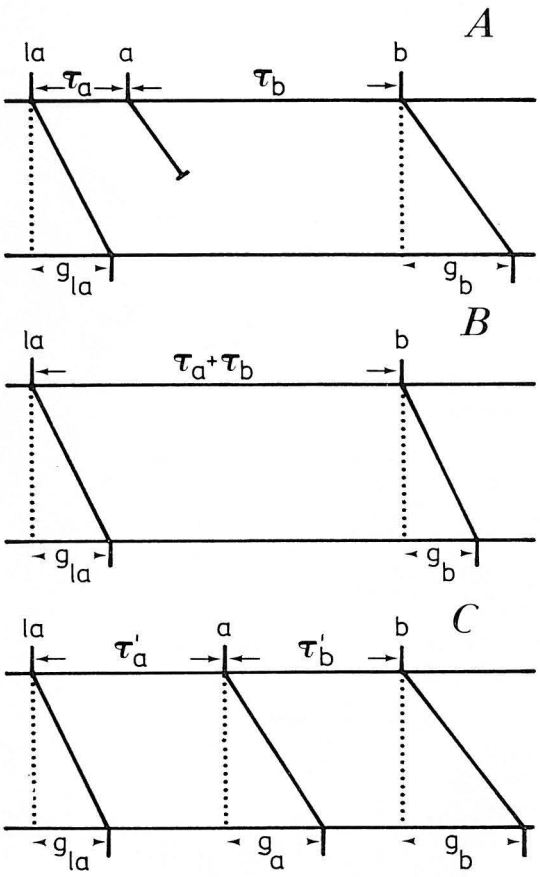

FIG. 11 *Schematic representation of impulse propagation through the A-V node at different stimulation sequences.*

where B_0 and μ_0 are independent of the intervals τ_a and τ_b. The value of μ_0 does not differ significantly from μ.

From the results shown in Fig. 7 it follows that B_0 and μ_0 either do not depend on the third preceding stimulation interval. As the influence of a n-th stimulation interval on a n+i-th conduction time decreases quickly with increasing i, it is concluded that there is a strong suggestion from the aforementioned results that the influence of stimulation intervals on B_0 and μ_0 may be neglected.

Because of the numerical equivalence of μ_0 and μ the correction term can be written as:

$$B_0 e^{-\mu(\tau-\tau_{ref})}$$

This suggests that it is not the stimulation interval itself that is the relevant parameter, but the time elapsed since the A-V node has become excitable again.

Relationship between A-V junctional refractory times and stimulation intervals

The model developed here covers quantitatively conductive properties of the A-V junction. To calculate A-V conduction times, constants had to be determined. The variables in this model are the stimulation intervals, the refractory periods, and the conduction times. In a similar fashion, as is done in our previous paper, it can be demonstrated that (using the generalized recurrent equation (9) for stimulation intervals in case no blocking occurs) the conduction time at a given moment can be calculated from the five preceding stimulation intervals and refractory times. If a relationship exists between the refractory times on the one hand and the stimulation intervals or the conduction times on the other hand this relation could be used, so that the final result would be that in all cases the conduction times could be determined from the stimulation intervals. It has been stated (Capelle, Perron, and Durrer, 1971) that the refractory time of a (n+1)-th atrial beat depends only on the conduction time of the n-th beat and not on the previous history of the A-V conducting system and that in some cases the conduction time of the n-th atrial beat parallels the refractory time following this beat. The last statement would imply that: $\tau_{ref}=g_n+\text{Constant}$. Our results do not confirm this, as is shown in Fig. 13. In this plot A-V conduction times of atrial extrasystoles at 110 resp. 200 ms after 16 basic stimuli are given together with the refractory times following these extrasystoles as a function of the basic stimulation interval. It can be seen that there is a systematic change in conduction time of the extrasystole as a function of the basic stimulation interval, but this is not the case with the refractory time.

In Fig. 14 a plot is given of the steady state relations of conduction time and refractory time versus the stimulation interval. From these results we have to conclude that, for stimulation intervals in the range of constant stimulation without blocking of impulses, the refractory time defined above depends only on the preceding

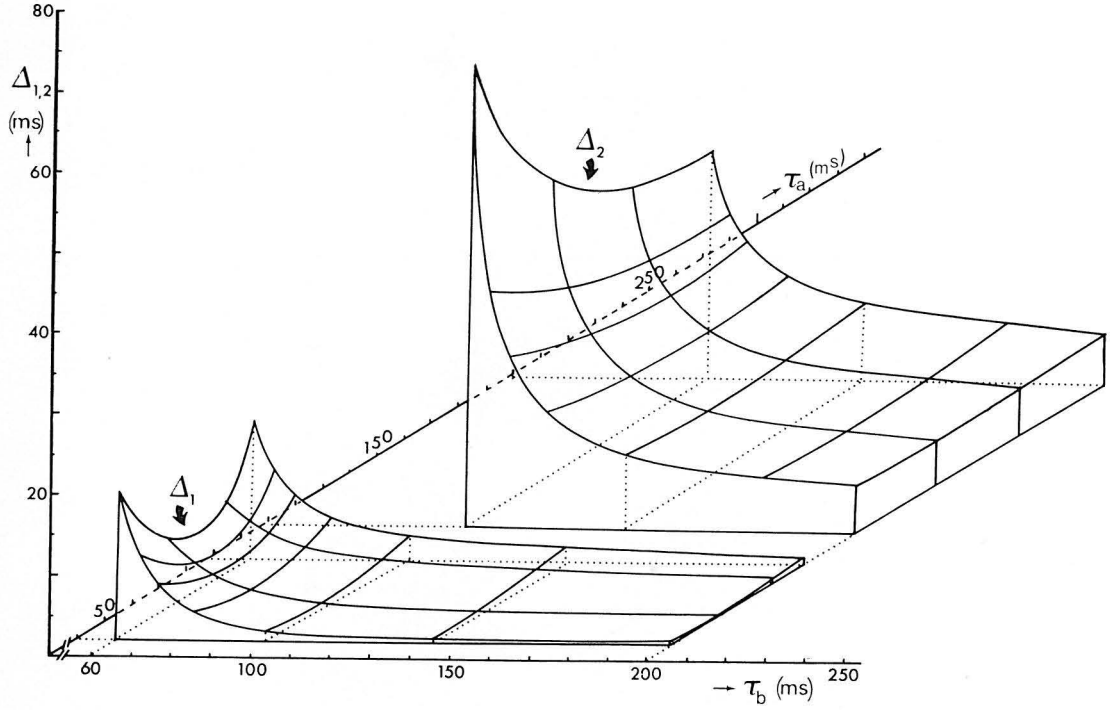

FIG. 12 *Plot of the parameters Δ_1 and Δ_2 versus τ_a and τ_b.*

stimulation interval and not on the preceding conduction time.

Determination of atrial behaviour from ventricular response

In our previous paper it has been shown that, if the steady state relation $g_{n,\infty}=g(\tau_n)$ is known, the stimulation pattern can be determined from the ventricular response during random stimulation of the right atrial appendage of the heart. From this paper it follows that this is possible for the long intervals without knowing the relationship: $g_{n,\infty}=g(\tau_n)$. This last is not necessary because an algebraic expression of $\rho(\tau)$ has been found. Only a few constants have to be determined. With these constants it is possible in an analogous way, as shown in the paper mentioned above, to calculate the atrial stimulation sequence from the ventricular intervals. For the short intervals the constants μ and B_0 have to be determined. Also refractory times have to be known. From Fig. 8 it follows that different atrial stimulation patterns can cause identical ventricular intervals. Also in Fig. 9 is shown that an alternating atrial stimulation pattern can cause the same ventricular intervals as can be obtained with regular atrial stimulation. When blocked impulses are also taken into consideration, the number of atrial stimulation patterns, which may cause the same sequence of ventricular intervals, increases quickly. That means that for a certain pattern of R-R intervals sequence there are many atrial impulse sequences possible. This is subject of study at this moment.

Ventricular intervals

From our experiments done with isolated rat hearts, only shapes of curves, as shown in Fig. 8, were measured for the ventricular intervals. No other shapes were found as has been done by Moe and Hoffman (Moe, Preston, and Burlington, 1956; Hoffman, Moore, Stuckey, and Cranefield, 1963). In some cases they measured by exposed dog hearts, that a decrease of τ_{ex} resulted in a sudden increase in ventricular interval or in other cases there was, in spite of a

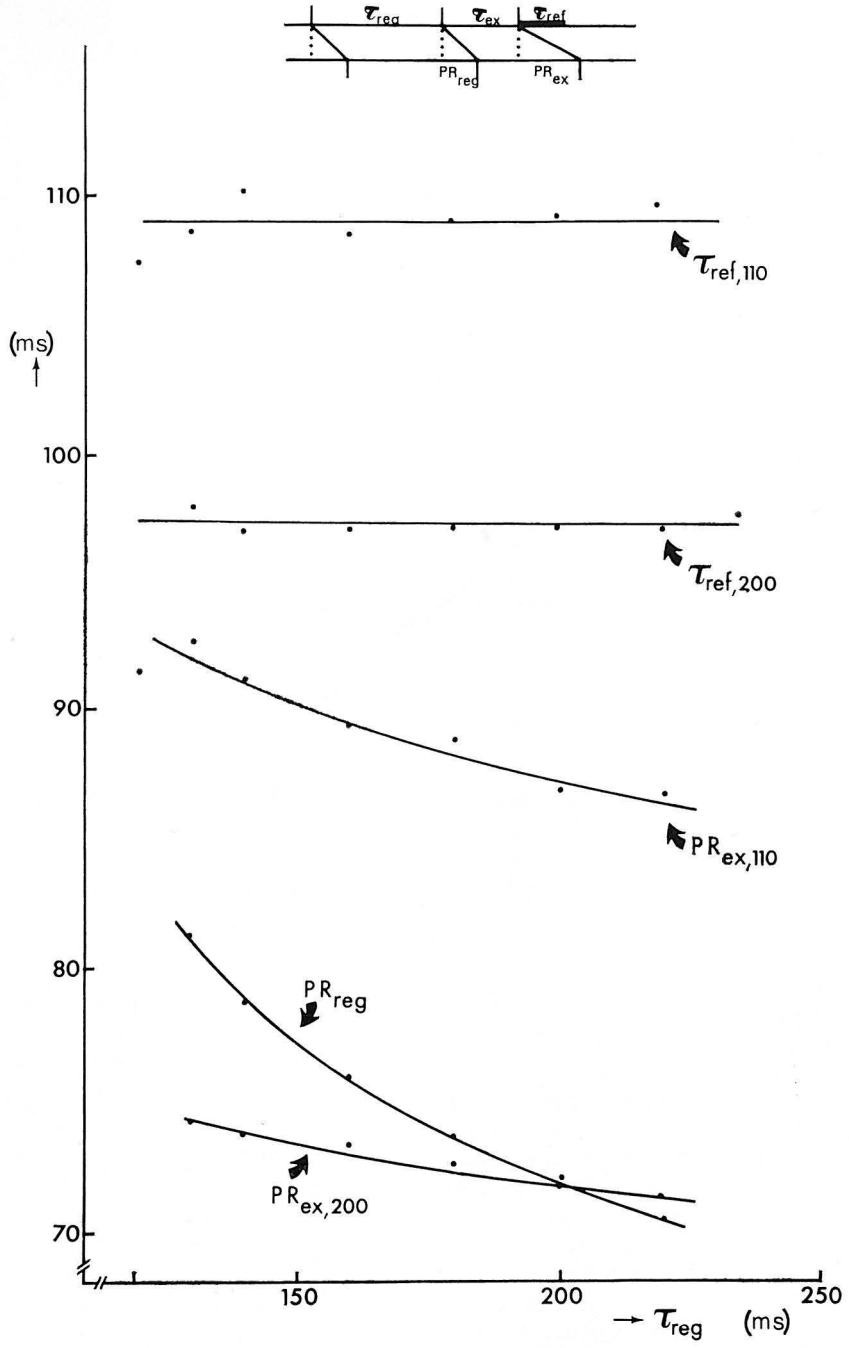

FIG. 13 *Plot of A-V conduction times of atrial extrasystoles at 110 resp. 200 ms after 16 basic stimuli together with the refractory times after this extrasystoles versus the basic stimulation interval. Also steady state conduction times are plotted versus the stimulation interval.*

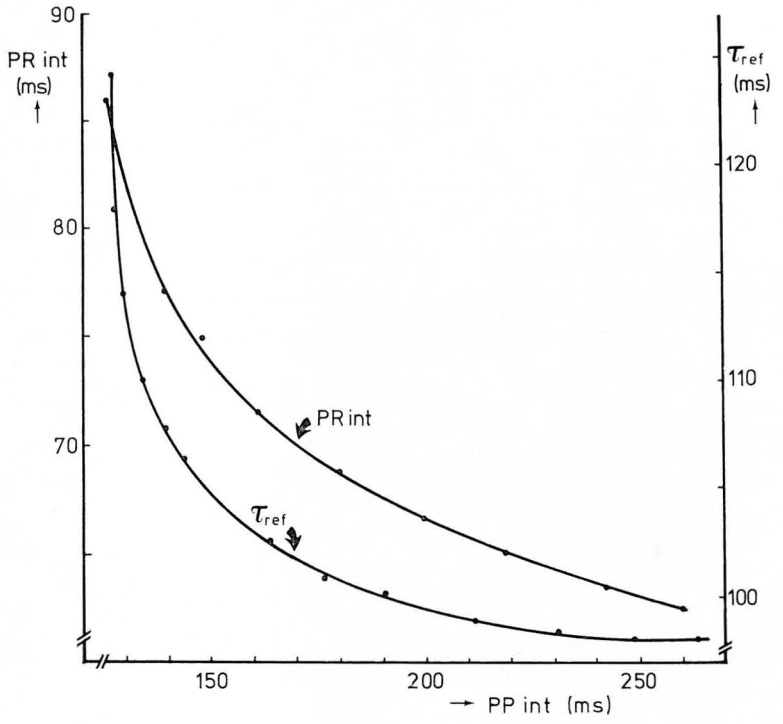

FIG. 14 *Steady state conduction and refractory times versus the stimulation interval.*

decrease of τ_{ex} from a certain value, no change in the ventricular interval. However, in most experiments Hoffman *et al.* (1963) found curves in accordance of the curves shown in Fig. 8. In that case they concluded that the delay between stimulus and response was caused in the A-V nodal tissue.

Concealed conduction

In this paper we demonstrate that concealed conduction within the limited concept as used in our experiments can be described quantitatively. In essence, we state that the effect of a blocked impulse on the conduction time of the subsequent one is equal to the effect of a propagated impulse on A-V conduction time of the subsequent one.

Final remarks

The origin of the irregularity of the ventricular rhythm in atrial fibrillation has been and still is a striking phenomenon.

In his editorial, Brody (1971) has outlined the controversial viewpoints about the underlying mechanism of this irregularity and the role of the A-V junction herein.

From clinical studies (Bootsma, Hoelen, Strackee, and Meijler, 1970) we had to conclude that the role of the A-V junction during atrial fibrillation is limited to variable scaling of the atrial impulses.

In this paper we present a mathematical model of A-V junctional conduction during and after blocking of atrial impulses, so that the model can describe scaling properties. This enables us to predict the ventricular rhythm from the atrial rhythm and may contribute to insight into atrial rhythm, if the ventricular rhythm is known.

We do realize that our mathematical model of A-V conduction is derived from, and thus applicable only to, the rat heart.

From preliminary studies we have gained the impression that apart from other values of the constants the model will hold for the dog heart as well. It seems worthwhile to develop such a model for the human heart after cardiac cathe-

terization. With the model, the effects of pharmacological agents, such as quinidine, digitalis, and β-blockers on the A-V junction can be described quantitatively. It will also make it possible to distinguish, for instance, the effect of digitalis on the atrial myocardium from its effect on the A-V junction, in case the drug is used in atrial fibrillation. In general terms, it can be stated that the model may contribute to the understanding and eventual analysis of arrhythmias involving the A-V junction and the pharmacology of A-V junctional conduction.

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