Fourier analysis of electrical impedance variations in urinary bladder during changes of intravesical pressure

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Abstract. Original hardware and software system was used to record and analyze the variations of electrical impedance of the urinary bladder in narcotized rats (n=7) at rest, during instillation of physiological saline into the bladder resulted in elevation of intravesical pressure, and during subsequent urination accompanied by intravesical pressure release. Fourier analysis of impedance variations revealed three periodic components with the frequencies of heartbeat, respiration, and the Mayer wave (~0.1 Hz). In resting bladder, the amplitude of Mayer and respiratory spectrum peaks were high, and they increased to a different extent during physiological elevation of intravesical pressure, while a small cardiac peak did not change significantly and tended to decrease at high intravesical pressure. Urination released intravesical pressure and restored all the peaks to the resting level. It is hypothesized that Mayer and respiratory bioimpedance oscillations of urinary bladder are neural in origin, while the cardiac peak is mainly determined by hydrodynamic arterial pulsations. The novel method can assess vesical circulation and its neural control at various phases of bladder activity.

1. Introduction
Urinary bladder function at rest and during micturition is persistently controlled by central and autonomous nervous system, and depends on adequate blood supply [1]. Alterations in these systems are reported for pathological conditions of the bladder and voiding dysfunction examined with various methods in clinical and experimental trials.

The changes in bladder blood flow during its filling were examined in male patients with the help of laser Doppler flowmetry [2]. Vascular response of normal and obstructed rabbit bladders to distension was performed by morphometry and immunohistochemistry [3]. Activation of the afferent signals from urinary bladder during its distension were examined with different methods, including systemic blood pressure and heart rate measurements, neurological study of the reflexes, and direct recording of the neural activity [4-9]. While lots of methods are known to study separately bladder neural activity and circulation, no method is available to evaluate these regulatory factors of bladder function simultaneously.

Our aim was to apply Fourier analysis to variations of urinary bladder impedance for combined assessment of its circulation and autonomic nerve activity under various intravesical pressures.

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2. Material and methods
Experiments were performed on rats anesthetized with ether and chloralose. Filling cystometry with electromanometric pressure measurements was performed via cystotomy tube inserted into the bladder dome, while the rats were allowed to urinate spontaneously through intact urethra. Two silver chloride electrodes were attached to the bladder dome and neck in longitudinal direction to measure impedance of entire bladder. Simultaneous recordings of the intravesical (detrusor) pressure (Pdet) and the real (resistive) part of bladder impedance were carried out under the following conditions: (1) resting bladder, (2) during bladder filling (3) and after infusion arrest. Each record was obtained during 4 minutes. Original hardware and software (Biola, Russia) was used to measure the variations of electrical impedance at the measuring frequency of 100 kHz and to process them with Fourier analysis.

3. Results
Infusion of saline into the bladder increased Pdet (the arrow in figure 1, A). Fourier analysis revealed three periodic components of urinary bladder impedance corresponding to the frequencies of the heart beats, respiration, and Mayer wave of about 0.1 Hz (figure 1, B, C). These impedance oscillations changed during different periods of bladder functional activity, as figure 1 shows at rest (B) and at the onset of bladder filling with physiological saline (C). Filling increased Mayer peak (I), drastically decreased respiratory peak (II), and practically unchanged the cardiac peak (III).

![Figure 1. A- simultaneous recordings of rat urinary bladder impedance (variable 1 and basal 2 components) and pressure (3). B- spectrum peaks at rest, and C- during bladder filling at 0.01 ml/min.](image)

The basal (total) impedance of bladder (curve 2, figure 1, A) decreased during bladder filling in parallel with elevation of Pdet (curve 3), which agrees with clinical urodynamic studies demonstrating negative correlation between electrical impedance and bladder volume [10].
Table 1 shows the average data on bladder physiological characteristics and oscillatory parameters. At rest, the power of Mayer peak was nearly the same as the respiratory one, while the power of cardiac peak was significantly smaller. During bladder filling, Pdet increased 6-fold accompanied by a 32% growth of the power of Mayer peak. The powers of respiratory and cardiac peaks decreased by 73% and 26%, respectively.

**Table 1.** Interrelation between intravesical detrusor pressure, power of spectrum peaks, and basal impedance of rat bladder.

| Bladder status           | Mayer ($10^{-3}$ Ohm$^2$) | Respiratory ($10^{-3}$ Ohm$^2$) | Cardiac ($10^{-3}$ Ohm$^2$) | Pdet (cm H$_2$O) | Z (Ohm) |
|--------------------------|-----------------------------|----------------------------------|-----------------------------|-------------------|--------|
| Resting bladder          | 13.97±0.03                  | 15.81±0.04                       | 0.595±0.04                  | 4.64±1.40         | 448±19 |
| During bladder filling   | 18.47±0.09                  | 4.30±0.06                        | 0.443±0.04                  | 28.40±1.76        | 367±6  |
| After infusion arrest    | 7.67±0.08                   | 14.50±0.90                       | 0.546±0.09                  | 3.29±0.79         | 469±38 |

The Mayer peak attests to neural (sympathetic) control [11] of the empty bladder at rest and increased sympathetic activity during bladder filling (figure 1). Elevation of sympathetic activity during bladder filling is a well-known phenomenon reflected by an increase in systemic blood pressure and heart rate, sympathovagal balance shift in favor of general sympathetic activation, and increased activity in sympathetic neurons, renal, and pelvic nerve [4-6]. In our experiments, the amplitude of Mayer peak increased at the onset of infusion; in the following, it either increased (figure 1) or decreased (figure 2). Supposedly, the rate of infusion and functional state of the bladder can be responsible for these diverse reactions.

**Figure 2.** Three periodic components of the bladder impedance variations revealed by Fourier analysis at rest (A) and during high intravesical pressure (52.3 cm H$_2$O) inducing the contractile responses during bladder filling at 0.1 ml/min (B).

I, II, and III are Mayer, respiratory, and cardiac peak, respectively.
Similar controversial results were reported concerning activity of afferent neurons in the urinary tract evoked by bladder distension, which could trigger both excitatory and inhibitory reflexes [8]. Various changes of bladder afferent activity was revealed by cuff electrode recordings from the pelvic nerve during the changes in bladder pressure [7,9].

We suppose that relation between Mayer and respiratory peaks may reflect the balance of sympathetic and parasympathetic activity in the bladder, because this balance can shift during high intravesical pressure (at maximal bladder capacity) switching the bladder function from urine storage phase (bladder wall relaxation) to active bladder contraction and urination.

The important role of arterial supply to the bladder is evident, since ischemia can provoke detrusor contractile dysfunction. The vascular collapse was established with morphometric method for the bladder at all levels of its distension [3]. Laser Doppler flowmetry demonstrated the changes in vesical blood flow depending on bladder capacity and compliance. The present method can assess arterial bladder supply during different periods of its activity. In resting bladder, the power of cardiac peak was lesser compared to the power of Mayer peak; during bladder filling, the power of the cardiac peak decreased slightly (table 1). These data can be explained by application of physiological pressures in these experiments with urethra opened providing possibility to urinate voluntarily. Under large Pdet, the cardiac peak decreased pronouncedly (figure 2). In contrast, this peak did not significantly vary under low Pdet (figure 1, C).

4. Conclusions
Fourier analysis of bioimpedance variations in urinary bladder revealed three modes of oscillatory processes related to Mayer, cardiac and respiratory activity. These processes are described by the spectrum peaks whose power is determined by intensity of the changes in vascular tone and detrusor functional activity. The opposite changes in the value of Mayer and respiratory peaks attest to their predominantly regional neurogenic origin. In contrast, more stable behaviour of the cardiac peak indicates its predominantly “central” hydrodynamic nature. Therefore, Mayer and respiratory spectrum peaks seem to be important indicators of vascular tone and smooth muscle activity in the bladder. Thus, Fourier analysis of bioimpedance variations is a novel potent tool to examine autonomic neural control simultaneously with blood supply in bladder and other visceral organs.

5. References
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