Hypopotassemia-induced U wave in electrocardiogram
(an experimental study for possible mechanism)

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Summary

To define the mechanism of hypopotassemia-induced U wave change, we performed open-chest experiments in 20 dogs and obtained following results: (1) During hemodialysis U wave amplitude of epicardial electrogram increased significantly (p < 0.05) from 0.4 ± 0.3 (mean ± SD) to 1.2 ± 0.5 mV with lowering serum potassium (K) concentrations from 3.4 ± 0.4 to 2.2 ± 0.2 mEq/l (p < 0.001) in 6 dogs. (2) These hypopotassemia-induced U waves disappeared after instillation of high K⁺ solution into the regional coronary artery, without detectable increase in systemic plasma K⁺ concentration. (3) In 10 dogs, huge (0.5–1.0 mV), delayed (corrected Q-U apex = 0.66 ± 0.16) positive U waves were induced at the epicardial surface by infusion of K⁺-free, Ca⁺⁺-rich Tyrode solution into the regional coronary artery, whereas no appearance of negative U waves was shown at the endocardial surface. (4) In all of 6 dogs with infusion of K⁺-free, Ca⁺⁺-rich solution, monophasic action potential registered with suction electrode showed early afterhyperpolarization, which corresponded to appearance of huge positive U waves. These data indicate that hypopotassemia-induced U wave may reflect early afterhyperpolarization developed in the ventricular muscle.

Key words: hypopotassemia-induced U wave, hemodialysis, epicardial electrogram, monophasic action potential, early afterhyperpolarization

Introduction

The appearance of a prominent positive U wave in the electrocardiogram of patients with hypopotassemia (2, 6, 10, 13, 16) is believed to reflect either the negative (depolarizing) afterpotentials developed in the ventricular muscle (11, 14) or prolonged repolarization of the intraventricular Purkinje fiber (15). However, for lack of established experimental data, the exact electrophysiologic basis of the U wave is still vague. The purpose of the following experiments is to document it in canine hearts from the viewpoint of early afterhyperpolarization (5) developed in the ventricular muscle.

Methods

Twenty mongrel dogs weighing 10–15 kg were anesthetized with sodium pentobarbital (30 mg/kg i.v.). Respiration was maintained by a Harvard pump delivering room air via an endotracheal tube. The chest was opened through the fifth intercostal space. The pericardium was incised widely and secured to the chest wall as a cradle for the heart. In most experiments the sinus node was crushed, and then constant rate pacing of 60–120 beats/min was performed using stainless steel bipolar hook electrodes placed at the right atrial appendage. Electrodes for recording epicardial electrograms were silver discs of 2 mm diameter embedded in circular rubber discs 10 mm in diameter. These electrodes were placed at the epicardial surface of the left ventricle and were secured by a special glue (aronalpha A Sankyo Co.).
For the endocardial electrography an electrode, made of Teflon-coated silver wire (0.125 mm in diameter) with its tip bent into a small hook, was inserted into the endocardium. Unipolar electrograms were recorded with a subcutaneous needle in the right foreleg as the indifferent electrode. With a Bioelectric Amplifier (no. 8811A, Hewlett-Packard Co.) having low- and high-frequency responses of 0.15 Hz and 300 Hz, respectively, electrograms were displayed on a Sanei Rectigraph-8K multichannel recorder at a paper speed of 25–50 mm/sec and a sensitivity of 1–2 mV/mm. In 6 dogs the epicardial electrograms were recorded using DC isolation amplifiers fed to the DC input of the recorder. In six other dogs, monophasic action potentials (MAPs) were recorded with bipolar suction electrodes. The structure of the suction electrode and the criteria for the acceptable MAPs were identical with those reported by Autenrieth et al. (1).

Aortic pressure was measured through a cannula inserted via the carotid artery, and connected to Statham P23Db transducers.

In order to induce hypopotassemia-induced U wave change, rapid removal of potassium was carried out in 6 dogs by means of a hemodialyzer (Ex®-25 Extracorporeal S.A.). A flow of 70–100 ml of blood per minute through the machine was obtained by cannulation of the femoral artery and vein. The surface area of the cellulosic membrane was approximately 1.0 m². Prior to dialysis, the dead space in the machine was filled with heparinized blood drawn from donor dogs. The composition of the bath fluid approximated the electrolytes concentration of human serum except potassium. When potassium removal was begun no potassium was present in the bath. The duration of dialysis was limited to 90–120 minutes, because the level of the plasma potassium concentration dropped rapidly during the first hour and was stabilized at about 50 % of its original value thereafter as reported by Weller et al. (17), and also by Nichopoulos and Hoffman (12). After the development of hypopotassemia-induced U wave changes in those 6 dogs, 30–50 mM/l KCl solution was instilled into the regional coronary artery at a speed of 1.0–2.0 ml/min via a direct punctured cannulation needle (0.8 mm o.d.) under continuation of hemodialysis, to test the possible elimination or augmentation of the acquired U wave change.

In 14 other dogs, in order to see the effect of regional low K⁺ on U waves, either the left anterior descending or the left circumflex coronary artery was cannulated with a perfusion circuit originating in the left carotid artery, and warmed (37 °C) and oxygenated K⁺-free Tyrode’s solution was infused via the circuit at a speed of 46 ml/min for 30 to 60 seconds. In these experiments normal Tyrode’s solution had the following millimolar composition (mM/l): NaCl, 126.0; KCl, 5.4; CaCl₂, 1.8; MgCl₂, 1.05; NaHCO₃, 24.0; NaH₂PO₄, 0.42; Glucose, 5.0.

Sodium and potassium were determined with a flame photometer using lithium as an internal standard, chloride determined by the method of Cotlove et al. (4), and calcium by means of orthocresolphthalein complexone (3).

In the present experiments there were no difficulties in the U wave identity since there existed a distinct baseline or notch between the T and U waves.

Statistical analyses were performed using standard techniques for small samples. Mean values of differences between before and after interventions in the same dogs were compared using the paired Student’s t-test.

Results

1 Hypopotassium-induced U wave change

During hemodialysis serum potassium concentration decreased from 3.4 ± 0.4 (mean ± SD) to 2.2 ± 0.2 mEq/l (p < 0.001) in 6 dogs with the concentrations of other electrolytes being maintained at almost the same levels (table 1). With acute removal of potassium, amplitude of U waves in epicardial electrograms increased significantly (from 0.4 ± 0.3 to 1.2 ± 0.5 mV, p < 0.05), ST segment tended to be depressed, and T waves became round without consistent change in amplitude. An example is shown in figure 1.

The hypopotassium-induced epicardial U waves disappeared within 60 seconds after instillation of 30–50 mM/l KCl solution into the regional coronary artery at a speed of 1–2 ml/min and reappeared after stopping instillation in all 6 dogs (fig. 2). No detectable