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# Characterization of transient outward $K^+$ current and ultra-rapid delayed rectifier $K^+$ current in isolated human atrial myocytes from patients with congestive heart failure

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**KEY WORDS** potassium channels; congestive heart failure; heart atrium; myocardium; patch-clamp techniques

## ABSTRACT

**AIM**: To study the properties of transient outward $K^+$ current ($I_{to}$) and ultra-rapid delayed rectifier $K^+$ current ($I_{Kur}$) in isolated human atrial myocytes from patients with congestive heart failure (CHF). **METHODS**: Single cells were isolated from CHF patients with collagenase and protease. $I_{to}$ and $I_{Kur}$ were recorded using whole cell patch-clamp technique. **RESULTS**: The activation and inactivation of $I_{to}$ were voltage-dependent and time-dependent. The half-activation and half-inactivation voltage were (15 ± 12) mV and (−45 ± 4) mV respectively. When membrane potential went up from −40 mV to +60 mV, the activation time constant means decreased from (6.9 ± 2.3) ms to (1.40 ± 0.20) ms, while the inactivation time constant means decreased from (69 ± 17) ms to (21 ± 14) ms. Otherwise, the mean reactivation time constants was (125 ± 65) ms when the membrane potential was held at −80 mV, but the recovery was not complete during the interval observed. $I_{to}$ showed less frequency-dependent reduction at test frequency between 0.2 − 2 Hz. Compared with $I_{to}$, the activation of $I_{Kur}$ only showed voltage-dependence, without time-dependence. Its mean current densities was (3.4 ± 0.7) pA · $pF^{-1}$ when test potential was +60 mV. The half activation voltage of $I_{Kur}$ was (23 ± 14) mV. No clear frequency-dependence was observed at the same frequency range of $I_{to}$ either. **CONCLUSION**: $I_{to}$ and $I_{Kur}$ are important outward potassium channel currents in isolated human atrial myocytes from CHF patients and they have different kinetic properties.

## INTRODUCTION

Since the pioneering work of Trautwein *et al*[1] on human heart muscle, several investigators have been interested in the electrophysiological properties of human cardiac tissue. Based on patch-clamp techniques and dissociation methods of human cardiac cells, many reports[1,4,12] abroad have dealt with ionic currents on single human cardiac myocytes under different disease states, but very few experimental investigations on potassium channel current of human atrial cells from congestive heart failure (CHF) patients have been published so far at home.

Transient outward $K^+$ current ($I_{to}$) and ultra-rapid delayed rectifier $K^+$ current ($I_{Kur}$) are the major outward currents in human atrial myocytes. They take part in the repolarization process of cardiac myocytes, and their quantity or kinetic properties may have obvious effects on action potential duration and arrhythmogenesis. So it is of direct significance to clarify the properties of $I_{to}$ and $I_{Kur}$ for the prevention and treatment of heart failure. The present study was designed to investigate the characteristics of $I_{to}$ and $I_{Kur}$ in atrial myocytes from CHF patients.

## MATERIALS AND METHODS

**Myocyte preparations** Specimens of human right atrial appendage were obtained from CHF patients undergoing coronary arterial bypass surgery. Patients varied in age from 17 to 56 with functional classification of heart function between Ⅱ − Ⅲ degree. The procedure for obtaining the tissues was approved by the Ethics Committee of Xiehe Hospital, Wuhan. All atrial

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specimens were grossly normal at the time of excision. Upon excision, the samples were immediately placed in oxygenated cardioplegia solution (4 ℃) for transport to the laboratory. The time between excision and the beginning of laboratory processing was no more than 1 h. The cell isolation procedure was developed based on a technique described by Koster *et al*[2]. The myocardial specimens were cut with scissors into cubic chunks and placed in normal $Ca^{2+}$-free Tyrode's solution. Agitation of the chunks was ensured by continuous bubbling with $O_2$ and by stirring with a magnetic bar. After 21 min in this solution, the chunks were incubated in a similar solution containing collagenase 0.5 g/L (Sigma, type I), protease 0.4 g/L (Sigma, type XXIV), and bovine serum albumin 0.1 g/L (Sigma, fraction V) at 37 ℃. The first supernatant was removed after 45 min and discarded. Chunks were then reincubated in a second enzyme solution only containing collagenase 0.5 g/L (Sigma, type I). Microscopic examination of the medium was performed every 5 min to determine the number and quality of the isolated cells. When the yield appeared to be maximal, the cell suspension was centrifuged at 12 g for 3 min and then stored at room temperature in normal $Ca^{2+}$-free Tyrode's solution. The $Ca^{2+}$ concentration was then slowly increased in increments of 0.6 mmol/L up to the final concentration of 1.8 mmol/L. Isolated myocytes were kept in the medium at least 1 h before being used.

**Electrophysiological measurements** Experiments were carried out by standard whole-cell recording techniques using a patch-clamp amplifier (model EPC-9, List Instruments, Germany) with a 100 MΩ feedback resistor. Microelectrodes were pulled from borosilicate glass capillaries (outer diameter: 1.5 mm) and had resistances of 3.5 – 5.0 MΩ. Series resistance was compensated as much as possible (30 % – 80 %). To counteract the differences in cell size, current amplitudes were expressed in terms of current density. In order to eliminate the contamination of L-type $Ca^{2+}$ current ($I_{Ca}$) and $Na^+$ current ($I_{Na}$), nifedipine 5 μmol/L was used to block $I_{Ca}$ and a prepulse to – 40 mV from holding potential of – 80 mV was used to inactivate $I_{Na}$. All experiments were carried out at room temperature.

**Solutions** The cardioplegic solution contained (in mmol/L): NaCl 27, KCl 20, $MgCl_2$ 1.5, HEPES 5.0, Glucose 274; pH adjusted to 7.0 with NaOH. The normal Tyrode's solution contained (in mmol/L): NaCl 140, KCl 5.4, $CaCl_2$ 1.8, $MgCl_2$ 0.5, HEPES 5.0, Glucose 5.0; pH adjusted to 7.4 with NaOH. $Ca^{2+}$-free Tyrode's solution was made by omitting $CaCl_2$ from the normal Tyrode's solution. Patch-electrode solutions had the following composition (in mmol/L): Potassium aspartate 120, KCl 20, $MgCl_2$ 1.0, $KH_2PO_4$ 1.0, $Na_2ATP$ 5.0, egtazic acid 5.0, HEPES 5.0; pH adjusted to 7.2 with KOH.

**Statistical analysis** Nonlinear curve-fitting programs or SigmaPlot was used to perform curve-fitting procedures. Results are presented as $x \pm s$. Unpaired $t$-test was used to evaluate the statistical significance of differences between two group means. $P < 0.05$ were considered statistical significance.

## RESULTS

**Prevalence and general properties of $I_{to}$** Representative $I_{to}$ trace was elicited by a 300 ms depolarizing pulse to +60 mV from a holding potential of – 80 mV. The outward current reached the peak quickly, and then dropped rapidly too. The duration of $I_{to}$ was short, having marked time-dependence. When 4-AP 200 μmol/L was present, the amplitude of $I_{to}$ decreased (Fig 1).

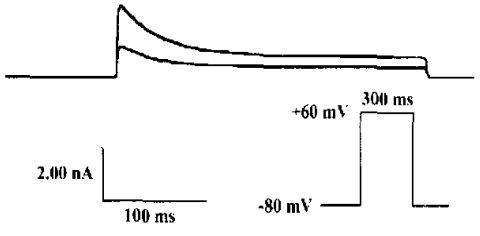


**Fig 1. Recordings of transient outward potassium current ($I_{to}$) from a myocyte in the absence (upper) and presence (below) of 4-AP 200 μmol/L. Currents were elicited by depolarization to + 60 mV for 300 ms from a holding potential of – 80 mV.**

**Current-voltage relationships of $I_{to}$** To measure the voltage dependence of $I_{to}$, test pulses were applied for 300 ms from a holding potential of – 80 mV to potentials ranging from – 40 mV to + 60 mV in 10 mV steps after a 20-ms prepulse to – 40 mV had been delivered to inactivate $I_{Na}$. The current traces of $I_{to}$ at every membrane potential were examined. $I_{to}$ could be distinguished at potential positive to – 30 mV, and it became larger when test potential increased. Current densities of $I_{to}$ were (11 ± 3) pA/pF at + 60 mV. The

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peak site went forward when the test potential increased. However, its duration at top was shorter, and then decreased rapidly, till a steady state (Fig 2).

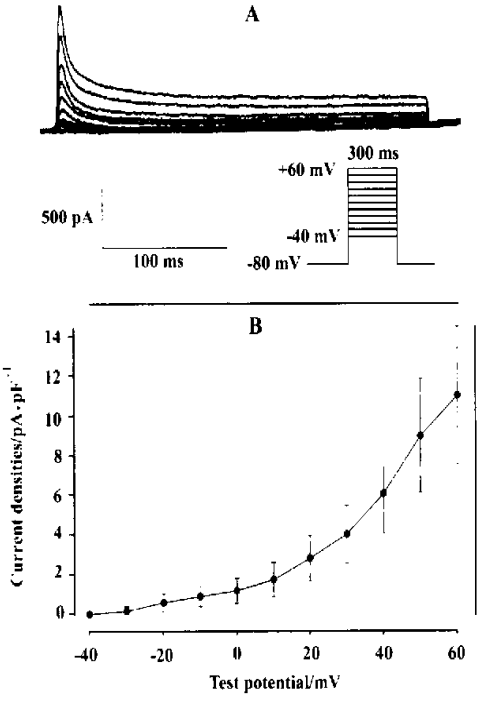


**Fig 2. $I_{to}$ in myocytes from human atrium. A: Original current traces elicited in response to selected voltage steps (-40 to +60 mV) from the holding potential -80 mV. Stimulation rate: 2 Hz. B: The current-voltage relationship of $I_{to}$. $n$ = 10 myocytes from 3 hearts. $\bar{x} \pm s$.**

**Voltage-dependent activation of $I_{to}$** The voltage dependence of $I_{to}$ activation was determined by calculating an activation variable with raw data (stimulation protocol was identical to that in Fig 2). Normalized currents were transferred to electric conductance ($g$) and fitted according to Boltzmann equation: $G = 1/\{1 + \exp[-(V - V_{1/2})/k]\}$, where $V$ is the membrane potential, $V_{1/2}$ is the membrane potential of half maximum activation, it determines the curve location, and $k$ is the slope of the activation curve, it represents the curve gradient. In this experiment, the $V_{1/2}$ was (15 ± 6) mV, and the $k$ was (15 ± 4) mV (Fig 3).

**Voltage-dependent inactivation of $I_{to}$** The steady-state inactivation of $I_{to}$ was evaluated with 2000 ms conditioning potential between -80 mv to 0 mV in increments of 10 mV every 10 s after a 20 ms prepulse to -40 mV to inactivate $I_{Na}$, and then $I_{to}$ was recorded during a 300 ms test pulse to +60 mV. Inactivation curve was obtained by fitting raw data with Boltzmann equation: $I = 1/\{1 + \exp[(V - V_{1/2})/k]\}$, where $V$ is the membrane potential, $V_{1/2}$ is the membrane potential of half maximum inactivation, it determines the curve location, and $k$ is the slope of the inactivation curve, it represents the curve gradient. When conditioning potential was -80 mV or more negative (results not illustrated), channel inactivation was not noticeable, but its degree of inactivation became augmented when the potential increased and was nearly complete at 0 mV. The $V_{1/2}$ was (-45 ± 4) mV and the $k$ was (12.3 ± 2.9) mV (Fig 4).

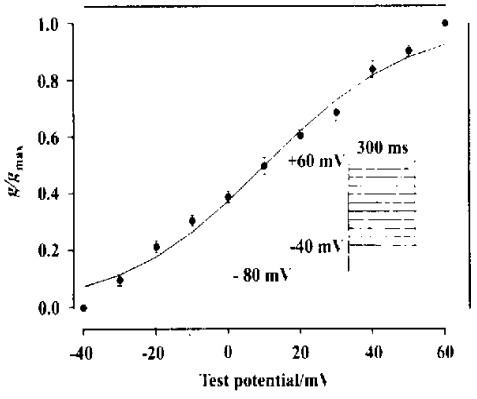


**Fig 3. Voltage-dependent activation curve of $I_{to}$. $n$ = 10 myocytes from 6 hearts. $\bar{x} \pm s$.**

**Recovery from inactivation of $I_{to}$** The time dependence of $I_{to}$ reactivation was studied with a paired-pulse protocol. Identical 200 ms pulses ($P_1$ and $P_2$) to +60 mV from a holding potential of -80 mV were delivered every 10 s, with varying $P_1$-$P_2$ intervals. The current during $P_2$ relative to the current during $P_1$ was determined as a function of the $P_1$-$P_2$ reactivation interval. Average data were fitted by a monoexponential equation. $I_{to}$ was not completely recovered during the interval observed. The recovery time constant ($\tau$) was (125 ± 65) ms (Fig 5).

**Frequency-dependent reduction of $I_{to}$** Because $I_{to}$ recovery showed significant time dependence, frequency-dependent reduction of $I_{to}$ might be expected at physiological relevant frequencies. We examined the effect of increasing frequency of pulses from 0.2 to 0.5, 1, 2 Hz on $I_{to}$. Test pulses to +60 mV from a holding potential of -80 mV were maintained for 300 ms after a 20-ms prepulse to -40 mV had been delivered. The

currents (from 11 pulses) at each frequency were normalized to the value at 1st pulse, and the currents (at 11th pulse) at different frequency were normalized to the value of the same pulse at 0.2 Hz. No obvious changes are shown in $I_{to}$ with repeated pulses at each frequency by an 11-pulse train and so are the currents at different test frequency.

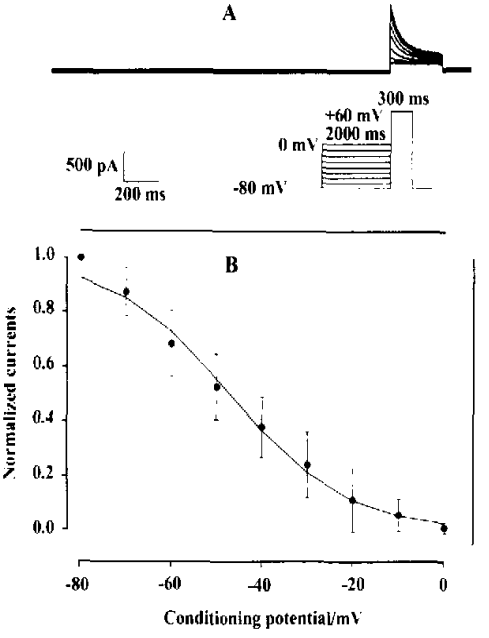


**Fig 4. Voltage-dependent inactivation of $I_{to}$. A: Representative recordings used to determine voltage dependence of $I_{to}$ inactivation with protocol shown in inset. B: Voltage-dependent inactivation relationships for $I_{to}$. $n = 11$ myocytes from 6 hearts. $\bar{x} \pm s$.**

**Time-dependent activation of $I_{to}$** We investigated the time dependence of $I_{to}$ activation with 300 ms depolarizing pulses from the holding potential of − 80 mV to different test potentials ranging from − 40 mV to + 60 mV in 10 mV steps after a 20-ms prepulse to − 40 mV had been delivered. Raw data were best fitted by a monoexponential equation. The activation time constant ($\tau$) values became smaller when test potential increased at the ranging from − 20 mV to + 10 mV (decreased from 6.9 ms ± 2.3 ms at − 20 mV to 1.5 ms ± 0.3 ms at + 10 mV), indicating that the time-dependent activation of $I_{to}$ was accelerated by the increase of test potential in this voltage range. But it was stable at potential positive to + 10 mV.

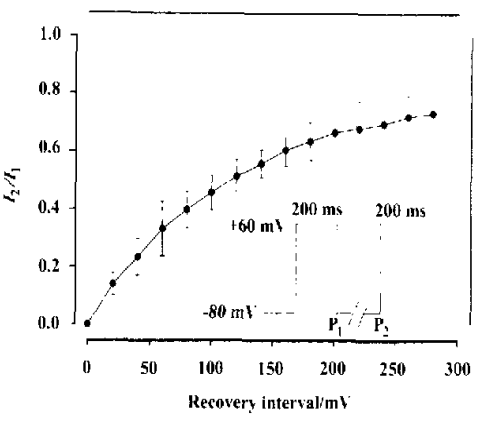


**Fig 5. Recovery of $I_{to}$ from inactivation. Experimental protocol was shown in inset. $n = 7$ myocytes from 4 hearts. $\bar{x} \pm s$.**

**Time-dependent inactivation of $I_{to}$** The time dependence of $I_{to}$ inactivation was studied with 300 ms depolarizing pulses from the holding potential of − 80 mV to different test potentials ranging from − 40 mV to + 60 mV in 10 mV steps after a 20-ms prepulse to − 40 mV had been delivered. Raw data were best fitted by a monoexponential equation. The inactivation time constant ($\tau$) values became smaller when test potential increased at the ranging from − 20 mV to + 60 mV (decreased from 91 ms ± 22 ms at − 20 mV to 21 ms ± 14 ms at + 60 mV), indicating that the time-dependent inactivation of $I_{to}$ was substantially accelerated by the increase of test potential.

**Prevalence and general properties of $I_{Kur}$** $I_{Kur}$ was elicited by 200 ms depolarizing pulse from the holding potential of − 80 mV 10 ms after 200 ms prepulse to + 60 mV had been delivered. The magnitude of $I_{Kur}$ was measured as the difference between the peak outward current and the steady-state current at the end of the depolarizing step. For analysis of average currents, $I_{Kur}$ was normalized to cell capacitance to evaluate current density and thereby control for variations in cell sizes. The $I_{Kur}$ derived from the second pulse was not different from that at the end of the first 200 ms pulse. Therefore, we measured $I_{Kur}$ as the amplitude of the current at the end of the first or second pulse relative to the zero current level. $I_{Kur}$ activated rapidly, but it was not inactivated during the interval observed (Fig 6).

To demonstrate that the $I_{Kur}$ induced from human atrial myocytes is the same as the $I_{Kur}$ reported by Wang *et al*[3], we added 4-AP, atropine and $BaCl_2$ in the

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external solution. The results indicated that $I_{Kur}$ was completely suppressed by 4-AP 1 mmol/L, but atropine 0.1 μmol/L could not affect it. When the duration of test pulse was extended to 1000 ms, the amplitude and shape of $I_{Kur}$ were not significantly altered. These results indicated that $I_{Kur}$ observed in this experiment was indeed the $I_{Kur}$ previously reported in human atrial myocytes.

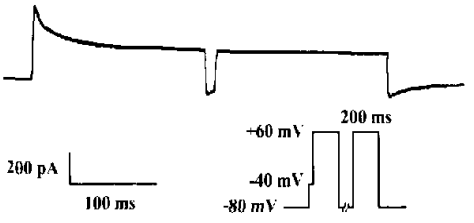


**Fig 6. Recording of ultra-rapid delayed rectifier potassium current ($I_{Kur}$) from a representative myocyte. $I_{Kur}$ was elicited by 200 ms depolarizing pulse from the holding potential of −80 mV 10 ms after 200 ms prepulse to +60 mV had been delivered to inactivate $I_{to}$.**

**Current-voltage relationships of $I_{Kur}$** The current-voltage relations of $I_{Kur}$ were determined using 300 ms depolarizing pulses from a holding potential of −80 mV to potentials ranging from −40 mV to +60 mV in 10 mV steps after a 20-ms prepulse to −40 mV had been delivered to inactivate $I_{Na}$. $I_{Kur}$ was obvious at potential positive to −30 mV, and becoming larger when test potential increased. Current densities of $I_{Kur}$ were (3.4±0.7) pA/pF, at +60 mV (Fig 7).

**Voltage dependent activation of $I_{Kur}$** To study the voltage-dependent activation of $I_{Kur}$, a prepulse to −40 mV was applied to largely inactivate $I_{Na}$. After this prepulse, the membrane was clamped to voltage between −40 mV to +60 mV in 10 mV steps for 300 ms from the holding potential of −80 mV. The currents were transferred to conductance ($G$) and fitted to Boltzmann equation to produce activation curve. The equation and the meanings of its letters were the same as Fig 3. The $V_{1/2}$ was 23 mV ± 14 mV, and the $k$ was 13 mV ± 4 mV (Fig 8).

**Frequency-dependence of $I_{Kur}$** To clarify the relations between heart rate change and $I_{Kur}$, we studied the frequency-dependence of $I_{Kur}$ with 300 ms repeated pulsing (11 pulses) from −80 mV to +60 mV at 0.2, 0.5, 1, and 2 Hz. The current during each frequency expressed as a function of the first pulse in a 11-pulse train (60 s interval between trains), and the current at different frequency was normalized to the value at 0.2 Hz. No obvious changes are shown in $I_{Kur}$ with repeated pulses at each frequency and so are those at different test frequency.

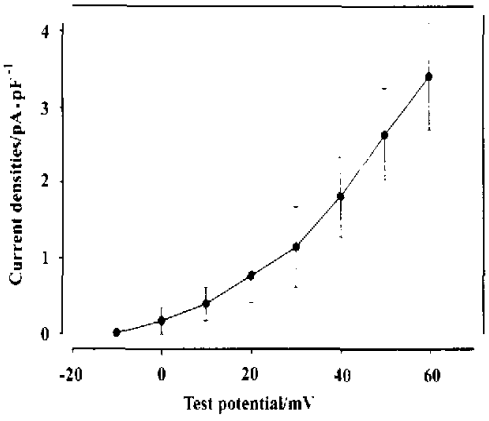


**Fig 7. Current-voltage ($I$-$V$) relationships for $I_{Kur}$ and test potential examined. Original current traces were shown in Fig 2A. Results were normalized with respect to cell capacitance. $n$ = 8 myocytes from 3 hearts. $\bar{x} \pm s$.**

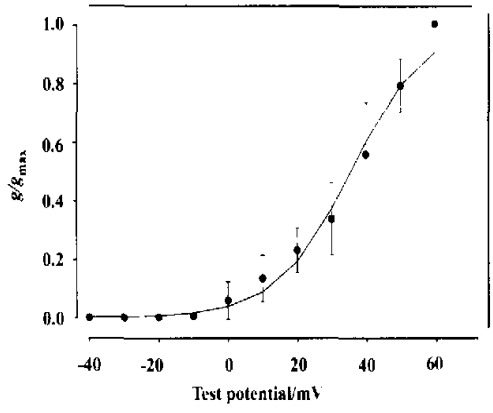


**Fig 8. Voltage-dependent activation curve of $I_{Kur}$. Original current traces were shown in Fig 2A. $n$ = 8 myocytes from 3 hearts. $\bar{x} \pm s$.**

## DISCUSSION

Recent papers indicated that certain potassium such as $I_{to}$ was related with human diseases[4,5,12]. The electrophysiological properties in cardiac myocytes from CHF patients were changed obviously. Because of race

difference, the results abroad might be inconsistent with those at home. Our experiment indicated that $I_{to}$ and $I_{Kur}$ were both sensitive to 4-AP. The activation and inactivation of $I_{to}$ were rapid with voltage and time dependence, but no frequency dependence was discovered obviously. The recovery of $I_{to}$ was not complete when holding potential was -80 mV. Besides, the current shape, current density when depolarizing to +60 mV, the half maximum activation or inactivation potential, and the recovery time constant of $I_{to}$ were identical to the reports by other researchers[6,7]. The activation of $I_{Kur}$ also had voltage dependence, but no time and frequency dependence could be seen. These characteristics were also consistent with the reports by Wang *et al*[3] and Gross *et al*[8]. All of above suggested that the properties of $I_{to}$ and $I_{Kur}$ in isolated human atrial myocytes from CHF patients were unanimous in those at home and abroad. $I_{to}$ and $I_{Kur}$ had no race difference.

Wettwer *et al*[7] and Li *et al*[9] thought that the recovery speed and degree of $I_{to}$ were related to holding potential. Its reactivation speed was slow at -40 mV and became faster at potential negative to -40 mV, but the reactivation level would drop at this condition. The current values of $I_{to}$ at -100 mV reached only 80 % of the control pulse even after 6 s of test pulse. The conclusion was consistent with our results (in our experiment, the $I_{to}$ recovery was not completive when membrane potential was clamped to -80 mV).

Our results showed that the process of time-dependent inactivation and reactivation of $I_{to}$ could be fitted to single exponential function as the same as majority of researchers. But, the data of Li *et al*[9] could only be fitted to biexponential function. The reason of this difference was unclear. Wettwer *et al*[7] and Beuckelmann *et al*[4] noticed that $Cd^{2+}$ could change the activation and inactivation characteristics of the $I_{to}$ and interfere with certain parameters measurement. Gotoh *et al*[10] reported that nifedipine could reduce the magnitude of $I_{to}$, accelerate its inactivation. So, the differences between the kinds or concentrations of blockers maybe lead to the changes in inactivation and reactivation kinetics of $I_{to}$.

The current density of $I_{Kur}$ was $(3.4 \pm 0.7)$ pA/pF at +60 mV in this experiment, but the results reported by Seki *et al*[6] was $(7.5 \pm 1.7)$ pA/pF, 1 more times larger than former. Tracing the study process, we could see that the samples used by Seki *et al* might not be defined coming from congestive heart failure patients. If the effect of experimental condition and other causes (such as temperature, external solution, holding potential, stimulus duration, and voltage) could be excluded, the results could just be compared with each other, thus drawing the conclusion that the current density of $I_{Kur}$ decreased when congestive heart failure happened, further leading to the change at electrophysiology of cardiac myocytes.

Because of the pathogenesis of CHF remaining unclear, the measure to the disease was limited. Clarifying the properties of $I_{to}$ and $I_{Kur}$ in cardiocytes isolated from CHF patients were helpful to the basic research and clinical treatment of congestive heart failure.

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## REFERENCES

1 Trautwein W, Kassebaum DG, Nelson RM, Hecht HH. Electrophysiological study of human heart muscle. Circ Res 1962; 10: 306-12.
2 Koster OF, Szigeti GP, Beuckelmann DJ. Characterization of a $[Ca^{2+}]_i$-dependent current in human atrial and ventricular cardiomyocytes in the absence of $Na^+$ and $K^+$. Cardiovasc Res 1999; 41: 175-87.
3 Wang Z, Fermini B, Nattel S. Sustained depolarization-induced outward current in human atrial myocytes. Evidence for a novel delayed recitifier $K^+$ current similar to kv1.5 cloned Channel Currents. Circ Res 1993; 73: 1067-76.
4 Beuckelmann DJ, Nabauer M, Erdmann E. Alterations of $K^+$ currents in isolated human ventricular myocytes from patients with terminal heart failure. Circ Res 1993; 73: 379-85.
5 Priebe L, Beuckelmann DJ. Simulation study of cellular electric properties in heart failure. Circ Res 1998; 82: 1206-23.
6 Seki A, Hagiwara N, Kasanuki H. Effects of propafenone on K currents in human atrial myocytes. Br J Pharmacol 1999; 126: 1153-62.
7 Wettwer E, Amos GJ, Posival H, Ravens U. Transient outward current in human ventricular myocytes of subepicardial and subendocardial origin. Circ Res 1994; 75: 473-82.
8 Gross GJ, Castle NA. Propafenone inhibition of human atrial myocyte repolarizing currents. J Mol Cell Cardiol 1998; 30: 783-93.
9 Li GR, Feng JL, Yue L, Carrier M. Transmural heterogeneity of action potentials and $I_{to1}$ in myocytes isolated from the human right ventricle. Am J Physiol 1998; 275 (2

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Pt 2): H3o9 - 77.
10 Gotoh Y, Imaizumi Y, Watanabe M, Shibata EF, Clark RB, Giles WR. Inhibition of transient outward $K^+$ current by DHP $Ca^{2+}$ antagonists and agonists in rabbit cardiac myocytes. Am J Physiol 1991; 260 (5 Pt 2): H1737 - 42.
11 Liang Y, Sun XM, Wang XL. Properties of transient outward potassium current and inward rectifier potassium current in immature human atrial myocytes. Acta Pharmacol Sin 1999; 20: 1005 - 10.
12 Kourni S, Backer CL, Arentzen CE. Characterization of inwardly rectifying $K^+$ channel in human cardiac myocytes. Alterations in channel behavior in myocytes isolated from patients with idiopathic dilated cardiomyopathy. Circulation 1995; 92: 164 - 74.

## 充血性心衰病人心房肌细胞瞬间外向钾电流和超快延迟整流钾电流的特征

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**关键词** 钾通道；充血性心力衰竭；心房；心肌；膜片箝技术

**目的**：研究充血性心衰病人心房肌细胞瞬间外向钾电流（$I_{to}$）和超快延迟整流钾电流（$I_{Kur}$）的特征．**方法**：全细胞膜片箝技术．**结果**：心衰病人心房肌细胞上的 $I_{to}$ 的激活和失活具有电压依赖性及时间依赖性．其半数最大激活电位（$V_{1/2}$）和半数最大失活电位（$V_{1/2}$）分别为（15 ± 12）mV 和（- 45 ± 4）mV．当膜电位从 - 40 mV 升至 + 60 mV 时，激活时间常数均值从（6.9 ± 2.3）ms 降至（1.40 ± 0.20）ms，失活时间常数均值从（69 ± 17）ms 降至（21 ± 14）ms，两者均随着膜电位的增加而减小．此外，该通道从失活状态下的恢复也很快．当保持电位为 - 80 mV 时，其恢复时间常数为（125 ± 65）ms，但在此条件下通道的恢复不完全．当测试脉冲频率为 0.2 - 2 Hz 时，此通道电流未表现出明显的频率依赖性．与 $I_{to}$ 相比，$I_{Kur}$ 的激活只具有电压依赖性但无时间依赖性．当测试电位为 + 60 mV 时，其电流密度平均为（3.4 ± 0.7）pA/pF．半数最大激活电位（$V_{1/2}$）为（23 ± 14）mV．在测试脉冲频率为 0.2 - 2 Hz 的范围内，通道电流也无明显的频率依赖性．**结论**：$I_{to}$ 和 $I_{Kur}$ 是充血性心衰病人心房肌细胞上主要的外向电流，其大小和动力学特征可显著地影响心房肌细胞的电生理特性．

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