Renal Vascular System in Stenosis of the Pulmonary Trunk with Different Level of Circulatory Compensation

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Stenosis of the pulmonary trunk impaired outflow of venous blood from the kidneys and oxygen supply to renal tissues. This was paralleled by adaptation increase in renal artery tone and rearrangement of some renal artery by the terminal type. Under conditions of decompensated stenosis these reactions are less pronounced in comparison with compensated defect and do not correspond to the level of hemodynamic disorders, which leads to more pronounced structural changes in glomeruli.

Key Words: *kidneys; vascular system; compensated and decompensated stenosis of pulmonary trunk*

The state of the vascular system in organs, including the kidneys, is the key factor for their structure and function [8,14]. That is why identification of the type of the vascular system restructuring under conditions of impaired circulation is an important problem of pathomorphology [4,11]. Changes in arteries, veins, and glomeruli of the renal basin under conditions of central hemodynamic disorders with different levels of circulation compensation are the least studied aspect of this problem.

We studied structural rearrangement of renal vascular system in experimental compensated and decompensated stenosis (CS and DS, respectively) of the pulmonary trunk.

MATERIALS AND METHODS

Pulmonary trunk stenosis was modeled surgically in 30 puppies as described previously [15]. Eight puppies developed signs of cardiovascular insufficiency (ascites, hydrothorax, hydropericardium, and anasarca) at the age of 1-6 months; they were sacrificed (group 1). Others were observed from the age of 6 months to 2 years (group 2). Ten age-matched dogs served as controls.

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Pressure was measured in all animals by the manometrical method, gas content in arterial and venous blood was measured using a Van Slyke-Neill blood gas analyzer with estimation of derivative parameters (oxygen saturation and oxygen deficiency). The animals were euthanized by bloodletting under ketamine and ether narcosis.

Histological sections of the kidneys were stained with hematoxylin and eosin, by the methods of Van Gieson, Masson, and Hart. During stereometric study (point counting) specific areas of renal veins, arteries, and glomeruli were determined. Morphometry of renal vessels was carried out using a screw ocular micrometer. The lumen of interlobar, arch, and interlobular arteries and glomerular efferent arteries was measured. In parallel, the percentage of arteries of different level of branching with obliquely and longitudinally oriented smooth muscle cells (SMC) in the intima was evaluated. The data were statistically processed using Student's *t* test.

RESULTS

Venous pressure increased 1.6 times in animals with CS (Fig. 1). Saturation of arterial blood with oxygen decreased from 91±3 to 78±3% ($p<0.01$), oxygen deficiency increased from 5.1±0.6 to 6.6±0.5 vol.% ($p<0.05$).

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Morphological study of the kidneys from group 1 dogs showed considerable changes in the vascular system. The veins were dilated and plethoric (Fig. 2, *a*), their specific area increased 2.3-fold (Fig. 3). By contrast, renal arteries were contracted. This was seen from increased plication of their intima, round contours of endothelial cells (Fig. 2, *b*), and a decrease of their specific area (by 1.2 times) (Fig. 3). The lumen of these vessels decreased to a different degree (Table 1): by 1.2 times in interlobar and arch arteries, by 1.6 times in interlobular arteries, and by 2 and 1.8 times in afferent and efferent arterioles, respectively. It is noteworthy that the number of renal vessels with bundles of obliquely and longitudinally oriented SMC in the intima increased (Table 2). These cells were sometimes seen in the control at the level of the arch and interlobular arteries. In animals with modeled stenosis the number of arteries with this orientation of muscle cells increased 2 and 13.6 times, respectively. Moreover, vessels with intimal muscles appeared among afferent glomerular arterioles.

Renal glomeruli were somewhere enlarged and plethoric (Fig. 2, *c*) and somewhere anemic and shrunk. However, thickening and sclerosis of the capillary walls were seen in both cases. Hyalinosis of arterioles was also seen. Specific area of these structures decreased 1.1 times (Fig. 3), which attested to predominance of collapsed glomeruli.

In animals with DS venous pressure increased more than 2-fold (Fig. 1) compared to the control and more than 1.3-fold surpassed the corresponding parameter in group 1. Blood saturation with oxygen decreased to 71.5±4.0% ($p<0.001$), which was appreciably lower than in dogs with CS. Oxygen deficit increased to 8.5±0.8 vol.% ($p<0.001$) and hence, was 1.3 times higher than in dogs with compensated defect.

Veins of animals from this series were characterized by sharp plethora (Fig. 2, *d*). Specific area of these vessels increased by 2.8 times (Fig. 3), which was higher than in dogs with compensated defect. Similarly to group 1, the tone of renal arteries increased, but to a different degree: some vessels were sharply contracted, while others were normotonic (Fig. 2, *e*). Specific area of arteries decreased 1.2 times (similarly as in dogs with CS). The inner diameter of these vessels decreased to a lesser extent as in group 1 (Table 1); for example, its decrease in interlobar arteries was negligible. The lumen of the arch arteries decreased 1.1 times, of interlobular arteries 1.4 times, of glomerular afferent and efferent arteries 1.3 and 1.6 times, respectively. Similarly as in animals with CS, vessels with intimal muscles were seen among arterial branches (Table 2), but the number of arch arteries with intimal muscles was 1.8 times lower than in animals with CS and little differed from the control. The number of such vessels among interlobular arteries increased 10-fold compared to the control, but was 1.3 times lower than in dogs with CS. The number of afferent glomerular arterioles with SMC in the intima little differed in the two groups.

Renal glomeruli in animals with DS were characterized by pronounced thickening of the walls in capillary loops and by arteriolar hyalinosis. Shrunk and sclerosed glomeruli were more incident than in CS (Fig. 2, *f*). The area occupied by these structures decreased 1.2 times (Fig. 3).

Hence, our studies showed that after creation of pulmonary trunk stenosis experimental animals develop progressing hemocirculatory disorders and disorders in oxygen supply to tissues, resultant from hemodynamic overload in the right compartments of the heart. Similar changes were described on clinical material [9]. They are paralleled by functional changes and restructuring of the renal vascular bed, which qualitatively do not depend on the level of circulation compensation. For example, venous plethora in the renal basin in the dogs is paralleled by an increase of its capacity. Disturbances in blood outflow are fraught with disorders of circulation in the glomerular capillaries and subsequent filtration disorders. Reflex contractions of renal arteries in these cases serve as an adaptation reaction. This reflex, called by some scientists as venoarterial reaction [2], consists in the following: increase in vascular tone is paralleled by increase in vascular resistance [6,10,12]. This is paralleled by a decrease in blood pressure in the glomerular capillary system, and glomerular function is not much disordered [7]. Our studies showed that this compensatory reaction alone is not sufficient for the protection of the renal microcirculatory bed. One more adaptation mechanism is triggered: more intense development of obliquely longitudinal intimal muscles in branches of

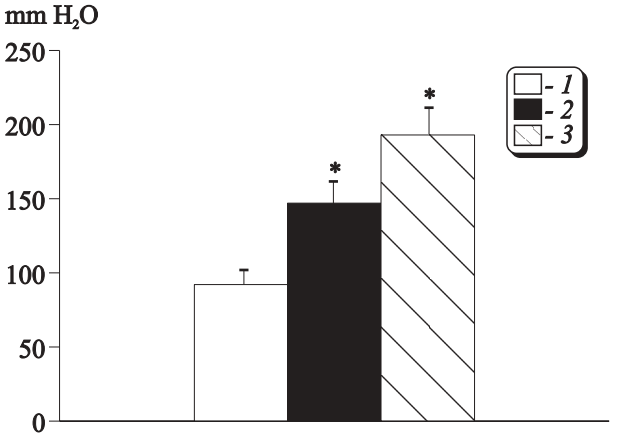

Fig. 1. Venous pressure in control (*1*) , compensated (*2*) and decompensated (*3*) stenosis of the pulmonary trunk. *$p<0.01$ compared to the control.

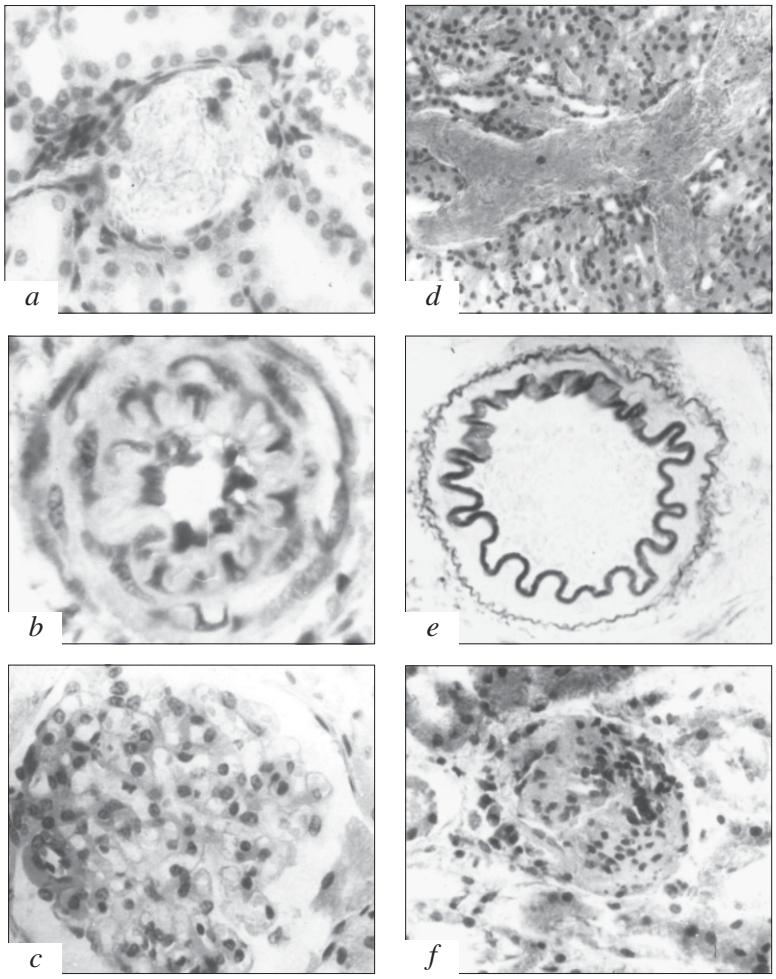

Fig. 2. Structural changes in renal tissue components in experimental compensated (*a-c*) and decompensated (*d-f*) stenosis of pulmonary trunk. *a*) plethoric renal vein; 6 months after stenosis modeling, ×220; *b*) increased tone of interlobular artery with shrunk lumen, increased plication of the intima, and round endothelial cells; 10 months, ×400; *c*) enlarged renal glomerulus with plethoric capillaries, sclerotic walls; arteriolar hyalinosis; 12 months, ×200; *d*) sharply plethoric renal vein; 5 months, ×100; *e*) wide lumen of interlobar artery with moderately plicated intimal elastic membrane; 5 months, ×200; *f*) shrinkage and sclerosis of renal glomerulus; 6 months, ×200. *a-f*: hematoxylin and eosin staining; *d*: Hart staining.

renal arteries. These muscle bundles are a result of SMC migration from the tunica media into the intima through fenestrated elastic lamina [3,5,13]. If the tone increases, they plicate the arterial trunk and form cushions almost completely obstructing the lumen. Due to this fact these vessels were called terminal and the obturation effect was called cushion obstruction [2]. These arteries provide redistribution of bloodflow in the renal basin under conditions of impaired renal hemocirculation, maintaining blood content needed for renal functioning in part of the glomeruli. Other part of these arteries becomes anemic, shrinks, and (with time) is sclerosed.

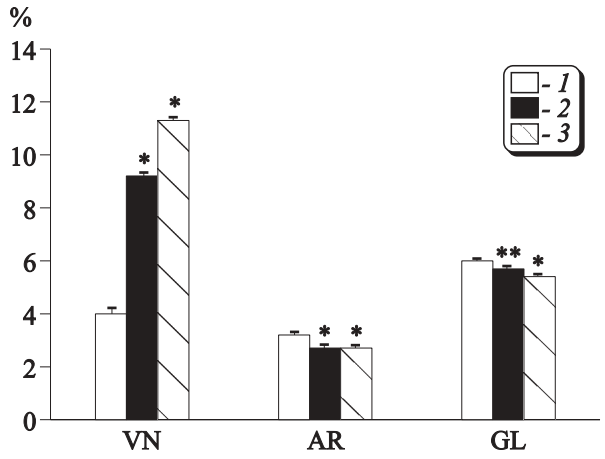

Fig. 3. Specific area of tissue components of the kidney in control (*1*), compensated (*2*) and decompensated (*3*) stenosis of pulmonary trunk. VN: veins; AR: arteries; GL: glomeruli. *$p<0.01$, **$p<0.05$ compared to the control.

Quantitative characteristics of the renal vessels are different in CS and DS. This directly depends on the severity of disorders in circulation and oxygen supply to tissues. For instance, pronounced venous congestion in dogs with DS was paralleled by more drastic dilatation of renal veins. On the other hand, defense reaction presenting as stenosis of arterial vessels of different caliber is less pronounced and obviously does not correspond to the severity of disorders in blood outflow from the kidneys. One more evidence in favor of this hypothesis is specific area of arteries, a summary indicator of renal arterial status in dogs with DS. It decreased as much as in dogs with CS, *i. e.* not adequately to the level of venous congestion. Functional

TABLE 1. Diameter of Renal Artery (μ) in the Control and after Pulmonary Trunk Stenosis ($M \pm m$)

Series	Arteries			Arterioles	
	interlobar	arch	interlobular	afferent	efferent
Control	220.0±6.0	80.0±1.6	40.4±0.7	20.5±0.3	13.3±0.2
CS	186.0±9.7*	65.0±1.1*	25.0±0.4*	10.5±0.2*	7.3±0.2*
DS	215.0±4.5*+	72.6±0.5*+	29.4±0.3*+	15.7±0.2*+	8.4±0.1*+

Note. *$p<0.001$ compared to the control, +$p<0.001$, ++$p<0.01$ compared to CS.

TABLE 2. Percentage of Renal Arteries with Intimal Musculature in Control and after Pulmonary Trunk Stenosis

Series	Arteries			Arterioles	
	interlobar	arch	interlobular	afferent	efferent
Control	0	2.3	2.5	0	0
CS	0	4.5	34.0	5.5	0
DS	0	2.5	26.0	6.2	0

and even structural changes in renal arteries aimed at protection of the microcirculatory system were less pronounced in dogs with DS. The number of terminal arteries in this series of experiments was remarkably lower than in animals with CS. This fact is explained by more pronounced hypoxemia and tissue hypoxia in DS, promoting relaxation of the arterial wall SMC and decrease of their migration capacity with restructuring of the vessels by the terminal type [1]. All this leads to incapacity of renal arteries to prevent plethora in the renal microcirculatory system. The inevitable result of these vessels adaptation failure is higher level of sclerotic changes in the renal glomeruli in DS.

REFERENCES

1. S. A. Bershtein, M. M. Gurevich, and A. I. Solov'ev, *Oxygen Deficit and Vascular Tone* [in Russian], Kiev (1984).
2. I. K. Esipova, *Proceedings of the 1st Congress of Russian Society of Pathologists* [in Russian], Moscow (1996), pp. 69-70.
3. V. A. Nagornev, *Arkh. Patol.*, **53**, No. 9, 13-22 (1991).
4. Yu. V. Novikov and A. V. Yal'tsev, *Byull. Eksp. Biol. Med.*, **133**, No. 2, 219-221 (2002).
5. E. V. Parfenova, O. S. Plekhanova, N. I. Kalinina, *et al.*, *Kardiologiya*, **40**, No. 9, 69-77 (2000).
6. Yu. V. Postnov, *Ibid.*, **35**, No. 10, 4-13 (1995).
7. V. V. Sura, I. A. Borisov, A. V. Gordeev, and O. I. Kamaeva, *Ter. Arkhiv*, **70**, No. 12, 5-8 (1998).
8. V. G. Florya and Yu. N. Belenkov, *Kardiologiya*, **36**, No. 12, 72-78 (1996).
9. A. A. Khikmatov, *Ter. Arkhiv*, **73**, No. 9, 73-76 (2001).
10. B. Folkow, *Hypertension*, **16**, 89-101 (1990).
11. S. Heeneman, P. J. A. Leenders, P. J. J. W. Aarts, *et al.*, *Arteriosclr. Thromb. Vasc. Biol.*, **15**, 1503-1511 (1995).
12. J. D. Imig and G. L. Anderson, *Ibid.*, **17**, 317-322 (1991).
13. R. S. Schwarz, *Am. J. Cardiol.*, **7A**, 14E-17E (1998).
14. E. L. Shiffrin, *Cardiology*, **86**, No. 1, 16-22 (1995).
15. S. V. Shormanov, *Cor Vasa*, **25**, No. 4, 259-266 (1983).