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Effects of a Bradycardic Agent (DK-AH 269) on Haemodynamics and Oxygen Consumption of Isolated Blood-Perfused Rabbit Hearts

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Objectives: Pharmacologic bradycardia is a promising strategy to improve myocardial energetic balance. We evaluated the effects of the novel sinus node inhibitor DK-AH 269 (DK) on ventricular function and perfusion in isolated rabbit hearts.

Methods: To differentiate between the effects of the negative force-frequency relation and a direct negative inotropic action of DK, measurements of haemodynamic and metabolic parameters were made during electrical pacing (EP), after application of DK (DK+EP), and after termination of pacing (DK–EP).

Results: Heart rate was significantly reduced by DK (EP: 161 ± 20, DK+EP: 161 ± 19 min^{-1}, DK–EP: 101 ± 32 min^{-1}, mean ± SD, p = 0.02). In parallel, diastole significantly lengthened without pacing (EP: 241 ± 35, DK+EP: 234 ± 38, DK–EP: 459 ± 220 ms, p = 0.04). Aortic flow was decreased in the presence of DK (EP: 40.6 ± 21.7, DK+EP: 32.8 ± 17.9 ml/min) and even further in the absence of pacing (DK–EP: 22.8 ± 24.6 ml/min). However, stroke volume (EP: 0.31 ± 0.16, DK+EP: 0.26 ± 0.14 ml) and peak isovolumic left ventricular pressure (EP: 109 ± 19, DK+EP: 92 ± 20, mmHg) were only moderately reduced. DP/dt_{max} remained essentially unchanged after DK (EP: 1355 ± 545, DK+EP: 1390 ± 830 mmHg/s), but decreased without pacing (DK–EP: 890 ± 500 mmHg/s). DP/dt_{min}, as a measure of early relaxation, had a tendency to decrease after DK with and without pacing (EP: –1245 ± 625, DK+EP: –1055 ± 410, DK–EP: –725 ± 340 mmHg/s), while the left ventricular end-diastolic pressure remained unchanged after DK and significantly decreased without pacing (EP: 10 ± 7, DK+EP: 9 ± 6, DK–EP: 5 ± 5 mmHg, p = 0.03). Coronary blood flow (CBF) decreased from 204 ± 29 to 156 ± 21 ml/min/100 g with DK and remained almost constant without pacing (148 ± 33 ml/min/100 g). The relation between subendocardial and subepicardial flow (colored microspheres) decreased slightly with DK (EP: 1.46 ± 0.39, DK+EP: 1.40 ± 0.28, DK–EP: 1.36 ± 0.41). The myocardial oxygen consumption (MVO_2) decreased with DK and further without pacing (EP: 9.8 ± 3.0, DK+EP: 8.7 ± 3.0, DK–EP: 6.2 ± 3.8 ml/min/100 g).

Conclusions: DK effectively reduced HR and prolonged diastole. The drug has no major negative inotropic effect, reduces MVO_2 and permits, in parallel, CBF to fall. In consequence, this novel bradycardic agent could prevent tachycardia in the experimental setting or could prevent unwanted, postoperative tachycardia. In addition, it could be an effective approach to induce bradycardia for off-pump coronary operations without compromising left ventricular function. *J Clin Basic Cardiol 2000; 3: 191–6.*

Key words: isolated blood-perfused heart, systolic and diastolic function, bradycardia, rabbit, oxygen consumption

Heart rate is tightly coupled to myocardial oxygen consumption [1, 2]. Hence, myocardial oxygen demand was reduced through bradycardia in patients with severe heart failure by using digitalis [3]. More importantly, heart rate reduction became well established, in particular since the introduction of β-adrenoceptor blockers [4] which are well established in treating various ischaemic heart diseases [4–6]. Since β-blockers also have negative inotropic and dromotropic effects that can reduce their usefulness in coronary heart disease, agents targeted exclusively at the sinoatrial node could be superior [5, 7]. One such agent, UL-FS 49 (zatebradine), which acts primarily on the I_f-pacemaker channel of the sinus node [5] was widely investigated. The effects on the contractile state, however, are controversial and may depend on the experimental model [8–10]. The effects of a newer bradycardic agent, DK-AH 269 (DK), on the myocardial contractile state are even less clear.

We investigated the benzazepinone-type DK which acts on the I_f-pacemaker channel (Fig. 1, from [11]): During systole, the channel is in its closed configuration, and the drug has no access to its putative intrachannel binding site. Upon hyperpolarization (diastole), the channel opens to allow cations to flow from outside to inside the cell. Competing against this ionic gradient, the drug may gain access to its binding site.

DK exhibits a greater bradycardic potency than UL-FS 49 in some experimental models [11, 12]. In two earlier studies using buffer-perfused or blood-perfused rabbit

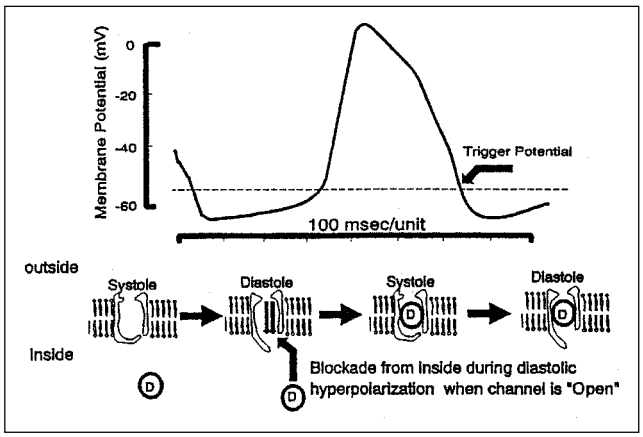

Figure 1. Mechanism of action of DK-AH 269 (for explanation see text; from [11], with permission)

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hearts, we described a dose-dependent reduction in heart rate by DK together with a prolongation of diastole [13, 14]. From these experiments and from others [11], however, it was unclear whether (1) that agent *per se* compromises myocardial inotropic performance, or whether the decreased function was due (2) to the negative force-frequency relation (= negative staircase phenomenon [15, 16]) or (3) to a time-dependent deterioration of the experimental model. To differentiate whether one or more of these effects were involved, experiments were performed on isolated, blood-perfused rabbit hearts that were paced before and after administration of DK. Additional measurements were made after pacing was terminated.

Methods

Experiments were performed on 10 isolated hearts of male New Zealand White rabbits with an average age of 7 months; body mass ranged from 2500 to 3500 g. The rabbits were handled according to the animal welfare regulations of the German federal authorities which are in accordance with Guide for the Care and Use of Laboratory animals (NIH publication #85–23, revised 1985). The animals were anaesthetized with 25 mg/kg i.m. ketaminhydrochloride and 5 mg/kg xylazine. After muscular relaxation (pancuroniumbromide 0.4 mg/kg) and tracheotomy, artificial respiration was performed with a small-animal respirator (Ugo-Basile, 7025). After thoracotomy and pericardiotomy, the hearts were rapidly excised and without intermittent ischaemia connected to a modified Langendorff apparatus (Fig. 2). They were perfused with a modified Krebs-Henseleit buffer that contained bovine erythrocytes to give a haematocrit of 30 %. To prevent oedema formation, bovine albumin was added. After opening the left atrium and cutting all chordae tendineae, a thin-walled latex balloon (HSE, #12–14) was inserted into the left ventricular cavity through the mitral valve. The balloon was connected to an artificial systemic circuit that contained a windkessel and two valves to respectively mimic aortic and mitral valves. For assessing aortic flow, an ultrasonic flow probe was used that was connected to a flow meter (T 206, Transonic Systems). In addition, this systemic circuit permitted changing preload and afterload. For the assessment of preload throughout the protocol, left intraventricular diameter was measured by sonomicrometry (System 6, Triton) using a pair of ultrasonic piezocrystals glued on either side of the balloon. A 3F microtip-manometer (TC 500, Millar) was inserted into the balloon for measurement of left ventricular pressure. A cannula was placed into the pulmonary artery for collecting the coronary venous blood. The coronary circuit contained a servocontrolled roller pump (505L, Watson Marlow) that provided a constant coronary arterial pressure of 80 mmHg. The flow within the coronary circuit was measured by using a second ultrasonic flow probe connected to the same flow meter. The blood was oxygenated (22 % O_2, 72 % N_2, 6 % CO_2) using a hollow fiber baby oxygenator (Masterflo 51, dideco). The difference between arterial and venous oxygen content was continuously measured using absorption spectrophotometry (AVOX Systems). The system was routinely calibrated against direct measurements provided by a Lex-O_2-Con analyzer. A pacemaker (Type 201, HSE stimulator P) was used for electrical stimulation. Both electrodes were attached to the right atrium.

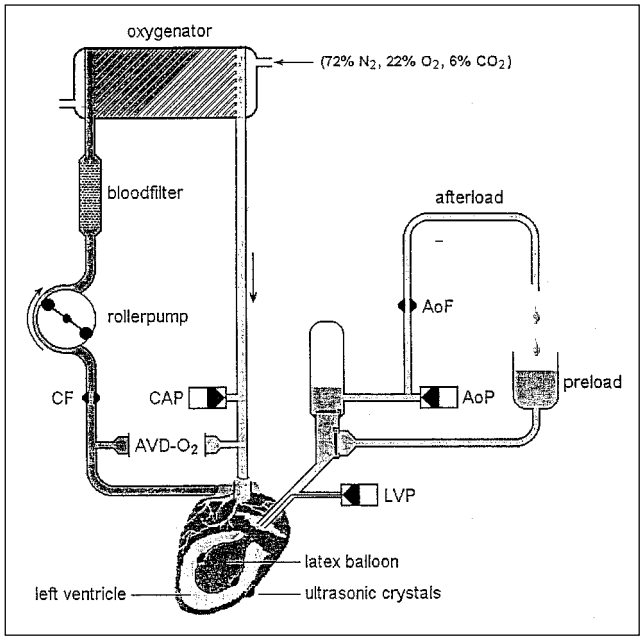

Figure 2. Modified Langendorff-Apparatus. The coronary perfusion circuit is shown on the left, and the systemic circuit is shown on the right. For details, see text.

Experimental Protocol

Measurements were performed after 20 min stabilization with electrical pacing to avoid negative inotropic effects of pacing. DK-AH 269 (DK) was administered at a concentration of 10^{-6} M, and measurements were repeated after 30 min. After termination of pacing, the measurements were repeated. To evaluate the regional myocardial flow, colored microspheres were injected after vigorous mixing (Vibrofix, IKA-Labortechnik) during each of the three experimental steps, ie during electrical pacing, after DK, and without pacing. The temperature of the heart was kept constant at 38.5 °C. At the end of each experiment, the hearts were arrested using saturated potassium chloride. To normalize blood flow both left and right ventricles were weighed.

Data analysis, calculations and statistics

Variables were recorded on a forced ink chart recorder (Brush 481). At periods of interest, the paper speed was 50 mm/s. The variables were stored simultaneously on a magnetic disc using a custom-made computer program (EASYDAT [17] and a personal computer (Pentium, 100 MHz). The time constant of pressure decay was calculated using a monoexponential equation with an asymptote [18]. Coronary blood flow was normalized to 100 g wet myocardial mass. Myocardial oxygen consumption was calculated according to Fick's principle using the normalized coronary flow and arterio-venous difference in oxygen content. Statistical analysis was performed using a computer program (SYSTAT [19]). A one-way analysis of variance with a subsequent posthoc correction according to Bonferroni was performed to exhibit differences between the three experimental steps. A p value < 0.05 was considered to represent statistical significant differences. All data are mean values ± SD.

Results

The heart rate during electrical pacing before (EP) and after (DK+EP) administration of 10^{-6} M DK-AH 269 (DK) was 161 ± 20 and 161 ± 19 min^{-1} respectively. Without pacing (DK–EP), heart rate significantly decreased to 101 ± 32 min^{-1} (Fig. 3, $p = 0.02$). In parallel, at unchanged length of systole,

the duration of diastole was maintained or increased respectively (EP: 241 ± 35, DK+EP: 234 ± 38, DK–EP: 459 ± 220 ms, p = 0.04). Aortic flow decreased by 19 % from 40.6 ± 21.7 to 32.8 ± 17.9 ml/min in the presence of DK and without pacing by an additional 30 % to 22.8 ± 24.6 ml/min (n.s.). Stroke volume was moderately reduced (EP: 0.31 ± 0.16, DK+EP: 0.26 ± 0.14 ml) and was further reduced to 0.21 ± 0.25 ml without pacing. Peak left ventricular isovolumic pressure exhibited a tendency to decrease during the three experimental steps from 109 ± 19 to 92 ± 20.3 to 75 ± 25 mmHg (Fig. 4, top). DP/dt_{max} as measure of contractile state, remained unchanged after administration of the agent (1355 ± 545 vs. 1390 ± 830 mmHg/s) and was decreased without pacing (890 ± 500 mmHg/s; n.s.) (Fig. 4, bottom). DP/dt_{min} was decreased with DK and furthermore without pacing (EP: –1245 ± 625, DK+EP: –1055 ± 410, DK–EP: –725 ± 340 mmHg/s). The time constant of pressure decay (τ) was slightly reduced with DK (EP: 40.6 ± 9.0, DK+EP: 35.3 ± 4.9 ms) and almost recovered without pacing (38.7 ± 6.5 ms). The left ventricular end-diastolic pressure was 10 ± 7 mmHg during control and remained almost unchanged in the presence of the agent (9 ± 6 mmHg). The decrease to 5 ± 5 mmHg after termination of pacing was significant (Fig. 5, p = 0.03). In parallel, the end-diastolic left ventricular diameter was decreased (EP: 10.07 ± 0.09, DK+EP: 9.89 ± 22, DK–EP: 9.39 ± 9.3 mm), ie preload was reduced. The global coronary blood flow was reduced from 204 ± 29 to 156 ± 21 to 148 ± 33 ml/min/100 g in the three experimental steps (Fig. 6, top). No significant transmural redistribution paralleled these changes: the ratio between subendocardial and subepicardial flow only slightly decreased (EP: 1.46 ± 0.39, DK+EP: 1.40 ± 0.28, DK–EP: 1.36 ± 0.41). The coronary blood flow per beat was reduced with DK (EP: 62 ± 20, DK+EP: 45 ± 12 μl/100 g) and reached predrug level after termination of pacing (DK–EP: 61 ± 10 μl/100 g) (Fig. 6, bottom). Conversely, the coronary resist-

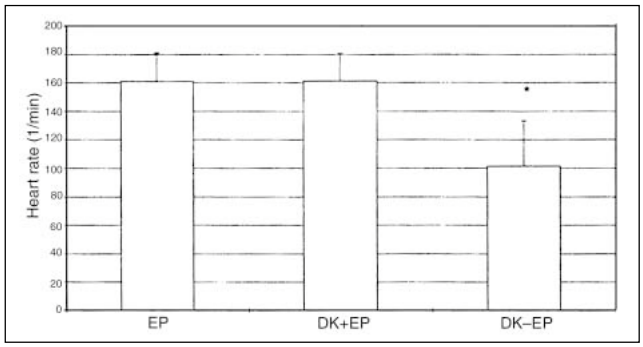

Figure 3. The heart rate (HR) was significantly reduced with DK. Mean ± SD during pacing (EP), DK-AH 269 10^{-6} M (DK+EP) and without pacing (DK–EP), *p = 0.02

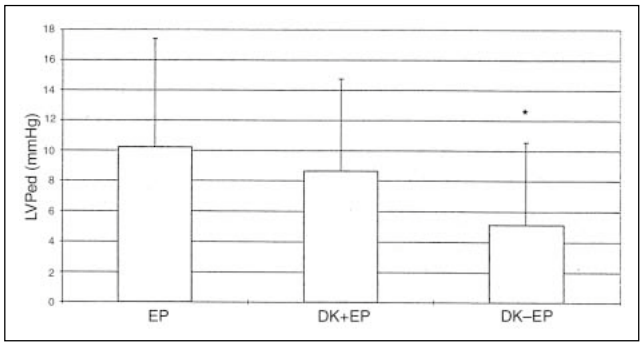

Figure 5. The end-diastolic left ventricular pressure (LVP) was significantly decreased with DK after pacing was terminated. Mean ± SD during pacing (EP), DK-AH 269 10^{-6} M (DK+EP) and without pacing (DK–EP), *p = 0.03

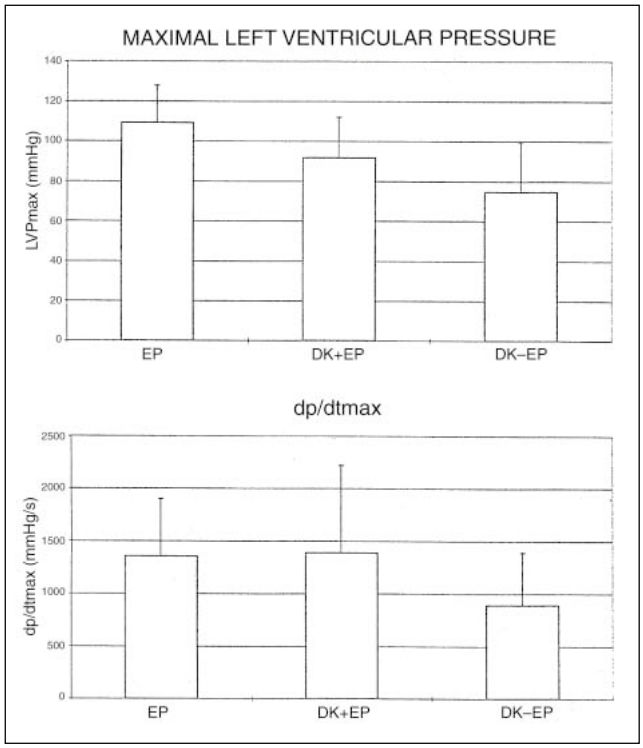

Figure 4. The peak left ventricular pressure (LVP_{max}) was reduced with DK (top); dP/dt_{max} was constant with DK+EP and was diminished without pacing (bottom). Mean ± SD during pacing (EP), DK-AH 269 10^{-6} M (DK+EP) and without pacing (DK–EP)

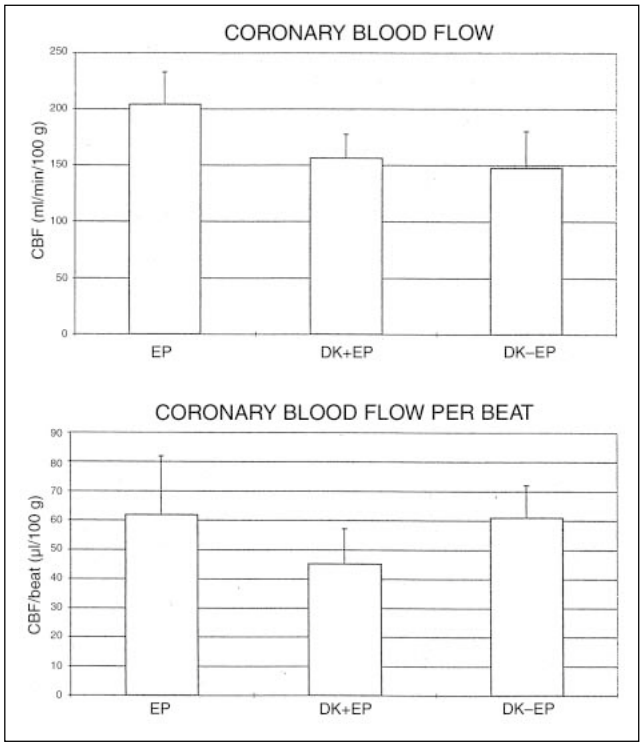

Figure 6. The global coronary blood flow (CBF) was reduced with DK+EP and remained constant after pacing was terminated (top) while the coronary blood flow per beat (CBF/beat) was increased in the last experimental step (bottom). Mean ± SD during pacing (EP), DK-AH 269 10^{-6} M (DK+EP) and without pacing (DK–EP)

ance was increased with DK (EP: 0.56 ± 0.24, DK+EP: 0.80 ± 0.34, DK–EP: 0.79 ± 0.42 mmHg (ml/min/100 g). MVO_2 slightly decreased in the presence of DK and further without pacing (EP: 9.8 ± 3.0, DK+EP: 8.7 ± 3.0, DK–EP: 6.2 ± 3.8 ml/min/100 g) (Fig. 7), and the MVO_2 per beat was reduced after DK with pacing but not without pacing (EP: 61 ± 28, DK+EP: 54 ± 33, DK–EP: 61 ± 30 μl/beat/100 g).

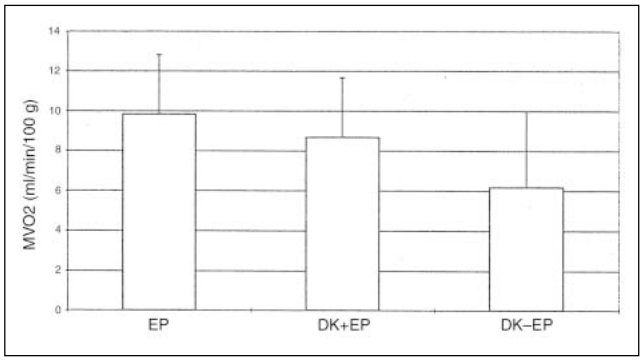

Figure 7. The myocardial oxygen consumption was decreased with DK+EP and furthermore with DK alone. Mean ± SD during pacing (EP), DK-AH 269 10^{-6} M (DK+EP) and without pacing (DK–EP

Discussion

Heart rate

Together with wall stress and contractile state, heart rate is a major determinant of myocardial oxygen demand [2]. Therefore, tachycardia in patients with coronary artery disease will likely induce detrimental ischaemia. Conversely, a decrease in heart rate may prove beneficial. With this rationale, we examined the haemodynamic effects of a novel bradycardic agent of the benzazepinone-type, DK-AH 269 (DK), that is reported to solely act on sinus node cells [20].

In former studies with buffer-perfused rabbit hearts [13] or on hearts of anaesthetized pigs [12], heart rate was significantly reduced and diastole prolonged after administration of DK. In other [11] and in our own [13] studies, DK was shown to reduce heart rate dose-dependently. Thus, only one dose was used in this study that was known to reduce heart rate by about one third. The bradycardic effect of 10^{-6} M DK on heart rate (37 % in this study) compares well with former studies using UL-FS 49 (zatebradine), a specific bradycardic agent of the same type [8–10, 21].

Bradycardic agents have no major effect on the duration of systole and, thus, prolongation of the cardiac cycle results in a prolonged diastole [22]. In this study, the length of diastole was almost doubled after DK. This is consistent with the mechanism of action of such I_f channel blocking agents, since these channels open only during diastole and therefore do not influence membrane potential during systole. Blockade of I_f channels results in a selective slowing of the spontaneous diastolic depolarization and therefore in a prolongation of diastole.

In particular, in the ischaemic heart two advantages should be associated with a prolonged diastole: the ventricle can more completely relax, resulting in a better end-diastolic filling and/or a lower end-diastolic pressure. On the other hand, myocardial perfusion should be improved since myocardial inflow – which occurs predominantly in diastole – should be increased [23].

Systolic function

The force-frequency relation (= staircase phenomenon) relates the contractile state to heart rate [15, 16, 24]. As a consequence, heart rate reduction can cause a reduction of myocardial contractility [11]. At a constantly held heart rate, systolic function was only moderately reduced after administration of DK (peak left ventricular pressure and stroke volume both by 16 % and dP/dt_{max}, unchanged).

In a former study using the same experimental model [25], the time-dependent deterioration of left ventricular function after administration of buffer was assessed. After a comparable duration of the protocol (ca. 45 min), left ventricular peak pressure, stroke volume and dP/dt_{max} were decreased by 8, 12 and 6 %, respectively, whereas heart rate remained unchanged. Thus, the change seen after DK can in part be attributed to the functional decay of the experimental model, and we exclude a major negative inotropic effect of DK in our experimental model.

If, however, electrical pacing was terminated and heart rate was allowed to decrease (37 %), systolic function was clearly decreased: peak left ventricular pressure, stroke volume and dP/dt_{max} were all decreased (18, 19, and 36 %). If these measures of systolic function were again corrected for the time-dependent deterioration (ca. 75 min), the pure effect of the negative staircase phenomenon was less pronounced: left ventricular peak pressure and stroke volume decreased by only 6 and 4 %, respectively. While the decrease in dP/dt_{max} (–25 %) was considerably more pronounced, it must be remembered that this measure not only reflects changes in contractile state but also depends on heart rate [26–28]. From these data we conclude that the considerably decreased heart rate was associated with an only moderately decreased systolic function in non-failing hearts. In failing human myocardium, frequency-induced potentiation of contractile force was found to be blunted or inverse [29]. We postulate from these findings that bradycardic agents either do not affect or do even improve systolic function.

The present data on the inotropic effects of DK are in concert with results from previous studies in which UL-FS 49 was used. In a study on isolated pig hearts, heart rate and in parallel, systolic function were reduced after administration of that agent [23]. During pacing at control rate, systolic function almost completely recovered, thus, nicely demonstrating the effects of the negative force-frequency relation in non-failing hearts.

Similar to this study, DK *per se* did not exert a major negative inotropic effect in anaesthetized pigs as long as the heart rate was maintained constant [11, 12]. Furthermore, incremental DK doses produced no change in ventricular or systemic pressures in those studies. During the course of the experiment, however, dP/dt_{max} decreased gradually by 16 % in the DK-treated animals, whereas this measure spontaneously decreased by 12 % during the time course of the experiment in the placebo group [11]. Thus, the agent exerts only a moderate negative inotropic effect.

Diastolic function

The effect of heart rate on myocardial relaxation has been carefully studied, but the results are not consistent. Whereas heart rate changes only slightly affect the time constant of left ventricular pressure decay (τ) [30], this measure was decreased if heart rate was increased [31]. Similarly, the impaired dP/dt_{min} after DK was more likely due to the reduced heart rate rather than to a direct drug effect on early relaxation. In contrast to the further reduction of dP/dt_{min} after termination of pacing, τ remained nearly constant in this study. Likely, τ is less heart rate-dependent than dP/dt_{min} [30]. Additional results from

a study on isolated pig hearts treated with UL-FS 49 support the notion that the benzazepinone-type agents do not affect early relaxation: in that study, neither dP/dt_{min} nor τ were significantly affected [8].

End-diastolic ventricular filling is inversely related to heart rate, as shown by vagal or atrial stimulation [32]. The prolonged diastole positively influences left ventricular filling [33], which, in turn, will affect end-diastolic pressure. Bradycardic agents must hereby not necessarily change diastolic pressure [8] and, therefore, the variable findings suggest that methodological aspects (experimental model, working point on the end-diastolic pressure-volume curve, degree of bradycardia) represent important factors in determining the effects of bradycardic agents on the end-diastolic pressure. Thus, the decreased end-diastolic pressure after DK without pacing in this study fits the concept that a reduction in heart rate is associated with a more complete late ventricular relaxation.

Global and regional coronary blood flow, myocardial oxygen consumption

Heart rate reduction with sinus node inhibitors such as alinidine [34], zatebradine [21, 23], or DK-AH 269 [11–13] is associated with a prolonged diastole, and thus, should allow an increase in coronary blood flow if it is limited by a stenosis. However, with almost intact vasculature, coronary flow in buffer-perfused hearts was decreased by 16 % (DK-AH 269 at 10^{-6} M; [13]) and in blood-perfused hearts even by 30 % [14].

The effects of bradycardia, however, look different, when coronary flow per beat is analyzed. It was significantly increased in our buffer-perfused hearts and remained unchanged in our blood-perfused hearts. In the present study, coronary blood flow per beat was considerably increased (+36 %) without pacing.

The relation between subendocardial and subepicardial flow remained nearly constant over the three experimental steps. This finding is in concert with our two preceding studies [13, 14]. From the previous studies and the present study on non-ischaemic myocardium, however, we cannot conclude whether bradycardia produces a selective increase in subendocardial blood flow in the ischaemic myocardium as described in other studies [35, 36].

After administration of 10^{-6} M DK, the coronary resistance was increased by 43 % in this study. It was similarly increased (49 %) in blood-perfused hearts [13] and less pronounced (21 %) in buffer-perfused hearts [14]. At first sight, the increased resistance would argue for a vasoconstrictive potency of DK. We suggest, however, an indirect effect that was due to the reduced oxygen requirements, ie vasoconstriction was initiated via autoregulation [21, 35].

Ventricular function was reduced in the non-paced hearts after administration of DK. In parallel, MVO_2 was decreased, a fact that might already be beneficial in the normal myocardium. Ischaemic myocardium should, however, benefit much more from reducing heart rate and the concomitantly reduced oxygen requirements; heart rate in this study was reduced by 37 % in the DK-treated hearts compared to control.

In summary: Although the heart rate was reduced by 37 % by the novel sinus node inhibitor DK-AH 269, systolic function in the isolated rabbit hearts was not significantly impaired. Similarly, early relaxation was not affected much and end-diastolic left ventricular pressure was diminished as a consequence of the considerably prolonged diastole. In parallel with these changes, the myocardial oxygen consumption was decreased.

Conclusion: The agent seems useful in the treatment of various heart diseases by improving myocardial energetic balance, and it seems of value in the operating theatre by decreasing unwanted tachycardia after cardiac surgery or by inducing bradycardia during coronary artery bypass procedures on the beating heart.

Acknowledgment

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References

1. Laurent D, Bolene-Williams C, Williams FL, Katz LN. Effects of heart rate on coronary flow and cardiac oxygen consumption. Am J Physiol 1956; 185: 355–8.
2. Braunwald E. Control of myocardial oxygen consumption. Am J Cardiol 1971; 27: 416–32.
3. Erdmann E. Digitalis therapy – relevance of heart rate reduction. Basic Res Cardiol 1998; 93: 156–9.
4. Gillam PMS. Use of propranolol in angina pectoris. Brit Med J 1965; 2: 337–9.
5. Goethals MA, Raes A, van Bogaert P. Use-dependent block of the pacemaker current I_f in rabbit sinoatrial node cells by zatebradine (UL-FS 49). Circulation 1993; 88: 2389–401.
6. Lechat P. Beta-blocker treatment in heart failure. Role of heart rate reduction. Basic Res Cardiol 1998; 93: 148–55.
7. Campbell DL, Rasmusson RL, Strauss HC. Ionic current mechanisms generating vertebrate primary pacemaker activity at the single cell level: An integrative view. Ann Rev Physiol 1992; 54: 279–302.
8. Chen Z, Reuter B. The sinus node inhibitor UL-FS 49 lacks significant inotropic effect. J Cardiovasc Pharmacol 1992; 19: 264–71.
9. Ryu K-H, Tanaka N, Ross JJ. Effects of sinus node inhibitor on the normal and failing rabbit heart. Basic Res Cardiol 1996; 91: 131–9.
10. Schulz R, Rose J, Skyschally A, Heusch G. Bradycardic agent UL-FS 49 attenuates ischemic regional myocardial dysfunction and reduces infarct size in swine: comparison with the β-blocker atenolol. J Cardiovasc Pharmacol 1995; 25: 216–28.
11. Guth BD, Dilger B. Effect of DK-AH 3 CI and its stereoisomers DK-AH 269 CI and DK-AH 268 CI on spontaneous beating rate and force of contraction in isolated guinea pig atria. 1992; personal communication.
12. Guth BD, Dietze T. Acute hemodynamic effects of DK-AH 269 CI in the anesthetized pig with or without atrial pacing. 1992; personal communication.
13. Granetzny A, Schwanke U, Schmitz C, Schmitz-Spanke S, Arnold G, Schulte HD, Schipke JD. Effekt einer neuen bradykarden Substanz auf das isolierte Kaninchenherz. Z Kardiol 1996; 12: 953–60.
14. Granetzny A, Schwanke U, Schmitz C, Schmitz-Spanke S, Arnold G, Schäfer D, Schulte HD, Gams E, Schipke JD. Pharmacological heart rate reduction: effect of a novel, specific bradycardic agent on isolated, blood-perfused rabbit hearts. Thorac Cardiovasc Surgeon 1998; 46: 63–9.
15. Boerth RC, Covell JW, Pool PE, Ross Jr J. Increased myocardial oxygen consumption and contractile state associated with increased heart rate in dogs. Circ Res 1969; 24: 725–34.
16. Anderson PAW, Rankin JS, Arentzen CE, Anderson RW, Johnson EA. Evaluation of the force-frequency relationship as a descriptor of the inotropic state of canine left ventricular myocardium. Circ Res 1976; 39: 832–9.
17. Brieden A, Schwanke U, Arnold G, Schipke JD. A computer program to acquire and process data from the experimental laboratory. Eur J Physiol 1997; 433: P 410 (Abstract).
18. Thompson DS, Waldron CB, Coltart DJ, Jenkins BS, Webb-Peploe MM. Estimation of time constant of left ventricular relaxation. Br Heart J 1983; 49: 250–8.
19. Wilkinson L. REGM: A multivariate general linear hypothesis program. Am Statistician 1980; 34(3): 182.
20. van Bogaert P, Goethals M. Pharmacological reference of specific bradycardic agents on the pacemaker current of sheep cardiac purkinje fibres. Eur Heart J 1987; 8: 305–402.
21. Schipke JD, Harasawa Y, Sugiura S, Alexander Jr J, Burkhoff D. Effect of a bradycardic agent on the isolated blood-perfused canine heart. Cardiovasc Drugs Ther 1990; 5: 481–8.
22. van Woerkens LJ, van der Giessen WJ, Verdouw PD. The selective bradycardic effects of zatebradine (UL-FS 49) do not adversely affect left ventricular function in conscious pigs with chronic coronary artery occlusion. Cardiovasc Drugs Ther 1992; 6: 59–65.
23. Breall JA, Watanabe J, Grossman W. Effect of zatebradine on contractility, relaxation and coronary blood flow. J Am Coll Cardiol 1993; 21: 471–7.
24. Miura T, Miyazaki S, Guth BD, Kambayashi M, Ross J. Influence of the force-frequency relation on left ventricular function during exercise in conscious dogs. Circulation 1992; 86: 563–71.
25. Korbmacher B, Sunderdiek U, Schulte HD, Arnold G, Schipke JD. Comparison between the effects of a novel Ca^{++} sensitizer and a phosphodiesterase inhibitor on stunned myocardium. J Pharmacol Exp Ther 1995; 275: 1433–41.

26. Maughan WL, Sunagawa K, Burkhoff D, Graves WLJ, Hunter WC, Sagawa K. Effect of heart rate on the canine end-systolic pressure-volume relationship. Circulation 1985; 72: 654–9.
27. Reeves TJ, Hefner LL, Jones WB, Coghlan C, Prieto G, Carroll J. The hemodynamic determinants of the rate of change in pressure in the left ventricle during isometric contraction. Am Heart J 1960; 745–61.
28. Mahler F, Ross Jr J, O'Rourke RA, Covell JW. Effects of changes in preload, afterload and inotropic state on ejection and isovolumic phase measures of contractility in the conscious dog. Am J Cardiol 1975; 35: 626–34.
29. Hasenfuss G, Reinecke H, Studer R, Pieske B, Meyer M, Drexler H, Just H. Calcium cycling proteins and force-frequency relationship in heart failure. Basic Res Cardiol 1996; 91: 17–22.
30. Weiss JL, Frederiksen JW, Weisfeldt ML. Hemodynamic determinants of the time-course of fall in canine left ventricular pressure. J Clin Invest 1976; 58: 751–60.
31. Kambayashi M, Miura T, Oh BH, Rockman HA, Murata K, Ross J. Enhancement of the force-frequency effect on myocardial contractility by adrenergic stimulation in conscious dogs. Circulation 1992; 86: 572–80.
32. Berglund E, Borst HG, Duff F, Schreiner GL. Effect of heart rate on cardiac work, myocardial oxygen consumption and coronary blood flow in the dog. Acta Physiol Scand 1958; 42: 185–98.
33. Guth BD, Heusch G, Seitelberger R, Ross Jr J. Elimination of exercise-induced regional myocardial dysfunction by a bradycardic agent in dogs with chronic coronary stenosis. Circulation 1987; 75: 661–9.
34. Schad H, Heimisch W, Haas F, Mendier N. Effect of the 'spezific bradycardic agent' alinidine on the function of ischemic myocardium. Thorac Cardiovasc Surgery 1991; 39 (Suppl): 211–6.
35. Dämmgen JW, Lamping KA, Gross GJ. Actions of two new bradycardic agents, AQ-AH 208 and UL-FS 49, on ischemic myocardial perfusion and function. J Cardiovasc Pharmacol 1985; 7: 71–9.
36. Gross GJ, Dämmgen JW. Beneficial effects of two specific bradycardic agents AQ-A 39 (falipamil) and AQ-AH 208 on reversible myocardial reperfusion damage in anesthetized dogs. J Pharmacol Exp Ther 1989; 238: 422–8.

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