MORPHOLOGY AND PATHOMORPHOLOGY

Pathomorphology of the Vascular Bed of Postinfarction Heart in Various Types of Remodeling

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Translated from *Byulleten' Eksperimental'noi Biologii i Meditsiny*, Vol. 135, No. 5, pp. 590-596, May, 2003
Original article submitted March 25, 2003

We evaluated pathomorphological changes in the vascular bed of postinfarction heart in various types of remodeling. Dilatational remodeling was characterized by dilation of coronary arteries, increase in their volume density, and regular arrangement. Signs of coronary blood flow reduction and microcirculatory disturbances in the left ventricle were revealed during hypertrophic remodeling. Aneurysmal remodeling was characterized by the presence of small-vascular collateral-anastomotic plexus and reduction of the microcirculatory bed. Endocardial remodeling was accompanied by hypervascularization of the myocardium, formation of new coronary vessels, and reduced capillarization in the left ventricle of postinfarction heart.

Key Words: *postinfarction heart; dilatational, aneurysmal, and endocardial remodeling; vascular bed; cardioventriculography; coronarography; cardiometry*

Postinfarction remodeling of the heart attracts much attention of physicians and pathomorphologists. This process is accompanied by pronounced structural changes in the necrotic zone, scar injury, and reorganization of the conventionally intact myocardium [8, 12]. Remodeling of postinfarction heart (PH) is associated with reconstruction of cavities in response to inadequate conditions of functioning [1].

Remodeling of the heart is a multifactor process characterized by changes in coronary vessels and microcirculatory bed. It is related to specific features and complexity in the diagnostics of various types of PH remodeling. Previous studies showed that vascular disorders play a role in patho- and thanatogenesis of the disease and complications [13].

Here we studied changes in the vascular bed of the heart in various types of postinfarction remodeling and evaluated factors of thanatogenesis and criteria for pathomorphological diagnostics.

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MATERIALS AND METHODS

We examined 200 hearts of patients died at various stages of the postinfarction period (128 men and 72 women, mean age 58.2±0.2 years). The mean duration of the postinfarction period was 8.2±0.2 years. Forty hearts without myocardial scars taken from individuals of comparable age after accidental deaths served as the control. The state of PH ventricles and the type of remodeling were determined by postmortem contrast polypositional cardioventriculography and weight-volume and planimetric cardiometry [3].

Postmortem contrast polypositional coronarography included measurements of the volume density of vessels in major regions of the heart [6]. The significance of differences was evaluated by complex coronarography and anatomical study recommended by the World Health Organization [6].

The state of vessels in the microcirculatory bed was determined by intravascular impregnation and

0007-4888/03/1355-0503$25.00

impregnation of frozen myocardial sections with $AgNO_3$ [5]. We performed morphometric examination of microcirculatory vessels and calculated the main morphofunctional parameters. The diameter and number of capillaries and muscle fibers per 1 mm^2 transverse myocardial section were determined using an ocular grid. The degree of capillarization and area of muscle fibers (%) were estimated as described elsewhere [5]. The mean radius of muscle fibers was calculated as described elsewhere [9].

The severity of scar injury in the myocardium was evaluated after cardioventriculography and coronarography by macroscopic examination of transverse cardiac sections. We analyzed samples with transmural postinfarction scars (diameter 2 cm or more). The results were analyzed by methods of variational statistics (Student's *t* test).

RESULTS

Dilatational remodeling of PH prevailed (86 samples, 43%) and was characterized by pronounced dilation of the left ventricle, lengthening of its cavity (Fig. 1, *a*), and displacement of the interventricular septum towards the right ventricle. Changes in the coronary system of PH were pathognomonic and manifested in dilation of vessels. Dilation was accompanied by segmentary coronary obstruction (predominantly in arteries of the left coronary bed). Dilatational changes were diffuse and occured in primary and secondary branches and collateral network (Fig. 1, *b*).

Dilation is the main type of injury in coronary arteries during postinfarction remodeling of the heart. It should be emphasized that this process plays a compensatory role in the early postinfarction period. Dilation promotes the transmural distribution of myocardial blood flow and its redistribution from the endocardium to epicardium. At later stages dilation reflects decompensation of coronary circulation [10]. Changes in the blood flow rate and pressure gradient, disturbances in laminar blood flow, pronounced congestion, and paradoxical discharge characterize "malignant coronary dilation" [11], which underlies the development of ischemic syndrome during dilatational remodeling of PH [6].

Dilatational remodeling of PH was characterized by reconstruction of the vascular bed due to pronounced changes in vascularization of the myocardium. Comparative coronarography revealed increased volume density of vascularization in the left ventricle of

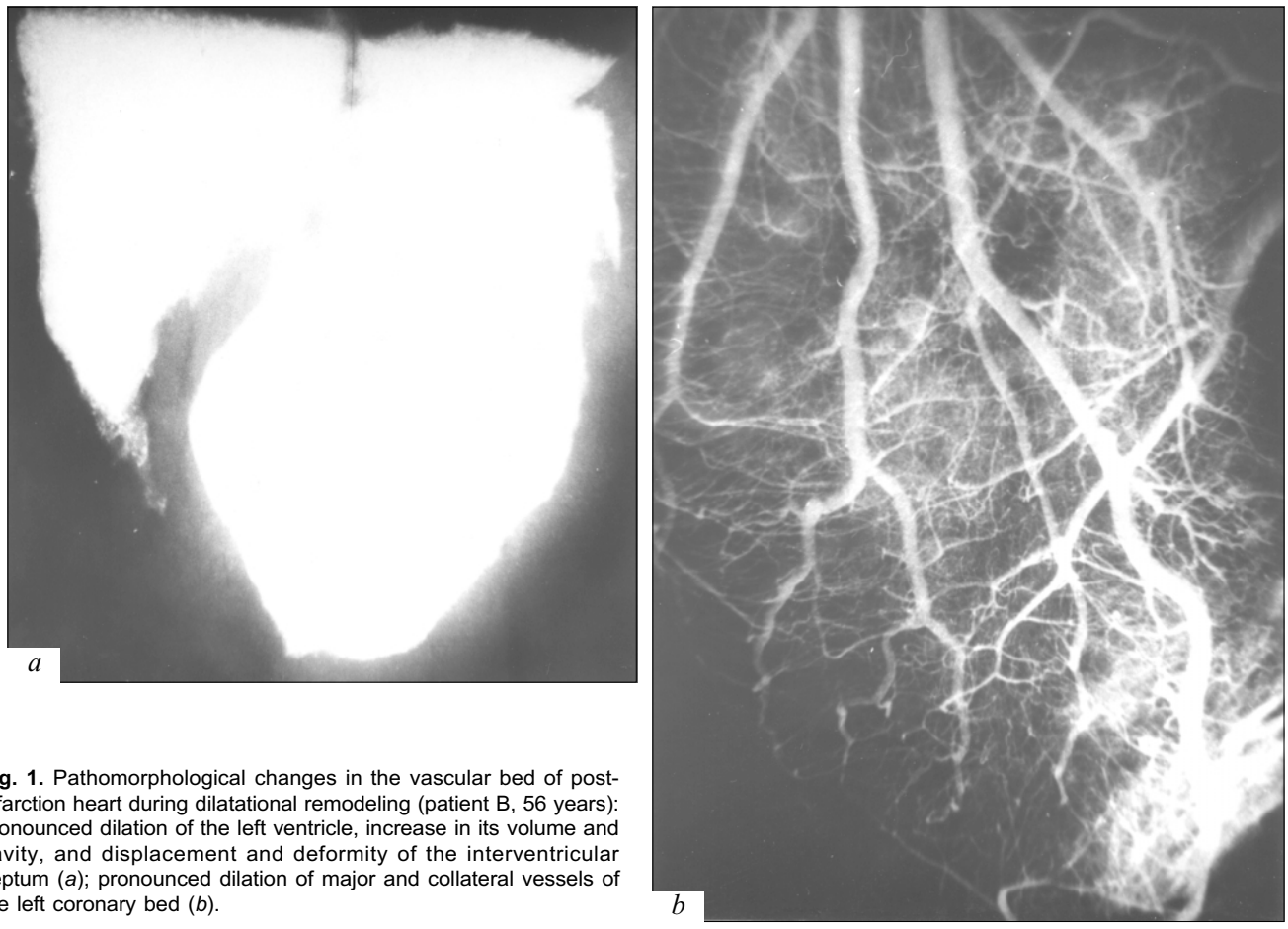

Fig. 1. Pathomorphological changes in the vascular bed of postinfarction heart during dilatational remodeling (patient B, 56 years): pronounced dilation of the left ventricle, increase in its volume and cavity, and displacement and deformity of the interventricular septum (*a*); pronounced dilation of major and collateral vessels of the left coronary bed (*b*).

PH (Table 1). Detailed analysis showed that the volume density of vessels increased in the anterior wall of the left ventricle, but decreased in the posterior wall. The degree of vascularization decreased most significantly in the interventricular septum. In the right ventricle of PH the degree of vascularization surpassed the control.

Changes in the architectonics of PH microvessels during dilatational remodeling were accompanied by their structural reorganization and acceleration of blood flow. The process played a compensatory and adaptive role. Morphometric examination revealed a considerable decrease in the surface area of capillaries, degree of vascularization, and number and diameter of muscle fibers (Table 2). These changes in the microcirculatory bed contribute to deceleration of blood flow and "inactivation" of some capillaries, which reflects severe hypoxia of the myocardium in dilated PH and decompensation.

Hypertrophic remodeling of PH ranked next to dilatational changes in the incidence (50 samples, 25%). This process was characterized by pronounced hypertrophy of the interventricular septum and walls of the left ventricle, decrease in its volume, and complex geometry of the cavity (Fig. 2, *a*). Changes in architectonics of PH vessels during hypertrophic remodeling included the symptom of "intensive coronarogram" [6,7]. This symptom is developed due to the presence of passable primary and secondary branches of major coronary arteries (microvascular bed of zonal topography). The observed changes were accompanied by focal reduction of coronary blood flow, predominantly in collateral vessels (Fig. 2, *b*). The reduction of coronary blood flow during hypertrophic remodeling was revealed coronarographically and confirmed by morphometric examination (decrease in the volume density of vessels in various regions of PH, Table 1).

Morphometric examination demonstrated a decrease in the degree of capillarization in the left ventricle characterized by reconstruction and functional load (Table 2). The surface area and volume density of capillaries decreased. It was primarily related to pronounced hypertrophy of muscle fibers, which contributed to the decrease in their number per 1 mm^2 tissue.

Macro- and microcirculatory changes in PH during hypertrophic remodeling indicate that coronary reserve does not satisfy the increased mass of cardiac muscle. Serious structural and functional disturbances in the coronary system and changes in the parenchymal

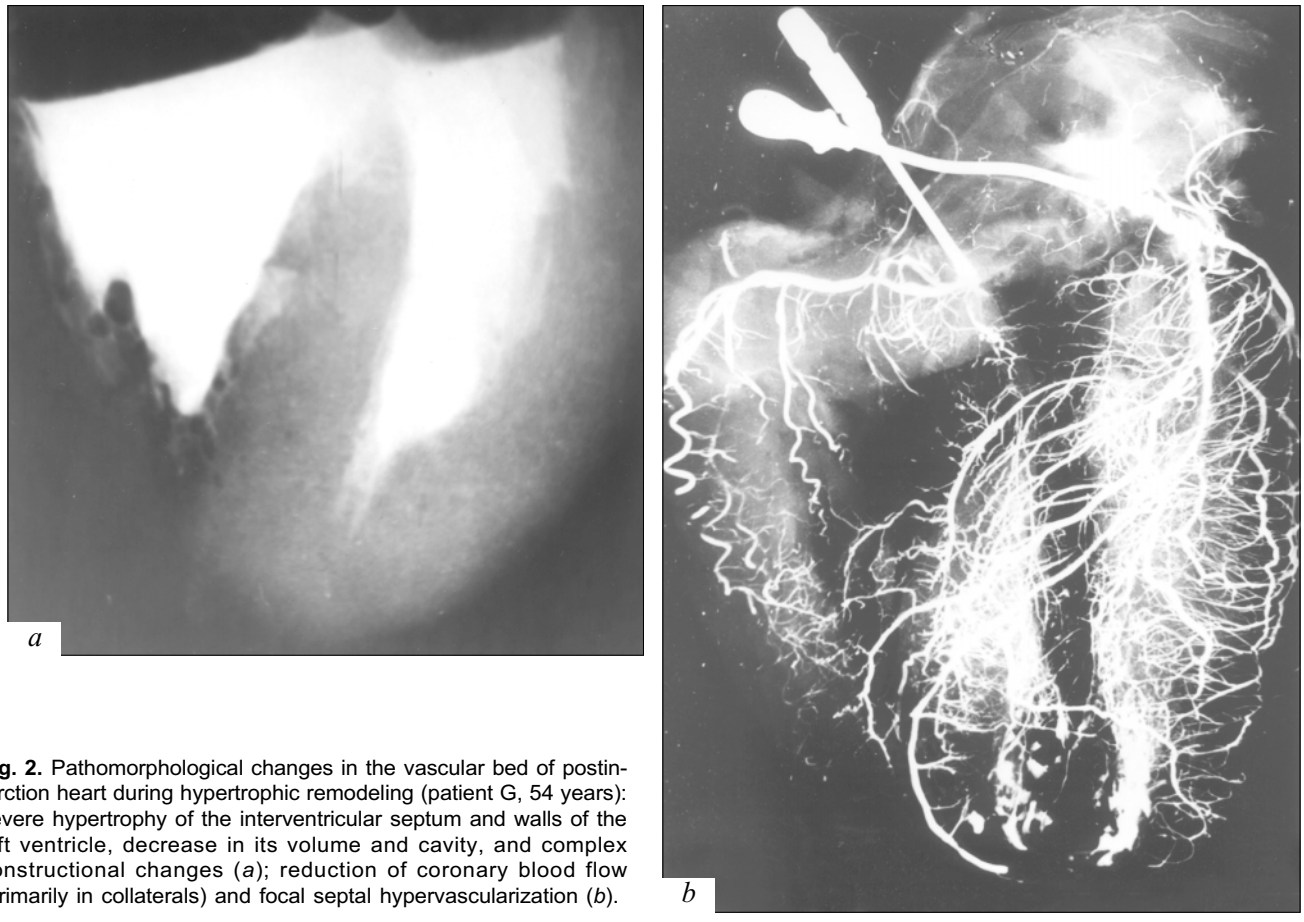

Fig. 2. Pathomorphological changes in the vascular bed of postinfarction heart during hypertrophic remodeling (patient G, 54 years): severe hypertrophy of the interventricular septum and walls of the left ventricle, decrease in its volume and cavity, and complex constructional changes (*a*); reduction of coronary blood flow (primarily in collaterals) and focal septal hypervascularization (*b*).

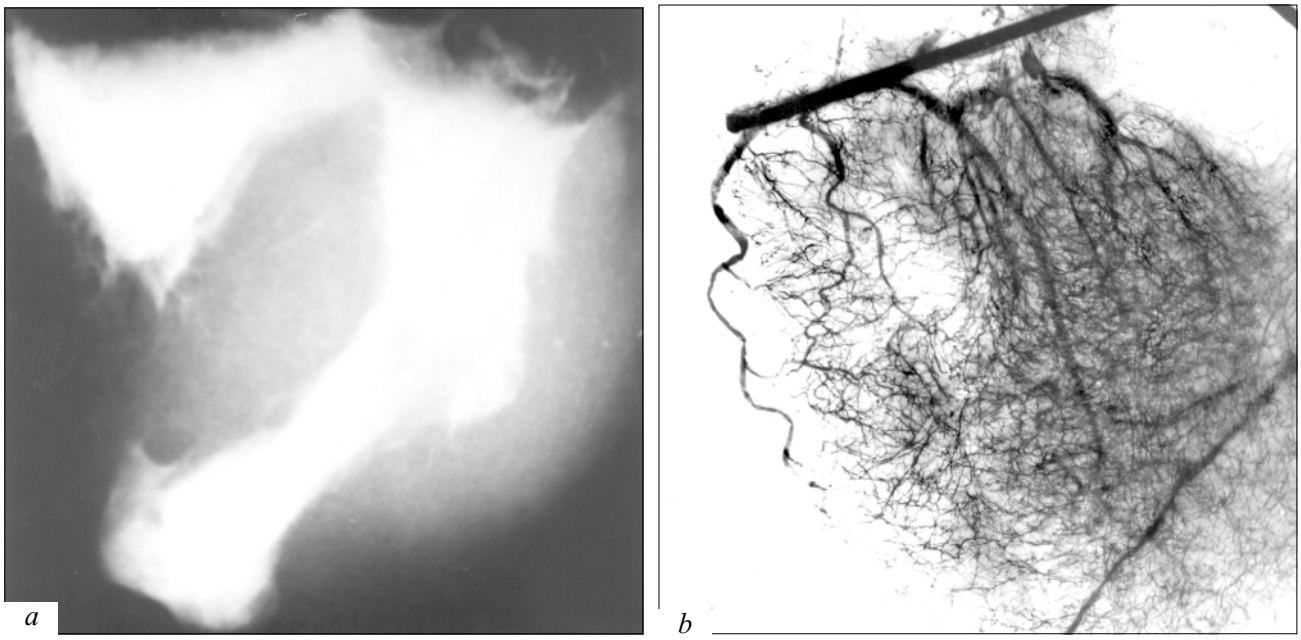

Fig. 3. Pathomorphological changes in the vascular bed of postinfarction heart during aneurysmal remodeling (patient M, 62 years): hypertrophy of the interventricular septum and walls of the left ventricle, constructional changes, and presence of 2 aneurysms (*a*); loss of magistral coronary arteries and presence of collateral-anastomotic small-vascular network (*b*).

stroma relationships aggravate tissue hypoxia and reflect decompensation of remodeled PH [2].

Aneurysmal remodeling ranked 3rd in the incidence (38 samples, 19%) and was characterized by the formation of aneurysms in the zone of postinfarction scars. They were primarily localized in the marginal zone of scars and involved terminal regions of the myocardium. In most samples we revealed hypertro-

TABLE 1. Volume Density of Vessels in Major Regions of Postinfarction Heart in Various Types of Remodeling (%, *M*±*m*)

Heart region	Control	Remodeling			
		dilatational	hypertrophic	aneurysmal	endocardial
Left ventricle	66.3±2.2	80.3±1.4*	62.3±2.6	60.3±1.8	78.3±1.4*
anterior wall	52.1±1.8	58.3±1.2*	50.2±1.4	48.2±1.2	56.1±1.2
posterior wall	50.3±1.6	42.2±1.6*	50.3±1.4	48.3±1.6	44.3±1.8*
lateral wall	34.4±1.2	34.3±1.4*	32.3±1.8	32.2±2.6	34.2±1.2
Interventricular septum	42.2±1.2	32.1±1.2*	32.3±1.6*	38.2±1.2	40.3±1.6
Right ventricle	50.4±1.4	56.3±1.8*	48.4±1.4	56.2±1.6*	56.2±1.4*

Note. Here and in Table 2: *$p<0.001$ compared to the control.

TABLE 2. Morphometry of the Myocardium in the Left Ventricle of Postinfarction Heart in Various Types of Remodeling (*M*±*m*)

Parameter	Control	Remodeling			
		dilatational	hypertrophic	aneurysmal	endocardial
Number of capillaries	2286±28	2244±14	2016±24*	1886±26*	2128±12*
Number of muscle fibers	1826±42	1616±24*	1422±14*	1244±12*	1618±18*
Diameter of capillaries, μ	6.40±0.04	6.20±0.04*	5.20±0.06*	5.80±0.04*	6.20±0.02*
Diameter of muscle fibers, μ	16.20±0.18	14.80±0.14*	18.8±0.12*	14.40±0.16*	15.80±0.18
Capillarization	1/2.8±0.02	1/1.2±0.04*	1/1.2±0.02*	1/8.8±0.04*	1/9.6±0.02*
Surface area of capillaries, %	48.0±1.8	42.0±1.2*	36.0±1.4*	36.0±1.2*	36.0±1.6*

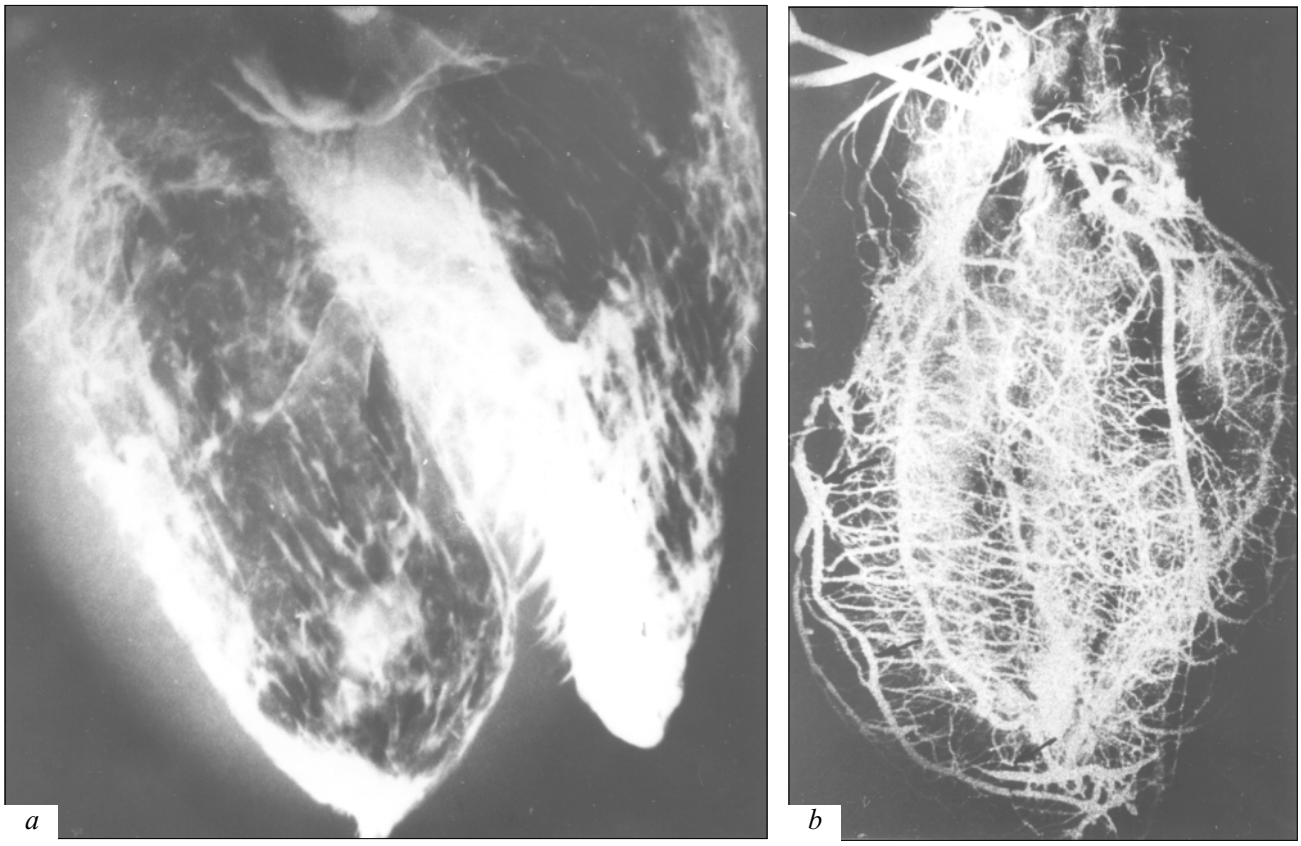

Fig. 4. Pathomorphological changes in the vascular bed of postinfarction heart during endocardial remodeling (patient A, 60 years): hypertrophy and connective tissue border in walls of the left ventricle, smoothening of the relief, and "creeping" cicatrization (*a*); hypervascularization of the myocardium due to numerous collateral vessels and dilation of major coronary arteries (*b*).

phy of the interventricular septum and walls of the left ventricle and changes in the shape of its cavity (Fig. 3, *a*). Changes in the coronary system of PH were presented by the coronarographic symptom of "increased cardiomyography" or "capillary blood flow" [14], which reflected the capillary phase of coronarogram. Major vessels of the coronary bed lost anatomical magistracy. Clearly contrasted small-vascular collateral-anastomotic networks were characterized by zonal or diffuse localization ("felt plexus", Fig. 3, *b*). Most small-vascular networks were found in scar aneurysmal regions, which reflected growing of capillaries into the damaged zone of PH during remodeling [14].

Changes in the vascular network of PH during aneurysmal remodeling were accompanied by a decrease in the volume density of vessels in walls of the left ventricle and interventricular septum. The diameter and number of capillaries and muscle fibers per 1 mm^2 decreased. By contrast, the volume density of vessels in the right ventricle surpassed the control (Table 1).

Aneurysmal remodeling of PH provided the biophysical basis for low-efficiency systole, which was associated with deformation and complex configuration of the left ventricle. Heterogeneous changes in the macro- and microcirculatory bed were followed by chronic ischemia of the myocardium and progressive insufficiency of PH (major factors of thanatogenesis).

Endocardial remodeling of PH was rarely observed (26 sample, 13%) and characterized by "scar covering" in the parietal endocardium that diffusely spread from the zone of cicatrization. The "creeping" type of cicatrization smoothened the relief and led to the formation of a connective tissue border in the left ventricle cavity (Fig. 4, *a*). Changes in the coronary system of PH during endocardial remodeling included the syndrome of "newly formed coronary vessels" [6] and pronounced hypervascularization of the myocardium due to numerous systemic collaterals. The major coronary arteries were dilated (Fig. 4, *b*).

As regards topographic and anatomic characteristics, collateral blood flow (hypervascularization) was most pronounced in the anterolateral wall of the left ventricle and diaphragmatic surface of PH. The formation of new coronary vessels was primarily due to intracardiac and transatrial vascular communications and multizonal hypervascularization of the myocardium.

Comparative coronarography revealed an increase in the volume density of vessels in the anterior wall

of the left ventricle and right ventricle of PH (Table 1). In the posterior wall of the left ventricle and interventricular septum the volume density of vessels decreased. Changes in architectonics of PH microvessels during endocardial remodeling were accompanied by insignificant reduction of the capillary bed and decrease in the number of capillaries and muscle fibers per 1 mm^2 (Table 2).

Changes in the vascular bed of PH during endocardial remodeling reflect prolonged myocardial ischemia and decompensation of coronary circulation. These parameters characterize changes in blood supply to the myocardium and determine insufficiency of PH during remodeling [15]. This process and profound changes in the parietal endocardium of the left ventricle contribute to severe diastolic dysfunction of PH that underlies thanatogenesis during endocardial remodeling [13].

Our results show that each type of PH remodeling is characterized by specific changes in the vascular bed. Pathomorphological criteria for changes in the vascular bed of PH elucidate the major factors of thanatogenesis under various conditions of remodeling and have considerable diagnostic value.

REFERENCES

1. L. G. Voronkov, *Ukr. Kardiol. Zh*., No. 1, 5-8 (1999).
2. E. V. Koshlya, *Vrach. Delo*, No. 1, 39-41 (1999).
3. L. M. Nepomnyashchikh and V. D. Rozenberg, *Cardiomyopathies: Pathomorphological Aspect* [in Russian], Moscow (1998).
4. A. N. Parkhomenko, *Ukr. Kardiol. Zh*., Nos. 5-6, 82-84 (1986).
5. V. D. Rozenberg, *Kardiologiya*, No. 11, 116-120 (1989).
6. V. D. Rozenberg and L. M. Nepomnyashchikh, *Coronarography in Pathomorphology* [in Russian], Novosibirsk (1987).
7. V. D. Rozenberg and L. M. Nepomnyashchikh, *Roentgenography of the Heart in Pathoanatomy* [in Russian], Moscow (1999).
8. V. D. Rozenberg and L. M. Nepomnyashchikh, *Byull. Eksp. Biol. Med*., **135**, No. 1, 110-114 (2002).
9. K. A. Shoshenko, *Arkh. Anat*., No. 9, 102-107 (1966).
10. H. Gewirtz, D. Williams, and W. Ohley, *Am. Heart J*., **106**, 674-680 (1993).
11. R. Goldstein, *Progr. Cardiovasc. Dis*., **24**, 419-436 (1992).
12. R. McKay, M. Pfeffer, R. Pasternak, and J. Markis, *Circulation*, **74**, 693-702 (1986).
13. P. Newman, *Am. Heart J*., **102**, 431-445 (1991).
14. B. Nordenstrom, C. Ovenfos, and G. Tornell, *Radiology*, **79**, 714-719 (1972).
15. S. Warren, H. Royal, J. Maris, *et al*., *J. Am. Coll. Cardiol*., **11**, 12-18 (1998).