GENERAL PATHOLOGY AND PATHOLOGIGAL PHYSIOLOGY

Analysis of Fluctuations of Capillary Blood Flow in the Cortex of Rat Kidneys during Ischemia

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The dynamics of fluctuations of capillary blood flow in the cortex of rat kidneys under conditions of transient occlusion of renal arteries and veins or simultaneous occlusion of afferent and efferent vessels was studied by laser Doppler flowmetry. The initial variability of blood flow in the right kidney was higher than in the left kidney. The most pronounced changes in the right kidney were observed during occlusion and subsequent recirculation. In the left kidney, the most pronounced changes were found during occlusion and after arterial occlusion. Spectral analysis gave similar results. The recovery of renal blood flow after transient venous occlusion took longer time than after arterial occlusion (especially in the right kidney).

Key Words: *laser Doppler flowmetry; kidneys; ischemia*

Blood flow fluctuations in rat renal cortex were studied on perfused isolated kidney [8,9]. Low-frequency harmonics in a range of 0.02-0.12 Hz were found. Blood flow oscillations responsible for autoregulatory abilities of the renal microcirculatory network were proposed to be of a myogenic nature. Myogenic and tubuloglomerular mechanisms inducing a resonance in the ranges from 0.1 to 0.2 Hz and below 0.06-0.08 Hz, respectively, are believed to provide the autoregulation of renal blood flow [10]. It can be assumed that some random variable contributes to normal functioning of living systems and increases their resistance [2]. Therefore, studies of specific features and particularities of fluctuating flows in organs and tissues are of great importance [1,6,9-12]. Here we examined the dynamics of blood flow fluctuations in rat renal cortex during occlusion of the afferent and efferent vessels.

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MATERIALS AND METHODS

Experiments were performed on 25 outbred rats weighing 200-250 g and narcotized with 5 mg/100 g body weight Nembutal. The adipose tissue adjacent to the kidneys was removed, and renal arteries and veins were separated. Blood flow in the renal cortex was recorded immediately after laparotomy, after isolation of the artery and vein, during a 3-min occlusion of the artery and vein or both these vessels, and over 10-min reperfusion. Blood flow was measured by laser Doppler flowmetry on a LAKK-01 capillary blood flow analyzer (LAZMA). Microcirculation index (MI) was read 30-40 times per min and processed by calculating the mean values (M), standard deviation (σ), dispersion (σ^2), standard error (m), and coefficient of variation ($CV=\sigma/M\times100\%$). Results were analyzed by Student's t test and contingency test. Spectral analysis was used to estimate the dynamics of the dispersion spectral density and amplitude-frequency (AFR) and phase-frequency (PFR) responses of blood flow [3,4].

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TABLE 1. AFR and PFR of Blood Flow in Rat Kidneys during Arterial and Venous Occlusions (*y*, AFR; and *x*, Frequency from 0 to 0.4 Hz)

State	Left kidney		Right kidney	
	AFR	PFR	AFR	PFR
Initial	y=7.5exp(-7.3x)	-36°	y=5.6exp(-7.1x)	-84°
Arterial occlusion	y=9exp(-7.3x)	70°	y=126exp(-7.6x)	-80°
Venous occlusion	y=38.8exp(-7.5x)	-32°	y=7.0exp(-7.3x)	20°

RESULTS

Measurements of MI in the renal cortex conducted after laparotomy before removal of the adipose tissues from large vessels showed that the right kidney has higher mean MI, CV (32.7-0.38 arb. units), and dispersion (28.32) than the left kidney (25.7-0.12 arb. units and 0.90, respectively). After preparation of renal arteries and veins for occlusion, MI in the left and right kidneys decreased by 3-17 and 6-38%, respectively. Therefore, this procedure smoothed out the differences in MI. The decrease in MI of the left kidney was similar during occlusion of the artery and vein, while in the right kidney it was more pronounced

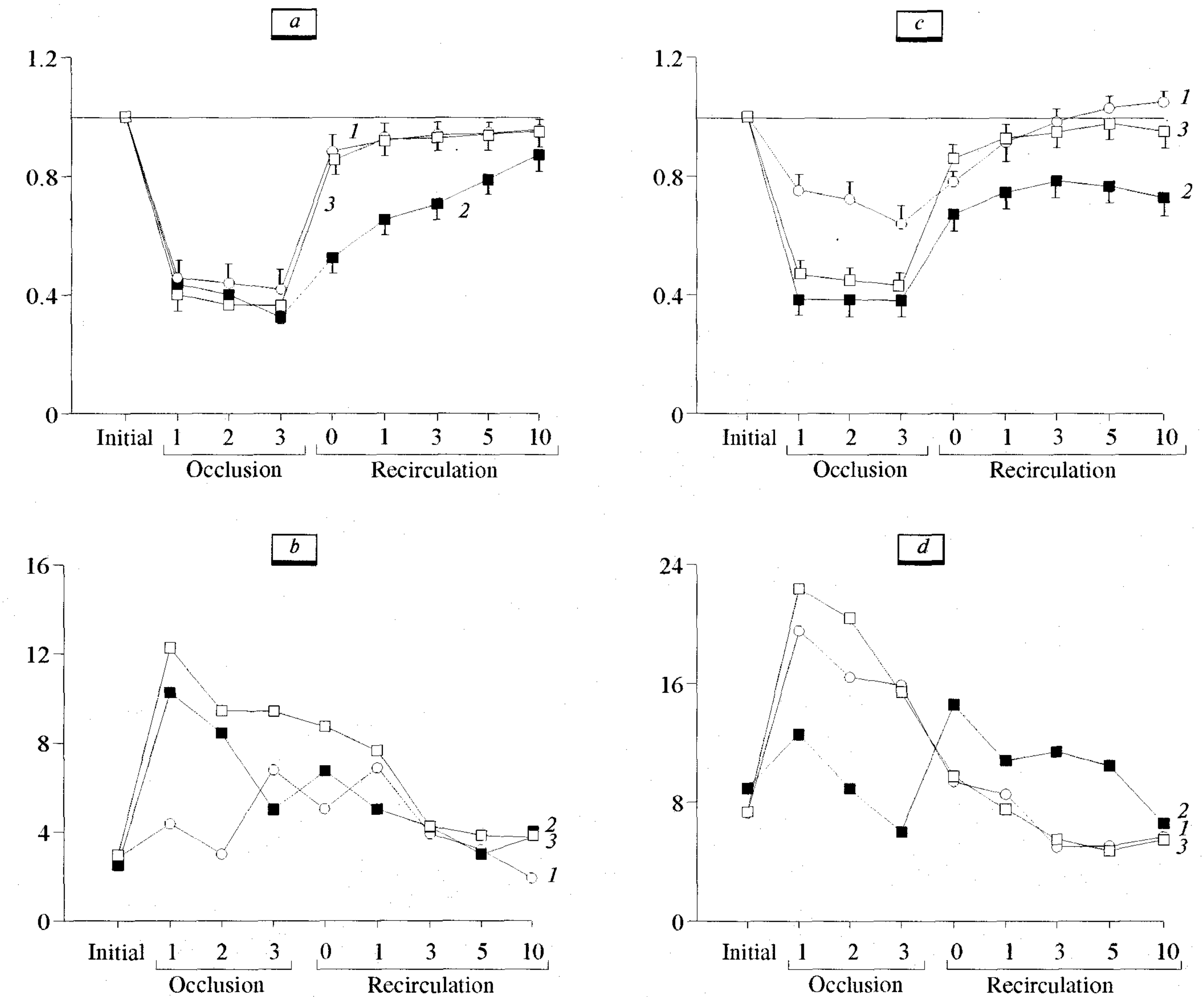

Fig. 1. Mean capillary blood flow indexes in rat kidneys during arterial occlusion (*1*), venous occlusion (*2*), and global occlusion (*3*). Ordinate: *a* and *c*: mean microcirculation index compared with this parameter before occlusion; *b* and *d*: coefficients of blood flow variation, %.

TABLE 2. Periodograms of Rat Blood Flow under Simultaneous Occlusion of the Artery and Vein (Value/Frequency)

Left kidney			Right kidney		
before occlusion	during occlusion	after occlusion	before occlusion	during occlusion	after occlusion
5.44/0.030	24.46/0.090	32.56/0.006	6.99/0.041	57.95/0.046	23.63/0.066
2.99/0.109	21.95/0.054	14.53/0.091	5.45/0.177	57.88/0.277	17.97/0.072
1.42/0.045	19.62/0.059	7.30/0.085	5.21/0.021	57.48/0.121	14.53/0.118
1.20/0.125	18.16/0.025	6.49/0.054	4.79/0.188	51.18/0.232	10.60/0.059
1.13/0.140	13.36/0.070	5.01/0.097	4.28/0.125	44.13/0.138	8.57/0.164
	Harmonics with a frequency below 0.1 Hz are prevalent			Harmonics with a frequency above 0.1 Hz are prevalent	

during venous occlusion (Fig. 1). Blood flow after arterial occlusion was restored more rapidly than after venous occlusion. In the right kidney, minor postischemic hyperemia was observed. Blood flow restoration after venous occlusion takes longer time after arterial occlusion, especially in the right kidney. The dynamics of CV showed that the blood flow variability sharply increased during occlusion of the left vein and right artery and during recirculation in the left kidney (after arterial occlusion) and right kidney (after

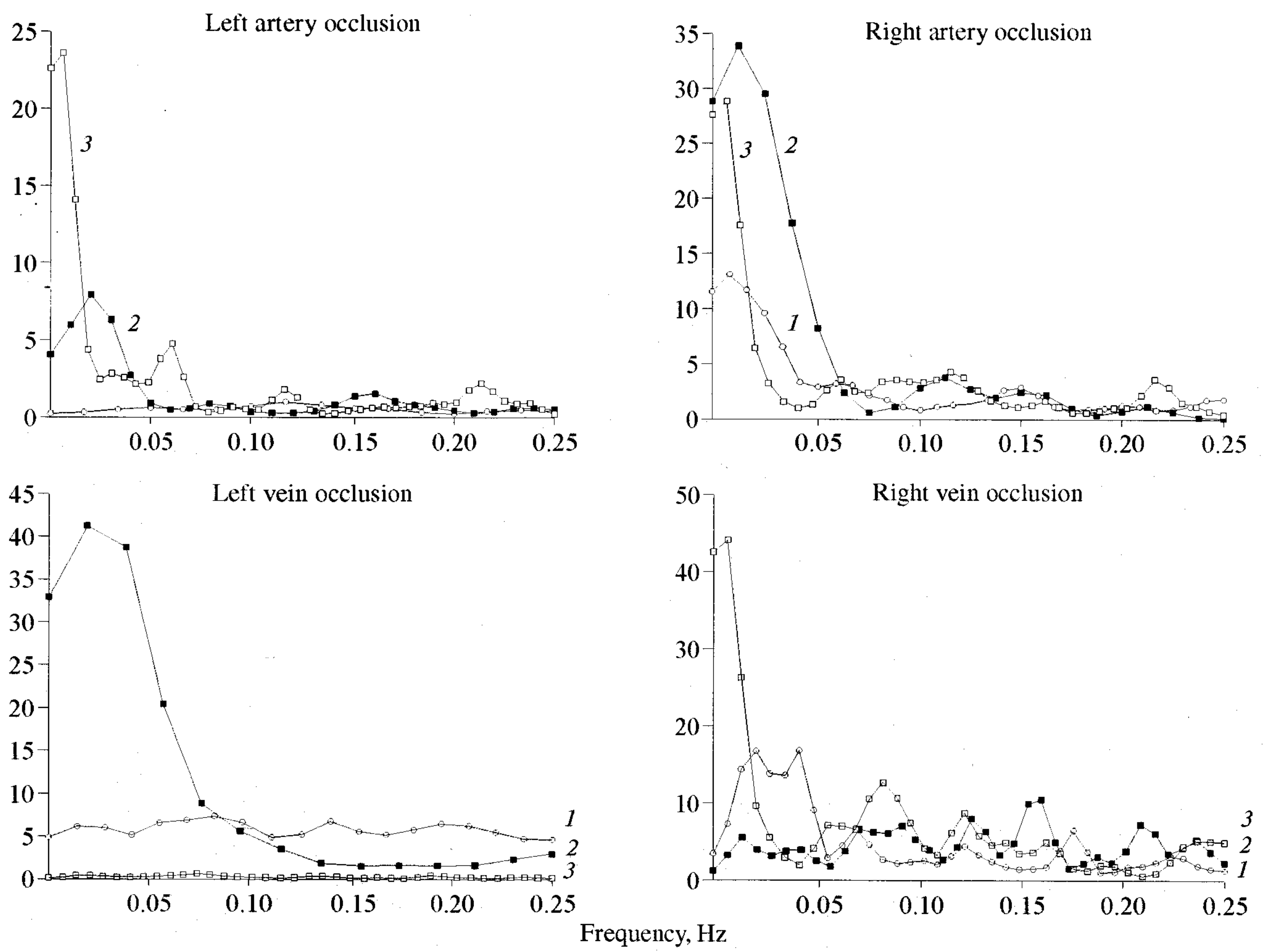

Fig. 2. Blood flow spectrograms of rat kidneys during occlusion of the artery or vein (left kidney was examined first). Here and in Fig. 3: ordinate — spectral density, arb. units. *1*) initial state; *2*) occlusion; and *3*) recirculation.

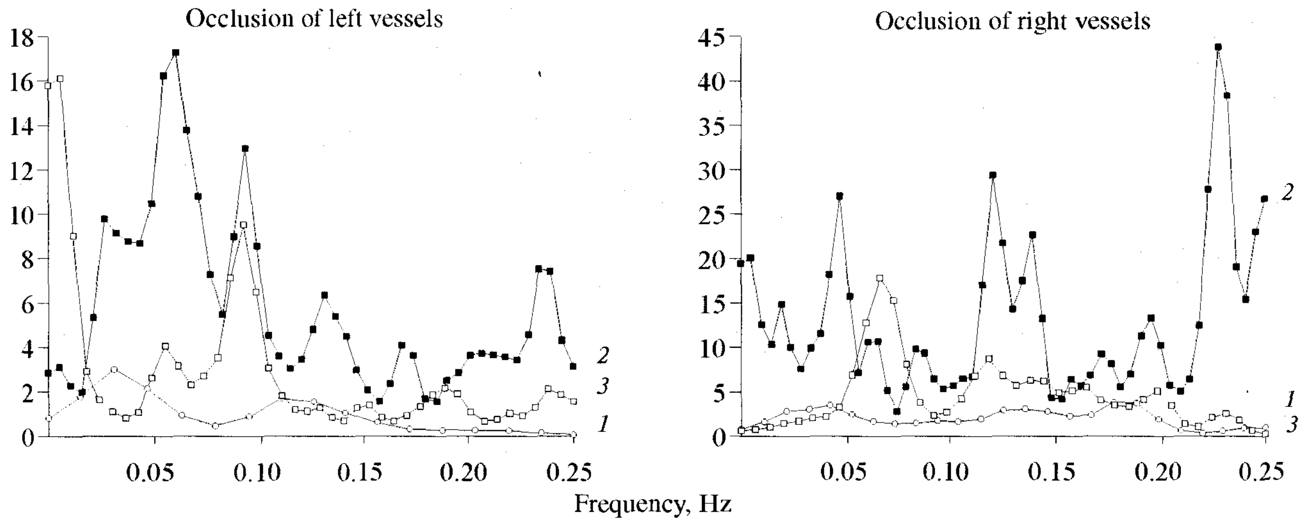

Fig. 3. Blood flow spectrograms of rat kidneys during simultaneous occlusion of renal artery and vein.

venous occlusion). During simultaneous occlusion of the afferent and efferent vessels, the dynamics of these indexes was similar to that observed after isolated venous (left kidney) or arterial occlusion (right kidney).

These results demonstrated the dynamics of two characteristics of fluctuating blood flow (mathematical expectation and dispersion). When calculating the third parameter of random function, the correlation function, both positive or negative values were found, which indicated its periodicity. Spectral analysis of AFR and PFR typical of blood flow in the kidneys was performed (Table 1). The dependence of AFR on the frequency was approximated by the method of least squares with exponential function: $y=B\exp(in)$. AFR of the initial blood flow in the left and right kidneys became low at 0.4 Hz. Changes in AFR were most pronounced during left vein occlusion and right artery occlusion (to a greater extent). Differences between AFR of initial blood flow in paired kidneys were small. PFR changed during left artery occlusion and right vein occlusion. Initially, PFR of blood flow were below zero. PFR in the right kidney were nearly -90°. Drawing an analogy between the vascular module and electrical network (similarly to the analog simulation of blood flow regulation [5]), we concluded that vascular network of rat renal cortex has a capacitive load. This is especially true of right renal vessels, while the left kidney has a mixed load with slight predominance of a capacitive component. Changes in the phase character can result from inertial capacities of the system reflected by the inductance factor during the analog simulation (the phase is above zero under the inductance load). The involvement of inertial factors in the regulation is probably responsible for insignificant changes of AFR during occlusion of the left artery and right vein. Otherwise, these parameters changed sharply (as during occlusion of the right artery).

Spectra of fluctuating blood flow under ischemic conditions had well defined maxima during occlusion of the left vein and right artery (Fig. 2). Simultaneous occlusion of the artery and vein led to the appearance of 5 harmonics in periodograms (Fig. 3, Table 2). Under varying conditions, frequency limits of blood flow decreased in the left kidney and increased in the right kidney.

The analysis of the dynamics of spectrograms and periodograms showed prevalence of tubuloglomerular and myogenic mechanisms of renal blood flow autoregulation in the left and right kidneys, respectively. This was confirmed by the fact that the resonance appeared more often in the right kidney at higher frequencies. It can not be excluded that har monics of higher frequencies are also present in the spectrum of fluctuating renal blood flow.

Our findings indicate that the mechanisms of blood flow regulation in the kidneys are different. Thus, a differential approach is necessary for studying paired organs under normal conditions and in disease.

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